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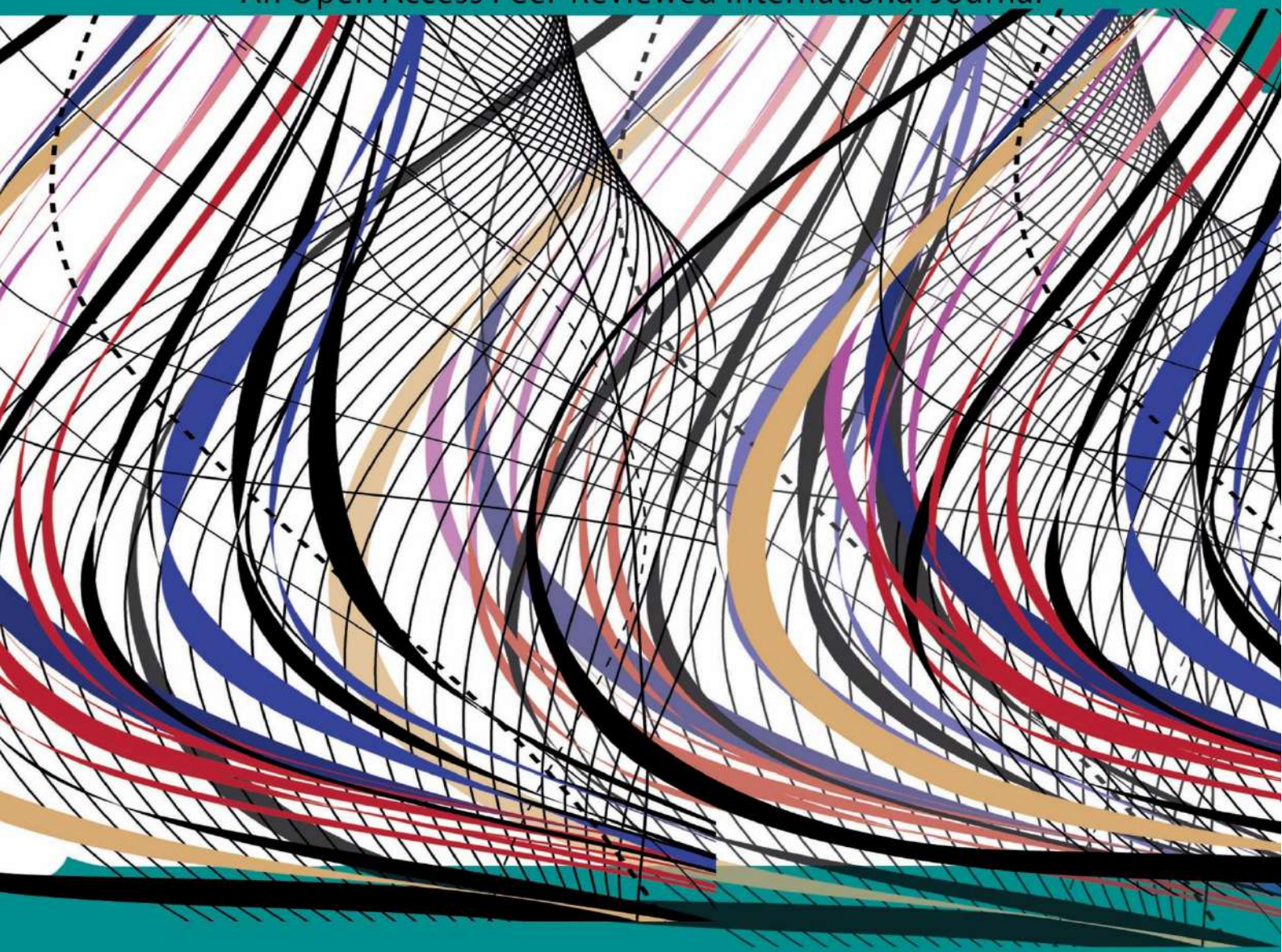

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Exploring the Personal Experiences of Gay Men in the Five Pillars of the Philippine Criminal Justice System: Basis for Sustainable Extension Program

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***Abstract*—** This study examines the experiences of individuals within the Philippine Criminal Justice System (CJS), focusing on the Law Enforcement, Prosecution, Court, and Correctional Pillars, as well as challenges in reintegration. Participants reported mixed experiences with law enforcement, from humane treatment to dissatisfaction over unclear arrest procedures and alleged coercion. In the prosecution stage, accessibility and quality of legal representation varied, with some expressing appreciation for dedicated defense counsel, while others faced frustrations over prolonged periods without representation, contributing to disillusionment with the judicial process. The Court Pillar highlighted the issue of "justice delayed, justice denied," as lengthy adjudication processes eroded trust in the judiciary. Within the Correctional Pillar, participants found conditions in the Capiz Rehabilitation Center to be more positive than anticipated, emphasizing the disciplined and respectful environment, strict anti-discrimination policies, and opportunities for personal growth through Technical Education and Skills Development Authority (TESDA) training and business ventures. However, overcrowding remained a significant concern. Reintegration into the community posed complex challenges, particularly for marginalized groups like the LGBTQ community, as societal stigma, limited employment opportunities, and the lasting impact of criminal records created systemic barriers to rebuilding their lives. Familial acceptance varied, further complicating transitions back into society. The study underscores the urgent need for reforms in arrest protocols, judicial efficiency, and correctional facility management. Additionally, fostering inclusive reintegration programs is crucial to addressing societal stigmas and supporting the successful transition of former Persons Deprived of Liberty (PDLs) into their communities.

Keywords*— *Court Pillar, Correction Pillar, Law Enforcement Pillar, Philippine Criminal Justice System, Prosecution and Defense, Reintegration and Stigma

I. INTRODUCTION

The Philippines, a multi-cultural country dominated by Christianity and Islam, faces significant challenges in fully accepting diverse gender identities, including Lesbian, Gay, Bisexual, Transgender, and Queer (LGBTQ+). While the Catholic Bishops' Conference of the Philippines (CBCP) opposes the SOGIE Bill, questioning it as a

form of cultural "colonization," it has also acknowledged that discrimination against the LGBTQ+ community contradicts Church teachings (Carino, 2020). The Philippine Criminal Justice System, composed of five interconnected pillars—Law Enforcement, Prosecution, Court, Correction, and Community—has faced controversies regarding its role in protecting LGBTQ+ rights. This system aims to maintain societal order, with the actions of each pillar influencing the others, from apprehending suspects to court rulings and correctional practices, which impact reintegration and recidivism rates (Collantes, 2019). Globally, LGBTQ+ individuals encounter systemic barriers, including discrimination in employment (Sears & Mallory, 2011), healthcare (Winter, 2012), housing (Grant, Mottet & Tanis, 2011), and education (Burns, 2011). They also face violent crimes, such as "corrective rapes" (Brown, 2012) and homicides, with Transgender Europe reporting 1,083 murders of transgender individuals between 2008 and 2012. Despite growing calls for equality, the persistence of such challenges highlights the need for systemic reforms and greater protections for LGBTQ+ individuals in the Philippines and worldwide.

The Law Enforcement Pillar and the Gay Community

The law enforcement pillar, comprising various government agencies, is tasked with enforcing the law, promoting public safety, and protecting citizens' rights. As the first point of contact for suspects, respondents, accused individuals, persons deprived of liberty (PDLs), and ex-convicts, it is responsible for arrests and filing criminal charges against those suspected of crimes. This section explores studies and accounts detailing the personal experiences and perceptions of the gay community toward law enforcement, both locally and internationally.

Effective policing hinges on legitimacy, which, at its core, means people obey the law because they perceive its benefits outweigh the costs. Police legitimacy is defined as the public's willingness to recognize police authority (National Institute of Justice, 2016). Tyler (2014) expands on this, emphasizing that legitimacy involves public trust and confidence, reflecting residents' willingness to defer to the law and police authority, alongside the belief that police actions are morally justified and appropriate.

Lawyering for the Gay Community

Lawyers play a critical role in defending individuals accused of crimes, including members of the LGBTQ+ community. When working with LGBTQ+ clients, attorneys must not only rely on anti-discrimination laws and ethical codes but also gain an understanding of their clients' legal goals and personal perspectives. To minimize unnecessary courtroom confrontations, attorneys should address relevant issues—such as the use of gender identity pronouns—prior to legal proceedings. Hon. Lewis A. Silverman emphasized during the 2022 NYSBA Annual Meeting program, *LGBTQ Lawyering: Representing Our Communities,* the importance of attorneys discussing with their clients how to handle gender discrimination during hearings. "You need to have a good conversation with your client beforehand. Some are focused solely on the lawsuit, while others may want to raise awareness of gender identity issues," Silverman advised (NYSBA, 2022).

Silverman also recommended that lawyers send a letter defining the client's pronouns to the judge and opposing counsel to preempt public confrontations. However, attorneys must be prepared to address bias from judges, as not all are well-versed in gender identity rules. Erin Harrist of the Legal Aid Society highlighted discriminatory remarks from court officers, such as referring to cases as "the he/she case," and advised addressing such issues proactively through conversations with clients and staff training (NYSBA, 2022).

Respecting a client's gender identity is crucial, particularly for detained individuals. Misclassification based on birth gender in facilities like Rikers Island poses significant risks to clients' safety. Sarah M. Telson of the LGBTQ Anti-Violence Project urged law firms to create inclusive practices, including clear procedures for name changes, addressing slurs, and fostering a welcoming environment through hiring practices and mission statements. Practical guidance for ethical considerations was further outlined during discussions led by legal experts, including Samuel W. Buchbauer and Christopher R. Riano, underscoring

the need for inclusive and informed representation for LGBTQ+ clients.

The Correctional System and the Gay Community

The Philippine correctional system comprises institutions managed by various agencies under the Department of Justice (DOJ), the Department of the Interior and Local Government (DILG), and local governments. The DOJ oversees national penitentiaries through the Bureau of Corrections (BuCor) and supervises parole, probation, and clemency via the Board of Pardons and Parole (BPP) and the Parole and Probation Administration (PPA). The DILG, through the Bureau of Jail Management and Penology (BJMP) and the Philippine National Police (PNP), manages district, city, and municipal jails. Youth offenders are rehabilitated by the Department of Social Welfare and Development (DSWD), while provincial jails are under the jurisdiction of provincial governments. The community also plays a role in corrections, offering rehabilitation services and reintegration support.

While corrections have evolved to focus on rehabilitation, conditions in many Philippine prisons remain dire. Overcrowding, inadequate provisions, and abuses by prison staff are common, as documented by the U.S. Bureau of Democracy, Human Rights, and Labor (2013). For LGBT prisoners, these issues are compounded by discrimination, victimization, and neglect of their specific needs. According to the United Nations Office on Drugs and Crime (UNODC, 2009), LGBT inmates face sexual violence, extortion, and prejudice, often receiving little to no protection from prison staff. Social stigma contributes to their vulnerability, with misconceptions labeling them as complicit in sexual violence (Eigenberg, 2000).

LGBT prisoners also encounter limited family support and often turn to other LGBT inmates for solidarity (Pintobtang & Bualar, 2012). However, forming such communities is discouraged, as authorities associate them with health risks, including sexually transmitted diseases (STDs), exacerbated by the lack of medical resources and preventive measures (Harawa et al., 2010; WHO, 2007). Mental health challenges, stemming from discrimination and abuse, are further neglected (APT, 2015; UNODC, 2009).

Despite the adversities, resilience among LGBT prisoners provides a narrative of hope. Highlighting their stories of perseverance can empower this marginalized group, as Ofreneo (2013) suggests reframing them from victims to agents. However, literature on Filipino LGBT prisoners remains scarce, necessitating more research to shed light on their lived experiences and promote equitable reforms.

Social Attitudes towards the Gay Community in the Philippines

The Philippines has been a pioneer in the Asia-Pacific region for LGBTQ+ advocacy, with the formation of the first gay and lesbian groups in the late 20th century. These groups evolved from social organizations into politically active entities by the 1990s. Notably, the Philippines hosted Asia's first gay pride parade in 1994, a tradition that has continued annually. While politicians have shown reluctant support for pride marches, many still avoid publicly participating due to lingering stigmas. In 2008, the first signs of public dissent against the pride parade appeared when protesters displayed anti-LGBTQ+ placards.

The Philippines made significant progress in 2009, lifting a ban on LGBTQ+ individuals serving in the military, with officials asserting that gay soldiers would receive the same treatment as their heterosexual counterparts. The police force similarly indicated non-discrimination towards LGBTQ+ applicants for service. However, incidents of harassment and abuse persist. The Lesbian, Gay, Legislative Advocacy Network (LAGABLAB) reports that gay men are often targeted under anti-vagrancy and anti-public scandal laws, with police exploiting these to extort bribes or break apart same-sex relationships through anti-kidnapping laws.

Despite legal progress, LGBTQ+ individuals in the Philippines still face widespread discrimination in various sectors, including education and employment. Reports from the Philippine Daily Inquirer and other sources highlight instances of violence, abuse, and ridicule, particularly towards gay men and lesbians. The societal view of homosexuality is often one of tolerance, with a focus on "knowing one's place," such as working in beauty salons or supporting political campaigns. Many politicians, including church leaders, maintain a

patronizing stance, acknowledging the presence of LGBTQ+ individuals but condemning same-sex relationships.

The Philippine Human Rights Commission (CHR) has committed to promoting LGBTQ+ rights, with its chairperson encouraging individuals to report discrimination or abuse. Numerous NGOs, such as the Rainbow Rights Project and Project Equality, are actively working to safeguard LGBTQ+ rights, push for anti-discrimination legislation, and provide legal support to those facing oppression. While social attitudes are gradually evolving, there is still a long road ahead for true acceptance and equal treatment for LGBTQ+ individuals in the Philippines.

Statement of the Problem

This study is aimed at determining the lived experiences of the members of the gay community in the Capiz Rehabilitation Center in their immersion to the five pillars of the Philippine Criminal Justice System. Specifically it sought to answer the following questions.

1. What are the group's experiences during their first contact with the law enforcement pillar?
2. What are the group's experiences during their legal talks with their legal counsel?
3. What are the group's experiences during court trial?
4. What are the group's experiences inside the Capiz Rehabilitation Center?
5. Is there such a thing such as social stigma to gay in the community?

II. METHODOLOGY

This research employed a **Phenomenological Research Design**, a qualitative approach that focuses on understanding the shared experiences of a specific group. Phenomenology aims to describe the essence of a particular phenomenon by examining how individuals perceive and make sense of their experiences (Creswell, 2013). Interviews are typically conducted with participants who have direct knowledge of the event or experience being studied, with the intent of answering two key questions (Moustakas, 1994): 1) What have you experienced in relation to the phenomenon? 2) What contexts or situations have influenced your experiences of the phenomenon? Additional data sources such as documents, observations, and art may also be utilized. The collected data is then carefully analyzed by reading it multiple times to identify recurring phrases and themes, which are grouped to form clusters of meaning (Creswell, 2013). Through this process, the researcher aims to uncover the universal meaning of the experience and gain a deeper understanding of the phenomenon.

With its roots in philosophy, psychology, and education, phenomenology seeks to capture the most authentic, unfiltered data. In some interpretations of the approach, the researcher practices **bracketing**—a technique used to acknowledge and set aside personal biases or preconceptions to ensure objectivity during the research process. One common method of bracketing is **memoing**, where the researcher documents their personal reflections to distance themselves from the data (Maxwell, 2013).

In this study, phenomenology was used to explore the lived experiences of **Persons Deprived of Liberty** (PDLs) at the Capiz Rehabilitation Center who identify as part of the **Gay Community**. Data was gathered through a **Focus Group Discussion (FGD)**. A focus group involves interviewing multiple individuals in a group setting, which, while not a replacement for individual interviews, offers a dynamic environment for information exchange (Given, 2008). This method is commonly used in marketing and political research, among other fields. During the FGD, the researcher directs the conversation and inquiry, which can be either structured (e.g., pretesting a questionnaire) or unstructured (e.g., brainstorming). Regardless of the format, the researcher-interviewer must adhere to established guidelines for conducting effective interviews (Dantzker, 2018).

III. RESULTS AND DISCUSSION

This section of the research manuscript will explore the personal and lived experiences of four (4) Persons Deprived of Liberty (PDLs) at the Capiz Rehabilitation Center who openly identify as members of the gay community, focusing on their experiences within the context of the Five Pillars of the Philippine Criminal Justice System.

Personal Experiences in the Law Enforcement Pillar

Several subjects reported negative interactions with law enforcement during their arrests, revealing feelings of mistreatment and disrespect. Subject no. 1 expressed dissatisfaction with her arrest, describing how she was allegedly invited to accompany officers without clear communication about the reason, leading to confusion and mistrust. Similarly, Subject no. 2 shared a troubling account of being threatened with physical harm (being shot in the leg) when attempting to flee. This theme reflects a broader sense of injustice and powerlessness experienced by the PDLs at the hands of law enforcement, highlighting the abuse of authority and lack of transparency.

- **Differing Experiences of Arrest Based on Circumstances** The subjects presented varied perceptions of their arrests, suggesting that the circumstances surrounding each arrest influenced their experiences. Subject no. 3 differentiated between two separate arrests. In her first arrest, she accepted responsibility for her actions as a drug dealer, leading to a more neutral view of the police's conduct. However, during her second arrest, she insisted on her innocence and described the officers' actions as forceful and unjust, showcasing how arrest circumstances (e.g., actual guilt vs. mistaken identity) shaped her interactions with law enforcement. Subject no. 4, on the other hand, emphasized being in the "wrong place at the wrong time," suggesting that her arrest was a result of her association with others rather than personal involvement in criminal activity.
- **Separation and Special Treatment of Female PDLs** Subject no. 1 highlighted the importance of gender-sensitive treatment, noting that she was separated from male detainees and given special attention by officers during her time in lock-up. She expressed that the officers were generally respectful, providing food and attending to her needs. This theme underscores the significance of gender-specific considerations within the Law Enforcement Pillar, suggesting that female PDLs may receive differentiated treatment based on their gender. However, this positive experience contrasts with the negative encounters described by other subjects, indicating that such treatment is not universal.
- **Sense of Injustice and Lack of Accountability** The experiences shared by the PDLs also conveyed a sense of injustice, with several subjects feeling wronged by law enforcement practices. For instance, Subject no. 3's repeated insistence on her innocence and mistreatment by police officers during her second arrest reflects a lack of accountability and fairness. Similarly, Subject no. 4's insistence on her innocence and being wrongfully associated with a drug bust further highlights how law enforcement can perpetuate feelings of injustice and misidentification.

The participants revealed a complex relationship between Persons Deprived of Liberty and the Law Enforcement Pillar of the Philippine Criminal Justice System. While there were instances of positive treatment, especially with regard to gender-specific considerations, the overarching themes reflect experiences of mistreatment, injustice, and a lack of accountability. The diverse perspectives of the subjects emphasize how the circumstances surrounding each arrest, as well as the behavior of the law enforcement officers, shape the PDLs' perceptions of the criminal justice system.

The Prosecution Pillar and the Defense Counsel in the Philippine Criminal Justice System

- **Dissatisfaction and Distance with the Prosecution and Defense Counsel** Subject no. 1's account of her last meeting with her defense counsel, which occurred more than four years ago when they filed a demurrer to evidence, reveals a sense of neglect and distance from legal representation. The lack of frequent communication and follow-up meetings suggests a disengagement from her lawyer, which may contribute to feelings of dissatisfaction or lack of support. This theme highlights potential gaps in legal representation, particularly in terms of regular communication and involvement in the case progression.
- **Satisfaction with Legal Representation** In contrast to Subject no. 1, Subjects no. 2, 3, and 4 shared positive experiences with their

respective defense counsels, emphasizing professionalism and effective handling of their cases. Subject no. 2 expressed high satisfaction with her lawyer's professional conduct, feeling confident in their ability to handle her case. Similarly, both Subjects no. 3 and 4 praised their defense counsels, specifically noting that the lawyer's professionalism was integral to their satisfaction. Notably, Subject no. 3 added an additional layer of connection by highlighting that her lawyer is a member of the LGBTQ community, which may have contributed to a deeper sense of understanding and trust.

- **The Role of Shared Identity in Legal Representation** Subject no. 3's specific mention of her lawyer's membership in the LGBTQ community introduces the theme of shared identity between the defense counsel and the client. This alignment may foster greater empathy, understanding, and communication, enhancing the overall experience for the PDL. The relationship between the defense counsel's identity and the client's sense of representation suggests that shared background or experiences could positively influence the legal process for marginalized groups, such as the LGBTQ community.
- **Consistency and Trust in Legal Counsel** Subjects no. 3 and 4, who share the same lawyer, both expressed strong satisfaction with the performance and professionalism of their counsel. This consistent positive feedback indicates a reliable and effective relationship between the lawyer and their clients. The sense of trust in their defense counsel, coupled with a shared positive experience, highlights the importance of consistent and dependable legal representation in fostering confidence in the criminal justice system.

The group discussion reveals a stark contrast in the experiences of PDLs with the Prosecution Pillar and their defense counsel. While some PDLs, like Subject no. 1, reported dissatisfaction and a sense of distance from their defense counsel, others, particularly Subjects no. 2, 3, and 4, expressed satisfaction and trust in their legal representatives. The positive experiences of the latter group emphasize the significance of professionalism, communication, and even shared identity between the client and defense counsel. These elements contribute to a more supportive and effective legal experience, while the lack of engagement noted by Subject no. 1 underscores the challenges in ensuring consistent and adequate legal support in the criminal justice process.

The Court Pillar in the Philippine Criminal Justice System

- **Dissatisfaction with Court Delays** A prominent theme across all subjects is their shared frustration with the prolonged delays in the legal process. The phrase "Justice Delayed, Justice Denied" was repeatedly expressed, underscoring a common sentiment of disillusionment with the court system. This dissatisfaction stems from the extended periods of time that individuals have spent incarcerated in the Rehabilitation Center while their cases remain unresolved. The delay in case resolution is perceived not just as a procedural issue but as a denial of justice, contributing to the emotional and psychological toll on those involved in the criminal justice system.
- **Extended Incarceration Due to Court Delays** Subject no. 1's specific mention of waiting for the court's decision on the "Demurrer to Evidence" for more than four years exemplifies the extended periods of incarceration that result from delayed court proceedings. This delay highlights the disconnect between the speed at which cases are processed and the prolonged physical and mental confinement of the accused. The subjects' prolonged detention without resolution of their cases illustrates the detrimental effect of delayed judicial processes, potentially violating their right to a fair and timely trial.
- **The Psychological and Emotional Impact of Delayed Justice** The repeated reference to "Justice Delayed, Justice Denied" also

suggests the psychological and emotional strain experienced by the PDLs as they wait for the resolution of their cases. The uncertainty and the inability to move forward with their lives as a result of court delays can create feelings of helplessness, anxiety, and frustration. This emotional toll further compounds the already challenging experience of being incarcerated, and suggests a need for reform to address timely case adjudication and the mental health impact on detainees.

The thematic analysis reveals that the subjects' dissatisfaction with the Court Pillar is primarily driven by the prolonged delays in their cases, contributing to a sense of injustice and emotional distress. The repeated use of the phrase "Justice Delayed, Justice Denied" captures the essence of their frustrations and the detrimental effects of these delays on their well-being. The themes suggest a significant need for reform in the judicial process to address case backlogs, ensure timely resolutions, and minimize the impact of these delays on the lives of individuals awaiting justice.

The Correction Pillar in the Philippine Criminal Justice System

- **Initial Fear and Misconceptions.** A dominant theme emerging from the focus group discussion is the initial fear and anxiety the subjects experienced upon learning they would be transferred to the Capiz Rehabilitation Center. Their fear was fueled by negative portrayals of correctional facilities in the media, particularly movies and news reports, which often depict overcrowded, violent, and abusive environments. This theme reflects the widespread public perception of jails and prisons in the Philippines as dangerous places, and the personal apprehensions of the subjects about potential mistreatment, abuse, and violence, particularly from other Persons Deprived of Liberty (PDLs) due to the nature of their offenses.
- **The Reality of the Correctional Facility.** However, the subjects' experiences in the Capiz Rehabilitation Center contrasted sharply with their initial fears. They found the facility to be well-organized, with disciplined, respectful, and courteous PDLs and Provincial Guards. This shift in perception highlights the theme of how personal experiences can challenge or subvert preconceived notions, particularly regarding the treatment of detainees. The implementation of strict anti-discrimination and anti-bullying rules within the facility helped ease the subjects' fears and contributed to a safer, more respectful environment. This theme emphasizes the importance of institutional policies that promote respect, safety, and equality within correctional settings.
- **Assigned Roles and Responsibility.** Another recurring theme is the subjects' involvement in assigned roles within the rehabilitation center. These roles, which include duties like preparing the chapel, cleaning cells and hallways, and assisting with technical training assessments, provide a sense of structure, responsibility, and purpose for the PDLs. This theme underscores the potential positive impact of providing incarcerated individuals with meaningful work and roles, which can help build self-esteem, reduce idle time, and contribute to personal development. The subjects' engagement in these tasks may also facilitate their reintegration into society upon release, as it encourages skill development and personal accountability.
- **Access to Education and Skill Development** .A key theme in the discussion is the availability of educational and vocational opportunities at the Capiz Rehabilitation Center, particularly through National Certification Trainings offered by the Technical Education and Skills Development Authority (TESDA). The subjects' involvement in earning National Certificates in skills such as massage therapy and tailoring reflects a rehabilitative aspect of the facility, aimed at equipping PDLs with practical skills that can improve their prospects upon release. This theme

highlights the importance of providing vocational training and education to PDLs, which not only benefits their personal growth but also supports their successful reintegration into society by increasing employability and self-sufficiency.

- **Overcrowding as a Persistent Issue** Despite the positive aspects of the correctional facility, all subjects expressed concern about overcrowding, which remains a significant challenge in the Philippine correctional system. This theme reveals that while certain reforms and improvements have been made, structural issues such as overcrowding continue to impact the overall conditions of the facility. Overcrowding can exacerbate tensions, reduce access to resources, and undermine the effectiveness of rehabilitation programs, highlighting the need for systemic reform to address this persistent issue.

The thematic analysis reveals a complex interplay of initial fear, personal growth, and systemic challenges within the correctional facility. The subjects' initial misconceptions about the Capiz Rehabilitation Center were dispelled by their positive experiences, particularly in relation to the respectful treatment by staff and fellow PDLs, assigned roles that foster responsibility, and access to skill-building opportunities. However, the theme of overcrowding remains a critical issue that undermines the overall conditions and effectiveness of the rehabilitation process. The analysis suggests that while improvements in the treatment of PDLs are evident, further reforms are necessary to address overcrowding and ensure more effective rehabilitation and reintegration.

The Community and Future Concerns for Incarcerated Gay Individuals

- **Family Awareness and Acceptance of Gender Identity** One notable theme in the subjects' narratives is the level of acceptance they experienced from their families regarding their gender identity. Most of the subjects indicated that their families had been aware of their sexual orientation since childhood, which suggests a relatively supportive and accepting environment. This theme underscores the role that familial acceptance plays in the emotional well-being and identity development of LGBTQ+ individuals. For many, having their gender identity recognized and accepted by their families can provide a sense of stability and reduce the emotional strain associated with societal rejection or discrimination. This is contrasted by Subject no. 3, whose experience differed significantly, as she had concealed her true gender identity until later in life.
- **The Emotional Strain of Concealing Identity** Subject no. 3's experience reveals a starkly different theme, one rooted in the emotional and psychological toll of concealing one's gender identity. At 32 years old, she shared the immense stress of hiding her feelings and identity, particularly within the context of her family's status in their municipality. This theme reflects the broader issue of societal pressures faced by LGBTQ+ individuals, especially those from influential families or conservative communities. Subject no. 3's narrative highlights the difficulty of living a double life and the strain it causes on relationships, particularly in the context of a marriage and public life, such as her role as a Barangay Kagawad. The theme speaks to the ongoing conflict that many LGBTQ+ individuals experience between personal identity and the expectations of family, community, and society at large.
- **Fear of Future Stigma and Discrimination** The subjects expressed a pervasive concern about the stigma they would face in the community and their future employment prospects. This theme reflects the widespread fear of discrimination and marginalization that many LGBTQ+ individuals face, particularly those who have been incarcerated. Subject no. 1 and 2's concerns about their ability to use their National Certificates to secure employment once they are released from the facility highlight the intersection of criminal justice involvement and LGBTQ+ stigma. The fear of being labeled as "former PDLs" and facing

additional societal discrimination poses a significant barrier to reintegration, economic stability, and personal development for these individuals.

- **Social and Professional Reintegration Challenges** Closely linked to the theme of stigma, is the issue of reintegration into society. Both Subject no. 1 and 2 voiced apprehensions about their future due to the ongoing legal proceedings that have delayed their release. This prolonged uncertainty is compounded by the social stigma they fear will accompany their status as former prisoners. Their worry about applying for jobs and reintegrating into society is heightened by the possibility of being rejected or marginalized due to their criminal records, even with the qualifications they have earned through National Certification Training. This theme underscores the difficulty that many formerly incarcerated individuals face when trying to rebuild their lives, especially those who belong to marginalized communities such as the LGBTQ+ population.

The group discussion reveals the complex and multifaceted nature of the subjects' experiences as incarcerated members of the gay community. While family acceptance plays a crucial role in their emotional well-being, many still face significant challenges due to societal pressures, emotional strain from concealing their true identities, and fears about future stigma and discrimination. The ongoing stigma attached to being a former PDL exacerbates concerns about their ability to reintegrate into society and secure stable employment. The analysis emphasizes the need for comprehensive support systems that address not only the legal and rehabilitative needs of incarcerated LGBTQ+ individuals but also the societal barriers to their reintegration and acceptance upon release.

IV. CONCLUSION

Based on the personal and lived experiences shared by the subjects in this research, the following conclusions can be drawn:

1. Negative Impressions of Law Enforcement: All subjects expressed dissatisfaction with their interactions with law enforcement, particularly during their arrests. They consistently felt that their arrests were unjust and that they had been wrongly accused. Furthermore, they noted irregularities and misconduct on the part of the law enforcement officers, which likely contributed to their negative perceptions. These feelings of discontent may stem from the police being their initial point of contact within the Criminal Justice System.
2. Court Delays and Backlog: The subjects highlighted significant delays in the judicial process, with many cases remaining unresolved for extended periods. This suggests that the court system is burdened with a high volume of pending cases, contributing to frustrations and perceptions of "justice delayed, justice denied."
3. Misconceptions About Prison Conditions: The subjects revealed that, before their incarceration, they held negative perceptions of prison conditions largely shaped by exaggerated portrayals in movies and the media. These depictions often fueled fear and anxiety about the reality of life in correctional facilities. However, upon entering the Capiz Rehabilitation Center, the subjects found the actual conditions to be more manageable, with an organized structure, respect among inmates, and a focus on rehabilitation through skills development and work assignments.

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Factors Influencing Level of Job Satisfaction Among Employees in Private Secondary Educational Institutions

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Abstract *— This study described the factors influencing the level of job satisfaction among employees in private secondary educational institutions. An adopted questionnaire was used to gather data from 100 purposively chosen respondents. The influencing factors that were considered were pay structure, working hours, training needs, reward and promotion system. The study revealed that: the employees demonstrate a moderate satisfaction level with their pay structure. They are highly satisfied with their work hours and with the training provided by their educational institutions. Additionally, they exhibit moderate satisfaction in terms of their reward and promotion system. The findings highlight the importance of addressing job satisfaction factors in private secondary educational institutions, as they indicate that while employees are generally satisfied with their working hours and training, there remains a need for improvement in pay structure and the reward and promotion system.*

Keywords *— Factor, influence, job satisfaction, pay structure, private schools*

I. INTRODUCTION

The degree of enjoyment or contentment an employee has with their work is known as employee job satisfaction (Qader, 2021). It is a crucial component of any company or institution. It addresses the fundamental requirements and worries of workers as determined by satisfaction surveys. Employees are more motivated to contribute to the success of the company when they are content with the management and work culture. Higher employee motivation and job satisfaction can be attained when a business creates plans to deliver critical components of job satisfaction.

In this study, the researchers explored the external influences on Job Satisfaction among employees in selected private secondary educational institutions in the province of Nueva Ecija, Philippines. Given the significance of these institutions in the province and their enormous contributions to the community, it is pertinently easy for them to switch between other educational institutions that would best suit their needs. Needless to say, the employees are the core of the business (Gošnik, Meško & Stubelj, 2023) and management always seeks to retain their productive employees; thus, it is vital to consider the factors affecting their job satisfaction to reduce turnover.

For private secondary educational institutions, statistics show the majority of the employees are not satisfied with their jobs, particularly their entry-level salaries. "The average salary in private schools is around P14,000 a month or less compare with an entry-level public school teacher who makes some P27,000 monthly" (Philippine Daily Inquirer, 2024). This is a very alarming issue since jobs are attributed to company incentives and benefits, salary for employees, job roles, training and development

programs, and career growth. A decreasing trend in job satisfaction is seen in employees lower incentives and compensation received from their organization (Sinaga, et al., 2022).

With the rising level of unsatisfied employees in the private education institutions in the Philippines, the researcher tried to explore the job satisfaction of employees in the private schools in Nueva Ecija to in order to identify the components and factors that contribute to their job satisfaction, which in turn influences their productivity and commitment to long-term employment.

Specifically, it aimed to investigate the levels of job satisfaction of the respondents based on factors such as pay structure, working hours, training needs, reward and promotion system.

II. LITERATURE REVIEW

While previous studies have been conducted on the areas of job satisfaction and motivation, the Researcher noticed that these studies had been focused mostly on industry setting. Not much has been written in the academic environment. And while there have been scarce materials mentioned about the academe, this study covered specific areas in Nueva Ecija, which covered a good cross-section of the academe.

The article by Mizne (2017) described proven ways to boost the job satisfaction of employees. Top the list of factors contributing to job satisfaction, and employee engagement were relationships with immediate supervisors and communication between management employees (Campbell, et al., 2020). Other factors influenced overall employee satisfaction and employee engagement in the work environment and trust between employees and managers, respect for employees at all levels, overall benefits, compensation, job security, relationship with immediate supervisor, opportunities to work skills and abilities, respect for employee ideas, financial stability of the organization, and recognition for employee job performance and enhancement (Yang, Jiang & Cheng, 2022; Subia, et al., 2022).

Job satisfaction in the workplace has both extrinsic and intrinsic characteristics (Kula & Gueler, 2014). It stated that "people bring with them certain drives and needs affect their performance; therefore, understanding how needs stimulate performance and job rewards on such performance lead to job satisfaction is indispensable for managers". Therefore, line managers in an organization have to be concerned about their subordinates' performance, requiring them to monitor the level of satisfaction of such employees continuously.

Some factors that contributed to the high turnover rate are lack of benefits, training and development, and low salary. Job satisfaction level changes in relation to the employee's career stage. Fresh graduates considered worker relationships as a priority, while managers gave emphasis to company reputation and self-development. Industries with the highest job satisfaction include the education sector, energy industries, and the government sector, while workers in the industries of retail and banking have lower satisfaction with their jobs.

Job satisfaction, which was generally perceived to be linked directly to personal well-being and productivity was the employee's sense of achievement and success (Tumo, 2017). It referred to a collection of beliefs and feelings the employees had about their current jobs and positive emotional state derived from one's appraisal of one's job and experience. It implied the work that one employee enjoyed and got a reward for one's effort. It was the key element leading to income, recognition, self-fulfilment, promotion, and the achievement of goals. The degree of satisfaction varies from satisfaction to dissatisfaction. Job satisfaction is the employee's emotional response to the situation of the job, determined by the manner in which an outcome can exceed and meet expectations.

The study of Angeles et al. (2015) focused on the job satisfaction and performance level of employees to determine their significance in employees' jobs and work environment. Job satisfaction and performance are viewed as employee's gratification for jobs accomplished, which are appreciated by supervisors. The study discussed employee needs that affect job satisfaction and the level of employee performance in the workplace.

According to Erasmus et al. (2018), promotion involves moving into a more senior position than before, with the new position demanding "higher-

level responsibility, more complex work, greater competency demands, and better remuneration".

There are various factors that have a great contribution to organizational outcomes and improve staff performance in the workplace. One of the critical factors proposed in Herzberg's Motivation–Hygiene Theory is job satisfaction (Herzberg, 1964). This organizational factor is defined in different types in various work environments and explained as a basic factor in the organization. In reality, this factor has a great impact on the health of organization and guarantees the well-being of staff at work. In fact, the presence of job satisfaction should be supported by the organization (Côté, Lauzier & Stinglhamber (2021).

These factors include salary, work (itself), co-workers, promotion, and supervision, which have a considerable contribution to the level of job satisfaction among staff at the organization. There are a lot of aspects to the effect of these kinds of factors (external factors) on job satisfaction at workplaces, and each of these views emphasized the effective role of external factors on the level of job satisfaction (Parvin & Kabir, 2016).

Job satisfaction as a positive factor provides an acceptable condition for effectiveness and avoid appearing to some difficulties and failure feeling among staff at the organization. In fact, this positive organizational factor offers suitable motivation to start and continue effective activities at the workplace. As well, job satisfaction is one of the effective factors among staff that modifies their views toward the job and any items that depend on it. In other words, job satisfaction has a vital role in the consequences of an organization (Wan Ahmad & Abdurahman, 2015).

Based on Islam, Akter & Afroz(2016), staff obtain new proficiency on the job by their work experience. If these new abilities are rewarded by institutions, they become satisfied with their jobs, otherwise, they will lose their motivation and make some abnormalities such as a low level of job satisfaction.

Conversely, Yang, Chen, Yang & Huang (2023) suggest that a reward that motivates is "something that is given without obligation", and that the moment that "something has been promised, it becomes compensation". The author further states that, once employees are entitled to payment, they are moved by it, but not necessarily motivated. The author concluded by indicating that a reward that motivates is "therefore something that is not only given without obligation but something that is given as recognition for good performance."

Furthermore, Erasmus et al. (2018) define remuneration as the financial and nonfinancial extrinsic rewards provided by an employer for the time, skills, and effort made available by the employee in fulfilling job requirements aimed at achieving institutional objectives.

III. METHODOLOGY

This study utilized a quantitative research design. This is about quantitative data gathering that was necessary to establish an objective result on how participants appreciated the tool introduced (Bloomfield & Fisher, 2019). The study's sampling technique is purposive sampling. This is a non-probability sampling design that selects a sample based on the characteristics of the population and the objectives of the study (Suryananda & Yudhawati, 2021). The elements of the sample were selected by the judgment of the researcher who perceived that they could obtain a representative sample through sound judgment that resulted in time and cost savings. The data were generated using an adopted survey questionnaire, by Malaca (2020), and distributed to the selected employees of the private institutions who were chosen to participate in the study. Data were collected using a survey questionnaire developed by the Researchers that was designed to answer the questions in the statement of the problem.

IV. RESULTS AND DISCUSSION

1. Pay Structure;

Table 1. Pay Structure

Pay Structure	Employees (n=100)	Verbal Description
1. The employee is satisfied with his/her current salary.	2.47	Slightly Agree/Low Level
2. The employee is satisfied with the allowances provided by the organization.	2.49	Slightly Agree/Low Level
3. The salary given to the employee motivates him/her to perform the job well.	2.84	Moderately Agree/Moderate Level
4. Incentives influence the employee's performance/productivity at work.	3.25	Strongly Agree/High Level
5. The employee is satisfied with the benefits given to him/her by the company like medical or insurance.	2.82	Moderately Agree/Moderate Level
Overall Weighted Mean	2.77	Moderately Agree/Moderate Level

Legend: 1.00 to 1.74 Very Low Level/Disagree; 1.75 to 2.49 Low Level/Slightly Agree; 2.50 to 3.24 Moderate Level/Moderately Agree; 3.25 to 4.00 High Level/Strongly Agree

Table 1 shows that the respondents have a moderate level of satisfaction in terms of their pay structure with an overall weighted mean of 2.77 and a verbal description of moderately agree.

The highest item in terms of the weighted mean is item number 4, "Incentives influence the employee's performance/productivity at work" with a weighted mean of 3.25 and a verbal description of the high level of satisfaction. On the other hand, the lowest is item number 1 "The employee is satisfied with his/her current salary" with a weighted mean of 2.47 and a verbal description of a low level of job satisfaction. This suggests that employees believe these motivators enhance their performance and productivity, indicating a positive organizational culture that values recognition and rewards. While the low satisfaction with current salaries highlights a potential area of concern, suggesting that financial compensation may not meet employee expectations. According to Akafo and Boateng (2015), employees are rewarded with cash in order to inspire them or to elicit positive conduct from them in terms of improving performance.

2. Working Hours;

Table 2. Working Hours

Working Hours	Employees (n=100)	Verbal Description
1. There is a flexible working hour policy in the workplace.	3.29	High Level/Strongly Agree
2. The use of time as flexible employees are often more disciplined in their time management.	3.25	High Level/Strongly Agree
3. It is easy for the employee to adopt a flexible working arrangement.	3.26	High Level/Strongly Agree
4. The company pays the employee once he/she renders overtime work.	3.22	Moderate Level/Moderately Agree
5. The employee is compensated when he/she works during holidays, company events and rest days.	3.24	Moderate Level/Moderately Agree
Overall Weighted Mean	3.25	High Level/Strongly Agree

Legend: 1.00 to 1.74 Very Low Level/Disagree; 1.75 to 2.49 Low Level/Slightly Agree; 2.50 to 3.24 Moderate Level/Moderately Agree; 3.25 to 4.00 High Level/Strongly Agree

Table 2 presents that the respondents have a high level of satisfaction in terms of their working hours with an overall weighted mean of 3.25 and a verbal description of strongly agree.

The highest item in terms of the weighted mean is item number 1, "There is a flexible working hour policy in the workplace" with a weighted mean of 3.29 and a verbal description of the high level of satisfaction. Conversely, the lowest is item number 4 "The company paid the employee once he/she rendered overtime work" with a weighted mean of 3.22 and a verbal description of a moderate level of job satisfaction. The high level of satisfaction with the flexible working hour policy indicates that employees value work-life balance and appreciate the autonomy it provides. In contrast, the moderate satisfaction regarding overtime pay suggests that while employees may feel reasonably compensated, there is still room for improvement in how the company recognizes and rewards extra effort. Companies and institutions that are implementing flexible working hours may experience increased productivity among their employees. According to Sabir (2017), happy, motivated employees who appreciate the opportunity to work from home may be more likely to interact with their company and contribute significantly.

3. Training Needs;

Table 3. Training Needs

Training Needs	Employees (n=100)	Verbal Description
1. The employee gets the training and development he/she needs in his/her job to identify the skills/knowledge gaps within the business.	3.15	Moderate Level/Moderately Agree
2. The employee has a role in supporting his/her work-related training and development needs.	3.26	High Level/Strongly Agree
3. The employee's team support his/her work-related training and development.	3.32	High Level/Strongly Agree
4. The employee is satisfied with the training opportunities available in my work.	3.22	Moderate Level/Moderately Agree
5. The employee's team helps him/her meet my work-related training needs.	3.34	High Level/Strongly Agree
Overall Weighted Mean	3.26	High Level/Strongly Agree

Legend: 1.00 to 1.74 Very Low Level/Disagree; 1.75 to 2.49 Low Level/Slightly Agree; 2.50 to 3.24 Moderate Level/Moderately Agree; 3.25 to 4.00 High Level/Strongly Agree

Table 3 shows that the respondents have a high level of satisfaction in terms of their training needs with an overall weighted mean of 3.26 and a verbal description of strongly agree.

The highest item in terms of the weighted mean is item number 5, "The employee's team helps him/her meet my work-related training needs" with a weighted mean of 3.34 and a verbal description of the high level of satisfaction. On the other hand, the lowest is item number 1 "The employee get the training and development he/she needed in his/her job to identify the skills/knowledge gaps within the business" of 3.15 and a verbal description of moderate level of job satisfaction. The findings indicate that employees feel a strong sense of support from their teams in meeting work-related training needs. Conversely, the adequacy of training and development to address skills and knowledge gaps suggests a need for improvement in training programs to better equip employees for their roles (Sloan & Geldenhuys, 2021).

4. Reward and Promotion System;

Table 4. Reward and Promotion System

Reward and Promotion System	Employees (n=100)	Verbal Description
1. I give recognition for significant employee achievement.	3.35	High Level/Strongly Agree
2. There is a formal recognition program that increases the motivational value of the employees.	3.26	High Level/Strongly Agree
3. The company looks at the skills of the employees to be promoted to higher positions.	3.15	Moderate Level/Moderately Agree
4. There is a high chance for promotion in the employee's job.	3.05	Moderate Level/Moderately Agree
5. The job promotions in our company are awarded fairly and without bias.	3.24	Moderate Level/Moderately Agree
Overall Weighted Mean	3.21	Moderate Level/Moderately Agree

Legend: 1.00 to 1.74 Very Low Level/Disagree; 1.75 to 2.49 Low Level/Slightly Agree; 2.50 to 3.24 Moderate Level/Moderately Agree; 3.25 to 4.00 High Level/Strongly Agree

Table 4 reveals that the respondents have a moderate level of satisfaction in terms of their reward and promotion system with an overall weighted mean of 3.21 and a verbal description of moderately agree.

The highest item in terms of weighted mean is item number 1, "I give recognition for significant employee's achievement" with a weighted mean of 3.35 and a verbal description of the high level of satisfaction. On the other hand, the lowest is item number 4 "There is a high chance for promotion in the employee's job" of 3.05 and a verbal description of a moderate level of job satisfaction. The findings suggest that employees feel highly valued and recognized for their significant achievements, which contributes positively to their overall job satisfaction. However, moderate satisfaction regarding promotion opportunities indicates a potential area for improvement, as enhancing career advancement prospects could further boost employee morale and retention (Rubens, 2024).

V. CONCLUSIONS

The following conclusions are drawn from the study's findings:

1. The employees express a moderate degree of satisfaction with their pay structure.

2. The employees at their educational institutions are highly flexible with their work schedules.

3. The instruction that their educational institutions have given them has left the employees feeling delighted.

4. The employees show a moderate level of satisfaction with their system of rewards and promotions.

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Evaluation of PHILHEALTH KONSULTA PROGRAM Implementation: Perspective of Selected Accredited Konsulta Providers in Nueva Ecija

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Abstract *— This study entitled Evaluation of the implementation of PHILHEALTH KONSULTA PROGRAM: perspective of selected accredited konsulta providers in Nueva Ecija utilized descriptive-quantitative research design. The researchers selected twenty-two PhilHealth Konsulta accredited providers in Nueva Ecija using purposive sampling. According to the report, the PhilHealth Konsulta Program in Nueva Ecija reveals a complicated terrain of implementation, efficacy, and areas for improvement. Even though the program can potentially improve healthcare quality and access, especially in impoverished areas, issues including system dependability, timely reimbursements, and financial management still exist. Stakeholders stress the need for evidence of better health outcomes, adherence to clinical guidelines, and increased patient satisfaction. To guarantee equal access to high-quality healthcare, the study promotes targeted initiatives to improve care standards and operational effectiveness, emphasizing the value of cooperation between communities, governmental organizations, and medical professionals. Effective program adaptation to changing public health requirements and goal achievement depends on ongoing monitoring and assessment.*

Keywords *– **Financial Sustainability, Konsulta Program, Konsulta Provider, Primary Care, System Efficiency***

I. INTRODUCTION

For many developing countries, including the Philippines where healthcare is rationed to the unfortunate and rich worthy of greater responsibilities, shared access to healthcare is still an aspiration. The Philippines is home to over 100 million people so providing equal opportunity to ones in need isn't a simple task. Amongst the steps taken to resolve health insurance issues, the PhilHealth Konsulta Program aims to improve all citizens' access to primary healthcare services including its overall quality. Philippines Health Insurance Corporation (PhilHealth) rolled out the PhilHealth Konsulta Program, which seeks to enhance the availability and standard of primary health care for all Filipinos. Accredited Konsulta providers play a significant role in the implementation of this program because they serve as the frontline healthcare professionals committed to delivering services to communities. This research

evaluates the PhilHealth Konsulta Program from the perspective of accredited Konsulta providers, providing insights into its efficiency, challenges and potential areas for improvement.

In an attempt to achieve universal healthcare coverage by 2022, the Philippine Health Insurance Corporation (PhilHealth) launched the Konsulta Program in 2020. The PhilHealth Konsulta Program aims to remove the systemic barriers that have previously prevented millions of Filipinos from accessing high-quality healthcare services, building on the progress made by previous healthcare initiatives such as the National Health Insurance Program (NHIP), which was created in 1995. The program's particular goals are to improve health outcomes and prevent and control health inequities. It targets the country's primary healthcare systems and reaches out to underserved areas.

Recent studies emphasize the importance of primary healthcare in achieving universal health coverage and improving health outcomes. Kruk et al. (2018) found that countries with strong primary healthcare systems have better health outcomes, including lower infant mortality rates and higher life expectancy. Mwai D, Hussein S, Olago A, Kimani M, Njuguna D, Njiraini R and others. (2023) pointed out that, more spending on primary health care has allowed for better accessibility to necessary medical services and overall better health around the world. These researches only emphasize the importance of primary healthcare in the attainment of health equity and universal coverage, but then again, so does the study done by Gizaw, Zemichael Astale, Tigist Kassie, and Getnet. (2022) looked at the effects of primary healthcare interventions on patterns of healthcare utilization and concluded that primary healthcare strengthening and tertiary care facilities. Similarly, a study by Callaghan, K.A. (2019) examined whether community-oriented primary care programs could improve health status and eliminate medical inequities. That research stresses the community-based approaches to eliminating health inequities and access to services. It calls for the full involvement of the community in the planning and implementation of primary health care. The results show that primary health care interventions such as the PhilHealth Konsulta Program can make a big difference in solving problems of accessibility and quality of health care. In Nueva Ecija, the health care system is both progressive and problematic, as it is in much of the province. Nueva Ecija has the responsibility of delivering health care services to a great variety of communities ranging from the urban city to the remote rural areas. Although the doctors hospitals and facilities are much better, there are still inequalities in healthcare in the sense that not everyone has access to it, not all of it is good, and not all of it is cheap, especially in poorer communities. Knowing this, The Assessment of the PhilHealth Konsulta Program to the Selected Accredited Providers in Nueva Ecija becomes a very important study. This is a program that is supposed to improve the delivery of primary care and erase the inequities in health care, hopefully, this will help with the immediate healthcare crisis that many residents of the province are experiencing. The purpose of this research is to provide some insight into the direction of targeted interventions, to assure some equality in healthcare access, and to contribute to the general betterment of the Nueva Ecija healthcare system through an analysis of its application and effect.

II. RESEARCH METHODOLOGY

The approach to this research was the quantitative method. Quantitative research is the process of collecting data and analyzing numerical data to describe and explain various phenomena. That's because all of this is based on established standards and quantifiable elements and statistical analysis to come up with these determinations. The questionnaire was distributed through Google Forms and the Google URL was posted on various social media like Messenger for the respondents to fill in. That was the easiest way to get primary data. This will be a good survey to see some statistically sound information about how well the Konsulta health program is working, how efficient the Konsulta system is, and if the program is being fiscally responsible. That's because the survey instrument was constructed that way, some of the questions were worded that way just so that it would be convenient and easy and brief for the respondent to answer, but at least it would make sense to the analysis Taherdoost, Hamed. (2022). The research took place in Nueva Ecija, specifically targeting

districts 1 and 4. The subjects of the study were the PhilHealth Konsulta accredited providers which also were the samples of the study and they all have attended the PhilHealth Konsulta Program. Purposive sampling is a type of sampling in which the researchers select the participants because of some characteristic that is of interest in the study. This sampling method allowed the sampling of healthcare workers from different towns in districts 1 and 4 of Nueva Ecija. This information was then coded and tabulated and was analyzed and computed using appropriate statistical tools.

III. RESULTS AND DISCUSSION

Table 1: Distribution of Respondents as to Age

Age	Frequency	Percentage
18-25	2	9.10
26-35	11	50
36-45	6	27.30
46-55	1	4.50
56 and above	2	9.10

The table above shows the age distribution of respondents indicating that the largest group, comprising 50% of the total, falls within the 26-35 age range. Following this, 27.30% are aged 36-45, while smaller percentages are distributed across the 18-25 and 56 and above age brackets, with 9.10% each, and 4.50% in the 46-55 age group.

Table 2: Distribution of Respondents as to Sex

Sex	Frequency	Percentage
Male	7	31.82
Female	15	68.18

The table shows that the majority of respondents, constituting 68.18%, are female, while 31.82% are male. This indicates a higher representation of females among the respondents surveyed.

Table 3: Distribution of Respondents as to Years of Experience as Healthcare Providers

Years of Experience as a Healthcare Providers	Frequency	Percentage
Less than a year	2	9.10
1 – 5 years	12	54.50
6 – 10 years	2	9.10
11 – 15 years	4	18.20
16 years and above	2	9.10

The table illustrates the distribution of respondents based on their years of experience as healthcare providers. The majority (54.50%) have 1-5 years of experience, followed by 18.20% with 11-15 years. There's relatively low representation for those with less than a year and 16 years and above of experience, both at 9.10%.

Table 4: Distribution of Respondents as to Years of Experience as Accredited Konsulta Provider

Years of Experience as an Accredited Konsulta Provider	Frequency	Percentage
0 – 6 months	6	27.30
6 – 12 months	-	-
13-24 months	6	27.30
25 – 36 months	6	27.30
36 months and above	4	18.20

The table presents the distribution of respondents based on their years of experience as accredited Konsulta providers. A significant portion (27.30%) has 0-6 months of experience, as well as those with 13-24 months and 25-36 months, each also at 27.30%. There's a smaller representation (18.20%) for those with 36 months and above of experience.

Table 5: Evaluation of Konsulta Health Program Quality

Item	WM	Description	Rank
1. Patients can easily access Konsulta healthcare services.	3.68	Always	4.5
2. Konsulta services reach underserved communities effectively.	3.45	Always	12

3. Effective outreach efforts and community engagement initiatives are in place.	3.54	Always	11
4. Patients can easily find Konsulta centers within a reasonable distance from their residences.	3.59	Always	9.5
5. Medical services provided by Konsulta are consistently adequate.	3.64	Always	7.5
6. Patients are generally satisfied with the healthcare services received from Konsulta.	3.77	Always	2.5
7. There is continuity and coordination of care across healthcare providers in Konsulta	3.59	Always	9.5
8. Clinical guidelines and standards of care are consistently followed in Konsulta.	3.82	Always	1
9. Healthcare outcomes for patients treated under the Konsulta program are positive.	3.68	Always	4.5
10. There is evidence of improved health outcomes among patients enrolled in the Konsulta program.	3.77	Always	2.5
11. Konsulta interventions effectively address the healthcare needs of the target population.	3.64	Always	7.5
12. The Konsulta program demonstrates a measurable impact on the overall health of the communities served.	3.68	Always	4.5
Average Weighted Mean	**3.65**	**Always**	

The table above shows the distribution of respondents in the following items. The highest-ranked item, "Clinical guidelines and standards of care are consistently followed in Konsulta" (Rank: 1), suggests that adherence to clinical guidelines is considered a top priority, indicating a strong emphasis on quality assurance. "Patients are generally satisfied with the healthcare services received from Konsulta" (Rank: 2.5) and "There is evidence of improved health outcomes among patients enrolled in the Konsulta program" (Rank: 2.5) are ranked similarly, indicating that patient satisfaction and evidence of improved health outcomes are highly valued within the program. "Patients can easily access Konsulta healthcare services" (Rank: 4.5) and "The Konsulta program demonstrates a measurable impact on the overall health of communities served" (Rank: 4.5) are ranked equally, suggesting that ease of access to services and measurable impact on community health are considered important but not as high a priority as adherence to clinical guidelines and patient satisfaction. "Patients can easily find Konsulta centers within a reasonable distance from their residences" (Rank: 9.5) and "There is continuity and coordination of care across healthcare providers within the Konsulta" (Rank: 9.5) are ranked similarly, indicating that ensuring proximity to centers and continuity of care are moderately important but not as high a priority as other aspects. "Konsulta services reach underserved communities effectively" (Rank: 12) and "Effective outreach efforts and community engagement initiatives are in place" (Rank: 11) are ranked the lowest, suggesting that while reaching underserved communities community engagement is valued.

Table 6: Evaluation of Konsulta System Efficiency

Item	WM	Description	Rank
1. The Konsulta system is user-friendly and easy to navigate.	3.36	Always	8.5

2. System response time is satisfactory	3.23	Often	10
3. System features are easy to understand and use.	3.59	Always	3.5
4. The Konsulta system provides a consistent user experience across different devices.	3.45	Always	6
5. The Konsulta system is always available when needed.	3.36	Always	8.5
6. Technical glitches or errors in the Konsulta system occur rarely.	2.91	Often	11
7. The Konsulta system is compatible with various devices and browsers.	3.55	Always	5
8. Security measures ensure the safety of data within the Konsulta system.	2.73	Often	12
9. Electronic health record management in the Konsulta system is accurate and reliable.	3.68	Always	1.5
10. Patient data in the Konsulta system is easily accessible and well-organized.	3.59	Always	3.5
11. Customization options in the Konsulta system meet specific practice needs effectively.	3.68	Always	1.5
12. The appointment scheduling process in the Konsulta system is efficient	3.41	Always	7
Average Weighted Mean	**3.38**	**Always**	

The table above shows the distribution of respondents as to their experience in utilizing the Konsulta system. "The Konsulta system is user-friendly and easy to navigate" (Rank: 8.5) indicates that users find the system intuitive and straightforward to use, which is a significant strength. "System response time is satisfactory" (Rank: 10) suggests that while response time meets basic expectations, there's room for improvement to enhance user experience. "System features are easy to understand and use" (Rank: 3.5) reflects positively on the system's feature design and usability, indicating that users find the features intuitive and easy to utilize. "The Konsulta system provides a consistent user experience across different devices" (Rank: 6) highlights that while consistency across devices is valued, there may be some variability in user experience across platforms. "The Konsulta system is always available when needed" (Rank: 8.5) is a strong indicator of reliability, suggesting that the system is consistently accessible, which is critical for uninterrupted service delivery. "Technical glitches or errors in the Konsulta system occur rarely" (Rank: 11) signifies a need for improvement in system stability and reliability to minimize disruptions in user experience. "The Konsulta system is compatible with various devices and browsers" (Rank: 5) reflects positively on the system's compatibility, ensuring accessibility across different platforms. "Security measures ensure the safety of data within the Konsulta system" (Rank: 12) suggests a need for bolstering security measures to protect user data effectively. "Electronic health record management in the Konsulta system is accurate and reliable" (Rank: 1.5) highlights the system's strength in managing electronic health records effectively, which is crucial for maintaining data integrity. "Patient data in the Konsulta system is easily accessible and well-organized" (Rank: 3.5) indicates that users can efficiently access and navigate patient data, contributing to improved workflow efficiency. "Customization options in the Konsulta system meet specific practice needs effectively" (Rank: 1.5) suggests strong adaptability and customization features, enabling tailored use according to specific practice requirements. "The appointment scheduling process in the Konsulta system is efficient" (Rank: 7) indicates that while the scheduling process is functional, there may be opportunities for improving and enhancing

efficiency.

Table 7: Evaluation of Konsulta Financial Sustainability

Item	WM	Description	Rank
1. Reimbursements for services rendered by Konsulta are timely and reliable.	3.00	Often	12
2. Reimbursement rates adequately cover service costs in Konsulta.	3.23	Often	11
3. Reimbursement processes and criteria are transparent	3.27	Always	10
4. Funding sources for Konsulta are stable and predictable	3.32	Always	9
5. Resources and funds in Konsulta are utilized efficiently.	3.41	Always	7.5
6. Budget allocation for program administration and support services in Konsulta is appropriate.	3.5	Always	6
7. Financial resources and funding opportunities in Konsulta are maximized effectively.	3.55	Always	3.5
8. Cost-saving measures or strategies in Konsulta are implemented successfully	3.55	Always	3.5
9. Konsulta's impact on practice revenue and financial viability is significant.	3.41	Always	7.5
10. Konsulta demonstrates long-term sustainability and adaptability to financial challenges.	3.68	Always	1.5
11. Financial stability in Konsulta is maintained amidst changes in healthcare policies and regulations.	3.55	Always	3.5
12. Additional revenue streams or diversification efforts in Konsulta are explored consistently.	3.68	Always	1.5
Average Weighted Mean	**3.43**	**Always**	

The table above shows the distribution of respondents as to the financial sustainability of Konsulta. "Reimbursements for services rendered by Konsulta are timely and reliable" (Rank: 12) and "Reimbursement rates adequately cover service costs in Konsulta" (Rank: 11) both receive lower rankings, suggesting challenges in timely reimbursements and ensuring adequate coverage for service costs. "Reimbursement processes and criteria are transparent" (Rank: 10) and "Funding sources for Konsulta are stable and predictable" (Rank: 9) receive slightly higher rankings, indicating relatively transparent processes and stable funding sources, though there's still room for improvement. "Resources and funds in Konsulta are utilized efficiently" (Rank: 7.5) and "Budget allocation for program administration and support services in Konsulta is appropriate" (Rank: 6) both receive moderate rankings, indicating effective resource utilization and appropriate budget allocation. "Financial resources and funding opportunities in Konsulta are maximized effectively" (Rank: 3.5) and "Cost-saving measures or strategies in Konsulta are implemented successfully" (Rank: 3.5) rank higher, highlighting effective maximization of financial resources and successful implementation of cost-saving strategies. "Konsulta's impact on practice revenue and financial viability is significant" (Rank: 7.5) receives a moderate ranking, indicating a notable impact on revenue and financial viability. "Konsulta demonstrates long-term sustainability and adaptability to financial challenges" (Rank: 1.5) and "Financial stability in Konsulta is

maintained amidst changes in healthcare policies and regulations" (Rank: 3.5) both receive higher rankings, indicating strong long-term sustainability and adaptability to policy changes. "Additional revenue streams or diversification efforts in Konsulta are explored consistently" (Rank: 1.5) also receives a high ranking, suggesting proactive efforts to explore additional revenue streams and diversification.

IV. CONCLUSION

Selected authorized providers in Nueva Ecija offer views regarding the PhilHealth Konsulta Program's implementation, effectiveness, difficulties, and possible areas for development. The study offers a thorough grasp of the program's many facets, such as the standard of care, the Konsulta system's user experience, and its long-term viability. The study's conclusions emphasize how crucial it is for the program to prioritize patient satisfaction, clinical guidelines, and proof of better health outcomes. Although the Konsulta system's functionality and user-friendliness have their advantages, there is always room for improvement, especially in system security and dependability.

The significance of financial management and resource allocation is further highlighted by issues with timely reimbursements and the suitability of reimbursement rates to cover service costs. Notwithstanding these obstacles, the PhilHealth Konsulta Program shows great promise in closing gaps in healthcare quality and access, especially in underprivileged areas. Building on the study's strengths and addressing areas for development would allow the program to further increase its impact and help improve healthcare services in Nueva Ecija and beyond.

Additionally, implementing focused interventions to raise the standard of care, boost the Konsulta system's dependability and efficiency, and guarantee the system's financial stability. Achieving its goals would require cooperation from all parties involved, including communities, government organizations, and medical experts, to bring about positive change and give every Filipino fair access to high-quality healthcare. The study's conclusions offer information that can guide evidence-based policymaking, decision-making, and policy actions meant to improve primary healthcare delivery and health outcomes in the Philippines. Through ongoing monitoring and evaluation of this program's implementation, stakeholders may collaborate to create a healthcare system that is more responsive and resilient and can meet the changing demands of the populace.

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Artisanal solar dryer adapted to the climate of the highlands of Madagascar

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Abstract *— Madagascar has vast cultivable land and great seasonal variation in agricultural production. At market levels, it encounters a period of overproduction which leads to a large drop in product prices. Thanks to the climatic conditions of this large island which has the advantage of sunshine throughout the year, we have studied and created in this article an Artisanal solar dryer adapted to the climate of the highlands of Madagascar. We are interested in studying a solar ginger dryer because this spice takes on important roles in terms of nutrients. Our dryer is made from locally available materials. According to our studies followed by experiments, we have observed the effectiveness of our homemade solar dryer. The maximum internal temperature of our dryer reaches a value of 50°C after 50 minutes of operation. The nutritional values of dried ginger are preserved, which proves the effectiveness of our dryer.*

Keyword *— **solar dryer, dried ginger, absorbent plate***

I. INTRODUCTION

Madagascar is a country with fertile soils. Various vegetables and fruits are produced in different seasons. Growers as well as consumers encounter problems when storing fruits and vegetables. The promotion of local products from Madagascar is very important given its abundance in a short period. Farmers use traditional methods to dry fruits and vegetables. To have more output and efficiency, we will present in this article studies, simulations as well as a design of an artisanal dryer adapted to the Malagasy climate. Our device is made from local raw materials available from farmers. The drying speed depends on several parameters including air temperature, ventilation speed and the intensity of solar radiation as well as air humidity.

Physical characteristic of a ginger [1] [2]

Ginger is a plant recently gaining attention in the food and pharmaceutical industries because of its spice and medicinal importance. Major post-harvest processing of ginger is being carried out locally in West Africa and Nigeria due to the unavailability of information on the engineering properties including physical, mechanical, thermal and optical properties which are the main considerations in the design of machines for post-harvest handling of crops. The research looked at some physical properties of ginger (Zingiber officinale) rhizomes such as major, minor and intermediate diameters, geometric mean, sphere city, bulk volume, bulk density, surface area, angle of repose and the coefficient of friction which are essential in the design and construction of the processing and handling equipment of Zingiber officinale. The properties were determined using ASAE standards. The average value obtained for major diameter, minor diameter, intermediate diameter, geometric mean, sphere city, bulk volume, surface area, bulk density and angle of repose within the moisture content range of 10.9 % and 51.6 % dry basis are 112 mm, 38.3 mm, 72.3 mm, 67.6 mm, 0.61, 832.5 cm^3 , 147 cm2 , 0.92 g/cm3 , 480 respectively. The coefficient of friction was obtained on three different structural materials, the values obtained are: 0.40 on glass, 0.49 on stainless steel and 0.55 on wood. All the physical properties measured showed some

deviations from the average values which is typical of biomaterials. The physical properties increase with an increase in the moisture content except the sphere city and bulk density which decrease as the moisture content increases.

Table 1: Summary of Physical Properties of Ginger

Property	Number of Samples	Range	Mean Value	Standard Deviation
Major Diameter(mm)	41	761-133	112	25,5
Intermediate Diameter(mm)	41	60-82,0	72,3	9,8
Minor Diameter(mm)	41	28-44,0	38,3	7,1
Geometric Mean(mm)	41	50,4-78,3	67,6	12,4
Sphericity(dec)	41	0,66-0,59	0,61	0,03
Surface Area(cm2)	41	79,8-192,6	147	49,8
Bulk Volume(cm3)	41	660-112,0	832,5	201,2
Bulk Density (g/cm3)	41	0,96-0,87	0,92	0,048

Chemical properties of ginger

The chemical composition and antioxidant activity (in aqueous and solvent extracts) of Ginger root (Zingiber officinale) were determined. The antioxidant components analysed were polyphenols, vitamin C, β carotene, flavonoids and tannins. Antioxidant assays such as free radical scavenging activity, reducing power and total antioxidant activity were carried out for ethanol, methanol, acetone, 80% methanol and 80% ethanolic extracts. Protein and fat of sample were 5.08 and 3.72 g/100 g respectively. Ash, minerals namely iron, calcium, phosphorous, zinc, copper, chromium and manganese) and vitamin C were 3.85 (g), 8.0 (mg), 88.4 (mg), 174 (mg), 0.92 (mg), 0.545 (mg), 70 (µg), 9.13 (mg) and 9.33 (mg) per 100 g of sample, respectively. Antioxidant components (polyphenols, flavonoids and total tannin) were higher in hot water (100°C) extract than other solvent extracts and 30°C water extract. Antioxidant activity by 3 different methods showed higher activity in solvent extract than water extract. Order of antioxidant activity by reducing power and free radical scavenging activity by DPPH was as follows, 80% methanolic > 80%ethanolic > methanolic > ethanolic > 30°C water >100°C water > acetonic extract. [4]

The obtained results recorded that hot water extract of ginger peels was the promising extract exhibiting promising antioxidant activity. Fractionation of this promising extract was achieved by silica gel column chromatography with petroleum ether/ethyl acetate as mobile phase. Six fractions were produced. Thin layer chromatography ($TLCF_{254}$) was used for separation of active compounds and bioautography confirmed their antioxidant efficiency. Higher antioxidant activity and cytotoxicity against HepG2 cell line was recorded by fraction No. 4. Cold water extract of ginger peels exhibited comparatively higher antioxidant efficiency while both aqueous peel extracts showed antibacterial efficiency against four Gram-positive and Gram-negative bacterial strains using well diffusion assay.[5]

Ginger root (Zingiber officinal Rose) was analyzed to identify its nutritional and anti- nutritional contents. The results showed that Ginger has 34.13% crude protein, 4.07% Ether Extract, 4.02% crude fiber content, 13.75% moisture content, 7.64% Ash content and 1.036% vitamin C. Furthermore, ginger contains major minerals like: Zn 64.0 mg/l, Mn 5.90 mg/l, Fe 279.7 mg/l, Cu 8.80 mg/l, Ca 280.0 mg/l and P 8068.0 mg/l. The result obtained confirmed the usefulness of ginger root as a potential functional food and could be explored further in new product and formulation. I. Introduction Ginger (Zingiber officinal rose) is an underground stem or rhizome of the plant Zingiber officinate. It has been used as traditional medicine in China, India, Malaysia and Arabic countries since ancient times. Ginger has been used to treat stomach upset, nausea, diarrhea, colic, arthritis, heart conditions, flu- like symptoms and painful menstrual periods 1. It was found that Ginger extracts have antimicrobial properties against E.Coli, sslmonella

typhi and bacillus substilis that are common cause of gastro intestinal tract infections 2 . The important active component of ginger root is the volatile oil and pungent phenol compound such as gingerol, which is a very potent anti-inflammatory compound. Modern scientific research has revealed that ginger possesses numerous therapeutic like anti-oxidant effects, an ability to inhibit the formation of inflammatory compounds and direct anti-inflammatory effects 3. Ginger has also been found to reduce all symptoms associated with motion sickness like dizziness, cold sweating, nausea and vomiting 4.[5]

***Table 2**: Nutritional composition of ginger (per 100g)*

Constituent	**Value**	**Constituent**	**Value**
Moisture	15,02 ± 0,04	Ash(g)	3,85 ± 0,61(4,53)
Protein(g)	5,087 ± 0,09(5,98)	Calcium(mg)	88,4 ± 0,97(104,02)
Fat(g)	3,72 ± 0,03(4,37)	Phosphorous(mg)	174 ± 1,2(204,75)
Insoluble fiber (%)	23,5 ± 0,01(27,65)	Iron(mg)	8,0 ± 0,2(9,41)
Soluble fiber (%)	25,5 ± 0,04(30,0)	Zing(mg)	0,92 ± 0(1,08)
Carbohydrate(g)	38,35 ± 0,61(4,53)	Copper(mg)	0,545 ± 0,002(0,641)
Vitamin C(mg)	9,33 ± 0,08(4,53)	Manganese(mg)	9,13 ± 0,01(10,74)
Total carotenoids	79 ± 0,2(9296)	Chromium(µg)	70 ± 0(83,37)

All value in this table represents the mean $\pm SD(n = 4)$. Figures in the parenthesis represent the dry weight values.

Table 3: Antioxidant components and total antioxidant activity of ginger in different solvent extracts.

Antioxidant components	**Water**		**Methanol**	**Ethanol**	**Methanol (80%)**	**Ethanol (80%)**	**Acetone**
	(0,060)	(0,010)					
Total Polyphenols mg/100g	840 ± 2,1	838 ± 3,0	510,22 ± 2,2	565 ± 4,1	780 ± 5	800 ± 4,3	325 ± 1,9
Tannin g/100g	15,1 ± 0,05	1,34 ± 0,08	1,12 ± 0,05	0,98 ± 0,03	1,28 ± 0,01	1,15 ± 0,1	0,67 ± 0,08
Flavonoids g/100g	2,98 ± 0,06	1,371 ± 0,01	0,685 ± 0,005	0,278 ± 0,003	0,404 ± 0,002	0,352 ± 0,002	2,249 ± 0,002
Total antioxidant activity *µmol/g* of sample	73529,4 ± 121	73529,4 ± 0,04	98822,5 ± 66	91176,25 ± 66	85295 ± 47	80000 ± 38	32056 ± 27

Table 4: Correlation between antioxidant activity and antioxidant component of sample in different solvent extracts.

Corrélation (R^2 values)	**Water extract**			**Solvent extract**		
Antioxydant components	Method of assay			Method of assay		
	DPPH	Reducing power	Total antioxydant	DPPH	Reducing power	Total antioxydant
Flavonoids	-1	-1	-1	0,493	0,505	0,613
Polyphenols	1	1	1	0,901	0,847	0,579
Total Tannin	-1	-1	-1	0,985	0,887	0,885

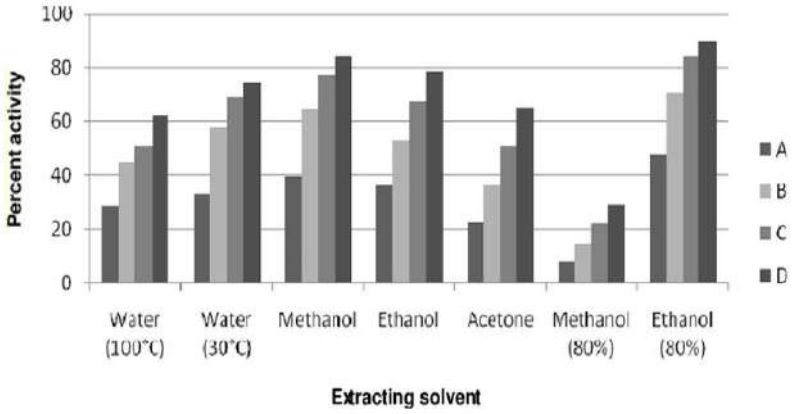

Fig.1 Free Radical Scavenging Activity of ginger in different solvent extracts. Concentration of sample (in mg): In 80% methanolic extract, A: 0.4, B: 0.6, C: 0.8 and D: 1.0. For all other extracts, A: 2.5, B: 5.0, C: 7.5, D: 10.

For solvent extract in DPPH method, methanolic extract was not included for statistical analysis since the concentration did not match with other extracts

It has been reported that the reducing power of bioactive compounds is associated with antioxidant activity (Yen et al., 1993; Siddhuraju et al., 2002). Hence, it is essential to determine the reducing power of phenolic constituents to explain the relationship between their antioxidant effect and their reducing power. The reducing power of different solvent extracts of ginger was estimated. Highest reducing power was also in 80% methanolic extract followed by 80% ethanolic extract (Figure 2). As reported by Chen et al. (2008), the reducing power of methanolic extract of 18 different species of ginger ranged from 0.34 to 1.6 nm in 100 mg of sample. In our study, methanolic extract of sample showed much higher activity of 0.208, 0.393, 0.558, 0.681 nm for 2.0, 4.0, 6.0 and 8.0 mg of sample. Antioxidant components and activity are highly dependent on extracting solvent and concentration of solvent (Turkmen et al., 2006), but they also vary within the samples. Many researchers have reported the relationship between phenolic content and antioxidant activity. In some studies, they found a correlation between the phenolic content and antioxidant activity (Velioglu et al., 1998), whereas others found no relationship (Kahkonen et al., 1999). As it is shown in **Table 4**, in this study we also found high correlation between polyphenol content and antioxidant activity in both water extract (R2 = 1) and solvent extract (DPPH, R2 = 0.901, reducing power, R2 = 0.847 and total antioxidant activity R2 = 0.579). Total tannin and flavonoids did not show any correlation with antioxidant activity in aqueous extract. In solvent extract, total tannin showed high correlation with reducing activity (R2 = 0.887), total antioxidant activity (R2 = 0.885) and free radical scavenging activity (R2 = 0.985). Flavonoids showed correlation with reducing power (R2 = 0.505), total antioxidant (R2 = 0.613) and DPPH (R2 = 0.493). Since the antioxidant activity was higher in alcoholic extract than aqueous extract, it is advisable to use the extracting media capable of extracting the lipophilic antioxidant compounds from ginger.

USES OF DRY GINGER [6]

Dried ginger is known for its health benefits and is utilised as a health supplement worldwide. They have been used extensively in respiratory, digestive, and cardiac conditions, boosting overall health.

Dry ginger powder is known for its digestive benefits. Adding it with buttermilk or vegetables can ease aches and discomforts associated with long-term digestion issues. Grabbing a pinch of dry ginger powder before meals kindles the digestive fire. It is renowned for its Grahi (absorbent or binding nature), making it suitable for constipation and IBS. It relieves bloating, intestinal gas, indigestion, and other discomforts.

Dried ginger is rich in gingerol and shogaol, contributing to its analgesic and anti-inflammatory properties. It can inhibit the release of inflammatory molecules and flush out toxins in arthritic conditions, including rheumatoid arthritis, osteoarthritis, etc. Traditional formulations include dried ginger as an active ingredient in herbal formulations for pain and swelling.

Consuming dried ginger can support the immune system. The anti-microbial properties help fight bacterial, viral, and fungal infections, strengthen the body's innate immunity, and improve overall health. The tradition of ginger tea or ginger kwath during winter has deep roots in enhancing the body's strength.

Whether it is a cough or a cold, ginger combinations always win the hearts of millions as the quickest remedy. Gingerol, the active constituent in dried ginger, contains anti-microbial compounds that help fight respiratory conditions. A pinch of dry ginger powder with honey or turmeric helps address dry cough and cold.

The increased cholesterol levels in the body may increase the risk of heart attack and other conditions. Incorporating dried ginger in meals can significantly reduce harmful cholesterol levels and improve good cholesterol levels.

Dry ginger powder can create wonders on the skin. Dried ginger's antioxidant and anti-inflammatory properties boost skin hydration, increase skin elasticity, reduce acne and wrinkles, improve skin tone, and prevent ageing.

Gingerols and Shogaols in ginger can stimulate various biological reactions, including burning belly fat and body weight. They can indirectly act on weight management by stabilizing blood sugar and improving digestion, absorption, and elimination of food we consume.

Ginger-based hair products, including oil, paste, or hair mask, can adapted according to your choice. They benefit from enhanced blood circulation to the scalp, improved hair growth, hair loss and premature greying, and prevention of scalp infections.

Dried Ginger Powder can be an ideal remedy for period-related issues such as muscle cramps, body aches, nausea, bloating, etc. Natural compounds in ginger can relax uterine muscles and reduce muscular contractions' intensity. Furthermore, they improve blood circulation, regulate hormones, and alleviate periods.

SOLAR DRYER

Solar dryers are devices that use solar energy to dry substances, especially food.

Traditional methods of food drying are to place the foodstuffs in the sun in the open air. This method, called sun drying, is effective for small amounts of food. The area needed for sun drying expands with food quantity and since the food is placed in the open air, it is easily contaminated. Therefore, one major reason why sun drying is not easily performed with larger quantities of food is that the monitoring and overview becomes increasingly more difficult with increasing food quantities. In contrast to sun drying, where the food is exposed directly to the sun, the solar drying method uses indirect solar radiation. The principle of the solar drying technique is to collect solar energy by heating-up the air volume in solar collectors and conduct the hot air from the collector to an attached enclosure, the meat drying chamber. Here the products to be dried are laid out. [7]

In this closed system, consisting of a solar collector and a meat drying chamber, without direct exposure of the meat to the environment, meat drying is more hygienic as there is no secondary contamination of the products through rain, dust, insects, rodents or birds. The products are dried by hot air only. There is no direct impact of solar radiation (sunshine) on the product. The solar energy produces hot air in the solar collectors. Increasing the temperature in a given volume of air decreases the relative air humidity and increases the water absorption capacity of the air. A steady stream of hot air into the drying chamber circulating through and over the meat pieces results in continuous and efficient dehydration. [8]

Solar dryers require a certain investment for the set-up of the appliance, but no expenditures for the fuel. The basic function of a solar dryer is to heat air to a constant temperature with solar energy, which facilitates extraction of humidity from crops inside a drying chamber. Ventilation is enabled at a constant rate through defined air inlets and outlets, small solar ventilators or temperature difference, either due to exposition or vertical height. In direct sun driers the food is put in boxes with a transparent lid. Additionally, the temperature in the drier is raised due to the greenhouse effect and the air exchange is regulated by vents. The food is not exposed to direct sunlight in indirect sun driers as the fresh air is heated separately from the food chamber. This method is preferable for drying foods which lose nutritional value when exposed to direct sunlight. Hybrid driers

combine solar energy with a fossil fuel or biomass fuel (Green and Schwarz, 2001a).

A first step when considering solar drying is to compare the different drying options available. Solar drying will only be successful, when it shows tangible benefits in comparison to existing drying methods. In comparison to the traditional way of drying outside in an open field, solar dryers prevent contamination of produce by dust, insects, etc., thereby ensuring quality. They allow small-scale farmers to transform their harvest into storable and tradable goods, which they can sell off-season at higher prices. The constant temperature and ventilation allow a consistent drying process which results in better product quality and higher prices. However, the investments costs of solar dryers vary highly depending on the size of the solar dryer, locally available materials and environmental conditions, such as slope and exposition of the side, rainy seasons. [9][10]

Different types of solar dryers

- direct drying (solar box dryer),
- indirect drying (solar cabinet dryer),
- mixed mode drying (solar tunnel dryer) or
- hybrid drying (hybrid solar/biomass cabinet dryer).

Benefits of Solar Dryers [11]

The technology provides several socio-economic benefits. One of the main issues facing developing countries today is the issue of food security. The solar food dryer can improve food security through allowing the longer storage of food after drying compared to food that hasn't been dried.

The solar dryer can save fuel and electricity when it replaces dryer variations that require an external energy source in the form of electricity or fossil fuel. In addition, solar food dryers cut drying times in comparison to sun drying. While fossil fuel or electrically powered dryers might provide certain benefits (more consistent air flow and higher temperatures), the financial barriers that these technologies provide might be too high for marginal farmers. For instance, electricity might be not available or too expensive and fossil fuel powered drying might pose large initial and running costs.

Fruits, vegetables and meat dried in a solar dryer are better in quality and hygiene compared to fruits, vegetables and meat dried in sun drying conditions. As mentioned, due to the closed system design, contamination of food is prevented or minimized. In addition, the food is not vulnerable to rain and dust, compared to the open system design of sun drying.

In rural areas where farmers grow fruits and vegetables without proper food drying facilities, the farmers need to sell the food in the market shortly after harvesting. When food production is high, the farmers have to sell the food at low price to prevent the food from losing value through decomposition. Therefore, the solar food dryer might be able to prevent the financial losses farmers in these situations face. Dried food can be stored longer and retain quality longer. Moreover, dried fruits and vegetables might be sold as differentiated products which possibly enhances their market value. For example, dried meat can be processed into a variety of different products.

Drying food reduces its volume. Therefore, in combination to longer storage times, the food is also more easily transported after drying which potentially opens up additional markets to the producer of the food.

II. METHOD AND MATERIALS

One cm thick plywood was used to make the entire dryer.

The air sensor is made up of:

- an insulated wooden board (plywood)
- two layers of polystyrene used as insulation
- a blackened aluminum sheet covering the insulation
- glazing covering everything a few centimeters above the sheet metal

The layers of polystyrene are placed on the wooden planks. Between the insulation and the black sheet, there is an empty part where air can circulate to the drying chamber. The black plate allows maximum irradiation to be captured, this is what we call the absorber. The air enters the dryer from the bottom, it is heated thanks to its contact with the black metal plate. For the glazing, which serves to increase the greenhouse effect of the sensor, we used 2.5 mm glass, leaving 2.5 cm of space between the glass and the sheet metal.

Fig.2: Painting the sheet metal

To assemble the plywood, we use wood glue, nails and vices so that everything holds together well.

Fig.3: Assembly of plywood

Steps for drying ginger

To dry gingers, first ensure that they are clean. Then we sort them and peel them. Then, we cut them with thicknesses of approximately 2 mm. The gingers are ready to be dried, finally, we place them in the dryer on the rack. We install the temperature probe to see the internal and external temperatures of the dryer.

Fig.4: Steps for drying ginger

To collect temperature varieties during drying, we used a thermistor called a "temperature sensor". and an Arduino board connected with the temperature sensor to transfer the values into the computer.

Fig.5: Temperature sensor

III. RESULT AND DISCUSSION

All the equipment is well installed, it remains to take the temperatures every 5 minutes. The measurements are carried out from 12 p.m. on January 18, 2024 and the data obtained are presented in the table below.

Table 5: outside and inside temperatures measured

Time in minutes	External temperature in °C	Internal temperature in °C
0	44.00	40.75
5	44.50	43.38
10	43.50	44.69
15	43.50	45.63
20	45.50	46.44
25	41.50	45.63
30	41.00	45.31
35	41.50	46.19
40	43.50	47.38
45	45.00	48.50
50	45.50	49.81
55	42.00	48.88
60	42.50	48.60
65	41.50	47.38
70	42.00	48.25
75	36.50	45.63
80	37.00	45.56
85	38.50	46.13
90	40.50	46.75
95	44.50	47.33
100	42.00	45.44
105	41.50	42.88
110	40.00	41.13
115	38.00	38.00
120	36.00	37.00
125	35.00	36.19
130	35.50	37.06
135	36.00	37.56
140	35.00	35.50
145	35.50	37.31
150	36.00	37.94

The internal and external temperature variation is represented by the figure.

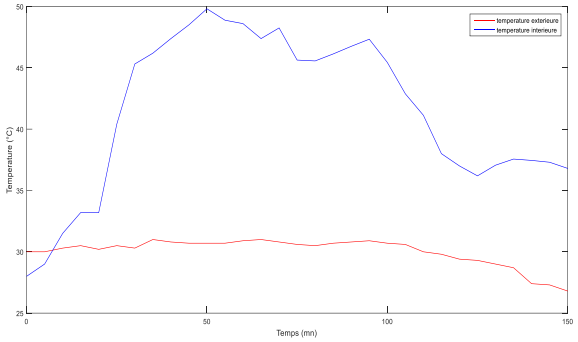

Fig.6: Internal and external temperature variation

At the beginning, the internal temperature is a little lower than that of the external. After a few minutes, equality between these two temperatures is reached. Then, we observe a gradual increase in the external temperature until reaching the maximum after about an hour thanks to the absorber and the greenhouse effect. The internal temperature begins to drop after two hours and the temperature gain is worth 10°C. A temperature reduction of up to 25°C can be achieved during a period under open air.

The test of Nutritional value of ginger before end after the drying is show in the **Table**. In the 10g, of raw and dried ginger, the quantity of nutritional value is kept.

Table 6: Nutritional value of ginger

Nutrient	Raw ginger (root) 10g	Dried ginger (ground) (10g)
calories	3,3	3,4
Proteins	0,1	0,9
Carbohydrates	0,3	0,4
Lipids	0,1	0,4
Dietary fiber	0,2	1,4
Vitamin	Antioxidants, B, C, Iron, Manganese, Potassium	Antioxidants, B, C, Iron, Manganese, Potassium

IV. CONCLUSION

We proposed a small capacity solar dryer, simple and easy to make with local materials which will be well suited for the Malagasy population. This is one of the possible means of preserving agricultural products given that Madagascar is a country rich in fruit and vegetable production. Ginger, which is a very

common spice in all regions, requires an artisanal drying technique so that its conservation is profitable in terms of specific nutrients.

We found an increase in the internal temperature of the solar dryer while that of the external remains almost constant. This increase in internal temperature shows that the homemade dryer is functional. In this article, we presented the principle of artisanal manufacturing of the solar dryer adapted to the climate of Madagascar.

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Enhancing the Energy Efficiency of Wireless Sensor Networks in IoT

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Abstract *— The core foundation of Internet of Things (IoT) systems are wireless sensor networks (WSNs). Energy limitations provide a significant problem for the wireless nodes in these networks that are in charge of sensing. The complexity results from the challenging task of recharging or replacing the batteries of these nodes, a task frequently met with great difficulty. The energy problem is made worse by the fact that many real-world IoT situations involve dynamic sensing components that are in motion. In light of these worries, the current research is carefully designed to solve the real-world difficulties posed by WSNs that include mobile sensing components. The main goal is to use concept of radio-frequency (RF) energy extraction to alleviate energy restrictions that are inherent in such settings. With a framework designed to handle mobile sensing components capable of RF energy harvesting, proposed technique presents a novel procedure for the election of cluster heads (CH) within WSNs. This method holds great potential for overcoming the persistent energy puzzles that have repeatedly hampered the smooth operation of such networks. This method's key strength is its capacity to harness RF energy, which renews the nodes' power sources and increases their operational lives. The effectiveness of the suggested strategy is exposed through thorough simulations, which puts it favorably in contrast to current methodologies. The parameters of residual energy, count of functioning nodes, and overall network longevity all highlight this approach's superior performance and highlight its potential to change the WSN landscape within the dynamic and energy-conscious IoT environment.*

Keywords *— **Wireless Sensor Networks, Energy Efficiency, Internet of Things, Cluster Head (CH).***

I. BACKGROUND

WSNs are key elements inside complex structure of IoT systems. Even though these networks are vital, controlling energy resources is a difficult task that poses a significant difficulty. In particular, the dilemma of either replacing or recharging the batteries of the wireless sensor nodes nested within WSNs has raised questions about their effectiveness due to energy limitations. The fact that dynamic, movable sensor components are frequently used in real-world IoT settings further complicates the situation. This places a greater emphasis on energy-related challenges because the mobility issue makes the energy constraints these networks must deal with even more severe. The idea of radio-frequency (RF) energy extraction emerges as a beacon of potential in response to this complex web of worries. This novel idea has the potential to reduce the energy constraints seen in realistic WSN scenarios with mobile sensor components. This strategy offers a way to get over the

conventional energy bottlenecks and gives a sustainable technique to power these dynamic components within WSNs by utilizing RF energy.

The promise of RF energy extraction within the context of IoT is the primary emphasis of this research. It specifically aims to solve the energy limitations that have, up to now, limited WSNs' ability to operate without interruption, particularly those that use mobile sensors. This strategy tries to recalibrate the energy landscape of such networks by utilizing the latent energy potential of the surrounding environment, giving a fresh perspective on their durability. WSNs' importance is still paramount as IoT devices grow. Innovative solutions are required due to the complex interplay between energy constraints, mobile sensor components, and the dynamic nature of IoT applications. This research aims to reinvent the energy paradigm of WSNs through the perspective of RF energy extraction, opening opportunities to prolonged operation and improved efficiency within the dynamic IoT environment.

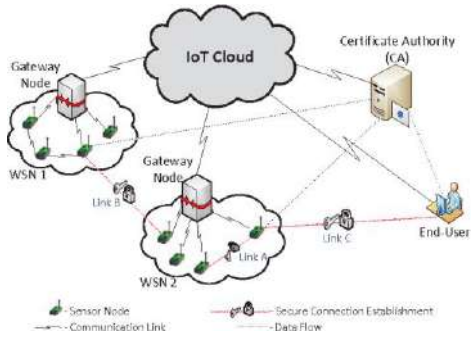


Fig.1.1: Typical WSN based IoT Network

(Source: Porambage, P., Schmitt, C., Kumar, P., Gurtov, A.V., & Ylianttila, M. 2014) [68]

IoT systems are predicted to enable device communication in a variety of environments in the near future, including homes, offices, agricultural fields, factories, transit systems, and battlefields, leading to a large rise in infrastructure needs [1]. In IoT systems, wireless sensor networks (WSNs) are crucial [2]. These networks are made up of numerous electromechanical or wireless sensing nodes that collect a variety of physical parameters and send the corresponding data to a base station/sink in the centre. It is then analyzed, processed, and transmitted over the Internet at the base station [3].

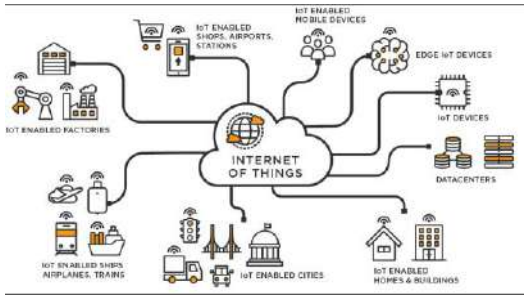


Fig.1.2: Internet of Things (IoT) connectivity with Web Applications

(Source: https://www.analyticsvidhya.com/blog/2022/09/how-to-connect-iot-sensors-wirelessly-with-a-web-application/) [69]

The need for sensing nodes has increased dramatically as a result of the Internet of Things' exponential growth. This growth is being driven by the complex interactions that IoT orchestrates between systems, devices, and data streams. Numerous problems have emerged as a result of the widespread use of wireless connections to connect these nodes, all of which call for sharp focus and creative solutions. The growing number of these interconnected nodes lies at the heart of this developing environment. While they open the door for never-before-seen data interchange and insights, this upsurge also gives rise to a number of complexities that demand careful consideration. The requirement to acquire an adequate communication frequency spectrum takes precedence over all other complications. Innovative spectrum management techniques are required to deal with the expanding number of nodes varying for a piece of this scarce resource in order to avoid overcrowding, signal interference, and general network congestion. Additionally, the increased interconnectedness calls for a significant expansion of data security measures. The sophisticated web of communication paths becomes more vulnerable to hacks, data spills, and cyberattacks as the IoT mosaic grows. Due to these nodes' dynamic nature and the volume of data they manage, data security must be approached from several angles, including encryption, authentication procedures, and anomaly detection systems.

At the same time, the expanding network of sensor nodes highlights the critical energy conundrum. Node consumption of energy resources is independent of size or complexity. This cumulative energy demand poses substantial issues as IoT deployments grow in size. As the continued operation of numerous linked devices is at stake, the race to develop energy-efficient technologies and techniques has never been more important. Transformative potential as well as complex obstacles are heralded by the symbiotic interaction between the IoT and the soaring need for sensor nodes. The solutions we develop will determine the course of the Internet of Things' continued expansion, influencing its ability to transform companies, societies, and the very fabric of connectivity itself, as we negotiate the landscape of communication frequency, data security, and energy efficiency [4, 5].

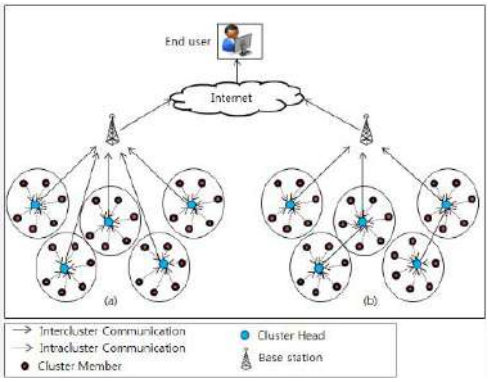


Fig.1.3: Typical wireless Sensor Network Deployment (Source: https://www.researchgate.net/figure/Cluster-based-wireless-sensor-network-WSN-with-different-data-communication-scenarios_fig1_331434432) [70]

Energy is a basic requirement for sensing nodes to operate. However, standard battery replacement or recharging procedures are impracticable in the case of WSNs because the nodes are frequently small and deployed in remote areas [6]. Energy-efficient methods have been developed to solve this problem by lowering the energy consumption of sensing nodes and extending the life of the network. Numerous research already in existence suggest clustering approaches in which the network region is separated into clusters, each of which contains several sensing nodes. Based on variables such as remaining energy and distance to the sink, cluster head (CH) chosen among nodes in each round [7]. In order to extend the lifespan of the network, the nodes in a cluster send data to the CH, which then talks with the sink for that round.

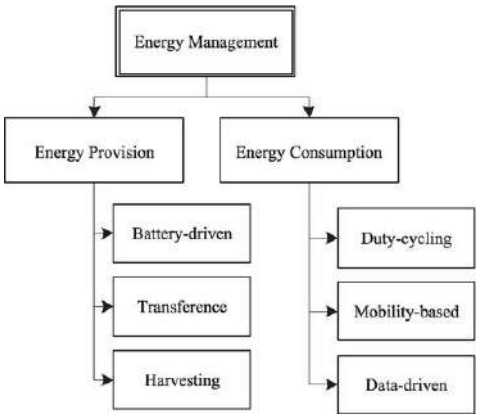


Fig.1.4: Energy Management issues in Wireless Sensor Networks

A viable method for fueling wireless sensing nodes is energy harvesting, a new technology [8]. Energy-harvesting WSNs include nodes that may draw power from ambient or specific sources [9], such as radio-frequency (RF) energy as well as non-natural sources like wind and sunshine. In particular, RF sources offer the ability for simultaneous wireless information and power transfer (SWIPT) [10]. These sources may be ambient, such as Wi-Fi or mobile towers, or they may be deployed RF sources specifically designed to energize WSN nodes [11]. Although RF sources may provide less energy than natural sources, their reliability and ongoing accessibility make them a good choice for wireless sensor nodes.

WSNs consist of mobile sensing nodes rather than fixed ones in many real-world applications [12]. Soldiers, military vehicles, or animals in their natural habitats are some examples of naturally moving objects in the sensing environment that are included in Mobile Wireless Sensor Networks (MWSNs) [13]. Additionally, vehicles with sensors that function as mobile sensing units can be a part of smart transportation systems. The difficulties with replacing batteries in MWSNs are significantly more

complicated than in static WSNs, highlighting the critical function of energy management. In this situation, RF energy harvesting can be quite important.

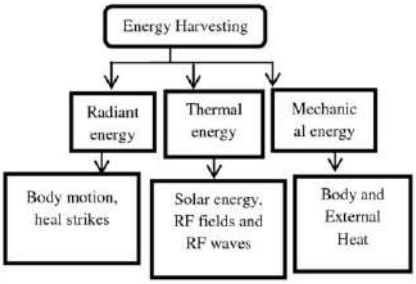


Fig.1.5: Energy Harvesting - WSNs

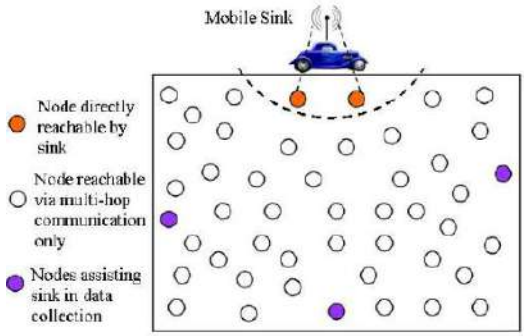


Fig.1.6: Mobile Wireless Sensor Networks (MWSNs) (Source: https://www.researchgate.net/figure/Network-architecture-of-a-mobile-wireless-sensor-network_fig2_260120791) [71]

Surprisingly little research has been done in the area of Mobile Wireless Sensor Networks (MWSNs) that can use RF energy. This gap in knowledge and research offers an enticing chance to delve into a world full with promise. The goal is to address an important issue: how to maximize the energy efficiency of nodes inside MWSNs, particularly when these networks collide with real-world scenarios involving mobile elements. The standard paradigms of energy management fall short in these dynamic contexts, necessitating creative solutions that can meet the constantly changing energy needs of mobile nodes. Therefore, the main goal of this research is to close the current energy efficiency gap by combining tried-and-true energy-saving techniques with the cutting-edge idea of RF energy extraction. This research aims to usher in a new era of energy sustainability for MWSNs by combining tried-and-true energy-conservation methods with the promise of RF energy harvesting. The main objective is to make it possible for these networks to thrive by being mostly self-sufficient, in addition to functioning seamlessly in the face of mobility. This project has the potential to fundamentally alter how we think about and use wireless sensor networks in mobile contexts. It is not only an academic undertaking. These networks could power themselves by utilizing the ambient RF energy that is all around us, minimizing reliance on outside energy sources and opening the door for longer-lasting, more autonomous, and environmentally responsible network operations.

As the research moves on, it hopes to not only add to the body of knowledge about MWSNs but also to elicit useful implications. These effects could improve the effectiveness of smart transportation systems or make it possible to monitor wildlife in far-off locations more successfully while resolving the energy issues that have hitherto hindered such attempts. This research sets out on an aim to close the MWSN energy efficiency gap. It aims to revolutionize the mobile wireless sensor network landscape through the merging of well-established energy-efficient tactics and RF energy extraction principles, ushering in an era of sustainability, resilience, and transformational possibilities for real-world applications. Cluster Head (CH) will finally be chosen for each simulation round, assuring energy-efficient CH choice and RF energy extraction in order to increase lifetime of the network as a whole by increasing sensing nodes lifespan. In the study, variables which are used for the analysis include:

- Initial/remaining energies
- Energy - Harvested
- Location changes
- Node's Average Energy

"Initial energy" and "remaining energy" relate to the energy levels of individual sensor nodes within wireless sensor networks (WSNs).

Initial Energy: Each sensor node in a WSN is initially powered by a specified amount of energy, which is often provided by batteries or other power sources. This initial energy is a representation of the node's

initial energy level as it starts to function inside the network. It's an important parameter since it controls how long the sensor node can function before running out of energy.

Remaining Energy: The remaining energy is used by each sensor node as the WSN runs to perform various tasks like sensing, processing, communication, and maybe other operations like data aggregation and routing. The quantity of energy that a sensor node has left over after carrying out its duties for a while is known as the leftover energy. Monitoring the remaining energy is essential for determining the network's health, estimating the nodes' remaining life, and enhancing energy-saving tactics.

Network administrators and researchers can make well-informed choices about node deployment, energy-efficient routing protocols, data collecting schedules, and methods for extending the overall network lifetime by being aware of the starting and residual energy levels in a WSN. Because the energy sources of the sensor nodes in WSNs are typically limited and non-rechargeable, managing energy usage is a significant concern.

Energy Harvested: "Energy harvested" in the context of wireless sensor networks (WSNs) refers to the act of gathering energy from outside sources to power the sensor nodes within the network. Energy harvesting, as opposed to exclusively depending on batteries, allows sensor nodes to recharge by obtaining energy from the environment, which can increase the operating lifetime of the network and decrease the need for frequent battery replacements. Radio Frequency (RF) technology can be used for energy harvesting. Through rectifying circuits, energy, or ambient RF signals like Wi-Fi or cellular signals, can be transformed into useful electrical energy. When it is inconvenient or expensive to replace the batteries in sensor nodes, especially in remote or difficult-to-reach areas, energy harvesting is extremely useful. WSNs can operate more sustainably and for a longer time by using environmental energy. The fluctuation in energy supply, the effectiveness of energy conversion, and the development of energy management systems that balance energy consumption and energy harvesting rates are some of the issues associated with energy harvesting.

Location Changes: "Location changes" often refer to the mobility of sensor nodes inside wireless sensor networks (WSNs). While nodes in typical wired networks are immovable, nodes in wireless sensor networks (WSNs) can be mobile within a given space or environment. In terms of network administration, data collecting, and communication, this mobility may present both benefits and constraints. Routing protocols, energy management approaches, localization procedures, and network architecture concerns are all used to control location changes in WSNs. It necessitates addressing the trade-offs between energy usage, data accuracy, network resilience, and data gathering efficiency.

Node's Average Energy: "Node's average energy" in the context of wireless sensor networks (WSNs) refers to the typical amount of energy used or left in a sensor node over a given amount of time. It is a statistic used to assess the effectiveness and energy efficiency of each node in the network. Designing energy-efficient protocols and methods requires an understanding of the node's average energy in order to evaluate the network's overall health and lifetime.

The idea of node's average energy operates as follows:

- Energy Consumption: Sensor nodes in a WSN use energy for a variety of functions, including environment sensing, data processing, data transmission and reception, and network connection maintenance. Depending on the exact applications and tasks the nodes are performing, the energy consumption pattern may change.
- Initial Energy: When a sensor node joins the network, it comes with an initial supply of energy, often delivered by batteries or energy-harvesting devices. The node's ability to function is determined by its initial energy.
- Energy Depletion: The node's energy level gradually drops as it fulfills its duties. The tasks carried out and the component efficiency of the node determine the rate of energy depletion.

- Calculating the Node's Average Energy: To get the node's average energy, divide the total energy used or still present in the node by the length of time used to collect the energy measurements. This computation reveals how quickly the node's energy is depleting and how long it can function without needing to be recharged or replaced.
- Energy management: It's essential to keep track of the node's average energy when coming up with energy management plans. Nodes with low average energy may require recharge or replacement, whereas nodes with high average energy may be better suited for tasks that require more energy.
- Network Lifetime: The total network lifetime is influenced by the average energy of all network nodes. A longer average energy across nodes may result in a longer network operating lifetime.
- Researches can create energy-efficient protocols and algorithms, such as duty cycling, data aggregation, adaptive routing, and sleep-wake scheduling, by studying the node's average energy consumption.
- Fault Detection: Extremely low average energy levels may signify faulty nodes or nodes with energy-sipping problems, which could cause network deterioration.

Given the scarce energy resources accessible to sensor nodes and the need of assuring the network's lifetime, measuring and managing the node's average energy is a crucial component of preserving the effectiveness and sustainability of wireless sensor networks.

Problem Statement

For wireless sensing nodes in Wireless Sensor Networks (WSNs), energy-related issues provide a significant and challenging barrier. This problem is mostly caused by the complex barriers involved in changing or recharging the batteries in these nodes. This conundrum is further complicated by the inclusion of mobile sensing components in a wide range of real-world Internet of Things (IoT) applications. The current energy problems are greatly made more difficult and complex by the integration of mobility. Gaining a thorough understanding of WSN situations that embrace the idea of mobile sensing elements is crucial in order to properly address these important issues. The ultimate objective is to develop methods and solutions that can successfully reduce, ease, or even avoid the severe restrictions imposed by energy resources by diving deeply into the dynamics of such scenarios. By doing this, we open the door for WSNs to operate more sustainably and long-term in the face of tightening energy supplies.

II. PURPOSE OF THE STUDY

The need to overcome the restrictions provided by energy constraints inside wireless sensor networks (WSNs) is driving the field of research to move its focus towards the analysis of practical situations that involve mobile sensing elements. The goal of this project is to develop creative solutions to the enduring energy-related problems that arise in such situations. Radio-frequency (RF) energy extraction offers a promising option for investigation in order to tackle these imposing problems. In this method, WSNs are strategically reconfigured to include a crucial component known as the cluster head, which houses movable sensing elements capable of capturing RF energy from the surroundings. The energy dynamics within WSNs could be completely altered by this integration of energy gathering capabilities. While earlier research has focused mostly on improving energy efficiency of WSNs through analysis of variables like initial energy reserves, residual energy levels, mean energy consumption & inter-node distances, there has been a glaring lack of research into the field of energy harvesting strategies designed to improve the energy efficiency of WSNs in practical, real-world scenarios. The significance of the suggested strategy, which aims to fill this information gap by introducing a CH selection system, is highlighted by this crucial gap. This innovative technique introduces a new age of increased energy utilization efficiency by enabling individual nodes within the WSNs to actively accumulate RF energy. According to the proposed technique, WSN behavior

in mobile sensing scenarios would undergo a comprehensive makeover. The suggested strategy not only has the potential to ease the energy-related challenges of mobile WSNs, but also to redefine the very fabric of energy sustainability within these networks. It does this by capitalizing on the untapped potential of RF energy extraction and integrating it with strategic CH selection mechanisms.

In short, research will address the following objectives.

- Addressing energy constraint in IoT applications in wireless sensing nodes in WSNs.
- Designing WSN nodes (mobility) by coming up with various clustering protocols for enhancing energy efficiency of WSNs and prolonging network lifetime.
- Coming up with a novel technique that will combine RF energy extraction with clustering scheme in order to extend lifespan of a MWSN.
- Validating effectiveness of proposed technique by demonstrating improvements in energy, node count, and network lifetime.

Research Questions

- Is it possible to address a significant constraint of energy requirements of WSN nodes?
- How to design real time scenario of mobility in WSN nodes using different clustering protocols for enhancing energy efficiency and prolong the network lifetime?
- How to come up with a novel technique combining RF energy with clustering scheme in order to extend the lifetime of a mobile wireless sensor network?
- How to validate the effectiveness of the proposed technique?

Significance of Research

The main goal of the study is to demonstrate the effectiveness and applicability of the suggested methodology by demonstrating how it affects many vital features of wireless sensor networks (WSNs). The suggested method seeks to greatly increase the number of operational nodes inside the network, fortify residual energy reserves of WSN nodes & extend network's total lifespan through thorough simulation-based analysis. The novel approach under discussion has ramifications that go beyond theoretical research since it is positioned to be a crucial tool in evaluating the viability and effectiveness of real-world Internet of Things (IoT) applications that are built on the basis of WSNs with mobile components. This suggests that the suggested technique has the potential to offer insightful analysis and workable solutions for situations where mobile components are crucial to data gathering and transmission. It's interesting to note that this strategy can be used in situations without naturally mobile objects. Additionally, it may be fluidly expanded to include scenarios in mobile WSN frameworks where elements might not necessarily have movement properties. This flexibility highlights the approach's adaptability because it can be modified to suit a variety of mobile WSN scenarios, regardless of whether mobility results from inborn movement or outside influences. The flexibility with which the proposed scheme can be altered to support alternative mobility models also highlights how adaptable it is. This adaptability aspect makes it possible to fine-tune the technique to suit the particular needs and dynamics of a particular application. This ensures the scheme's relevance and effectiveness in a variety of settings by allowing for smooth integration into a wide range of contexts. In addition to the theoretical justification of the technique's benefits, researchers are also interested in its real-world applications for improving mobile WSNs' energy efficiency, network robustness, and lifetime. The proposed technique emerges as a flexible and useful tool with broad implications for the area of wireless sensing and network sustainability by showcasing its potential through simulations and recognizing its applicability in both real-world IoT scenarios and diverse mobility settings.

III. LITERATURE REVIEW

In IoT systems, charging wireless sensor nodes turns out to be a significant obstacle. In Wireless Sensor

Networks (WSNs), the procedure of changing batteries is labor-intensive and ineffective, especially when nodes are placed in difficult-to-reach places. These scenarios involve detecting forest fires or attaching nodes to moving objects like soldiers or animals. It is clear that in order to get out of this jam, energy-efficient power management for sensor nodes requires a planned strategy. [15]. Researchers have created a wide range of clustering algorithms in response to the requirement to reduce excessive power consumption and improve the energy use of individual nodes. These algorithms are cutting-edge approaches created to improve the energy consumption patterns in WSNs. These algorithms try to more evenly distribute energy depletion across the network by intentionally establishing clusters of nodes and designating specific nodes as cluster chiefs. This distribution technique is especially important when certain nodes are required to consume a lot of energy because of their functions or the surrounding circumstances. Additionally, these clustering algorithms attempt to increase the operational lifespan of the entire WSN in addition to addressing issues with energy efficiency. The network as a whole becomes more resilient and sustainable by reducing the energy consumption of individual nodes, especially in extended deployments or situations where routine maintenance is impractical. Innovative solutions are required to address the problem of charging wireless sensing nodes in IoT systems in order to maintain their long-term durability and efficacy. By optimizing energy use, fostering network life, and improving the overall performance of WSNs in a range of practical scenarios, the implementation of effective clustering algorithms constitutes a significant step towards resolving these problems [15]. An early clustering algorithm, the low-energy adaptive clustering hierarchy (LEACH) algorithm [16], selects Cluster Heads (CHs) at random for each round in order to disperse energy depletion across nodes and prolong the network lifetime. To improve network performance, changes have been made to the LEACH protocol [17]. There have been several efficient clustering strategies [18] that take energy into account for CH selection [19]. In contrast to earlier systems [16, 18], a different strategy concentrates on energy of sensing nodes [20].

Researchers have explored various approaches for data aggregation in WSNs. One such approach is the cyclic grid-based approach (CBDAS), which divides the WSN into grids and utilizes a main head node to transmit data to the sink [21]. In contrast to CBDAS, an alternative grid-based network deployment (GHND) selects a zonal head based on factors such as energy levels & average distance b/w sensing nodes [22]. Another method, surpasses GHND in terms of stability & network lifetime, considers parameters such as the distance between nodes, the zone center, and the remaining energy to determine the zone head [23] [24].

In the literature, different Mobile Wireless Sensor Networks (MWSNs) are discussed, depending on whether the base station. Mobile-LEACH routing protocol analyses the communication between mobile sensing nodes and CHs [25]. Several strategies are used in the selection of cluster heads (CHs) in the context of a Mobile Wireless Sensor Network (MWSN). One such method, known as LEACH-mobile average energy (LEACH-MAE), establishes CHs based on the network's average energy levels [26]. When selecting CHs, another technique known as LEACH Distance-M considers things like remaining energy, threshold distance, and minimal mobility [27]. A modified variant of LEACH is suggested for MWSNs in a different investigation, where the clusters are constructed by taking into account the predicted placements of nodes in the future [28]. The LEACH-mobile energy-efficient and connected (LEACH-MEEC) routing protocol was developed to choose CHs by taking into account both residual energy and the connectivity status of nearby nodes in order to improve energy efficiency and connectivity [29]. The choice of CHs is also addressed when dealing with a MWSN that includes both mobile and stationary nodes in addition to a stationary base station [30].

Due of the lower energy requirements of WSN nodes, RF energy harvesting has received substantial research as a substitute energy source [31]. RF energy

harvesting circuits, protocols, and their effects on RF energy harvesting networks have also been covered [32]. The impact of RF energy harvesting on wireless nodes' capacity for packet transmission has been studied [33]. It has been investigated how to design RF energy harvesting antennas, with a preference for small, wide-band antennas for IoT applications [34]. Utilizing rechargeable batteries or cognitive nodes without batteries, RF energy harvesting has also been incorporated into cognitive radio networks [35, 36, 37]. There has been relatively little study on energy harvesting strategies in real-world settings involving mobile nodes. Incorporating RF energy collecting, this work suggests a CH selection technique for WSNs installed on moving objects.

The provision of sustained electricity to wireless sensing nodes is the fundamental challenge facing IoT systems. In a Wireless Sensor Network (WSN), replacing batteries on a regular basis is not only laborious but also extremely inefficient [38], especially given the potential deployment of nodes in distant or difficult-to-reach areas like forests for fire detection or on moving objects like animals or soldiers. In these cases, it becomes necessary for sensor nodes to use energy-conscious power management mechanisms, ideally freeing them from the need for batteries. Researchers have developed a number of clustering algorithms [39] that try to minimize unintended node energy use in order to optimize energy usage.

Among the earliest suggestions was the Low-Energy Adaptive Clustering Hierarchy (LEACH) [40], a ground-breaking clustering technique. The energy depletion across nodes is balanced by LEACH's randomized cluster head (CH) selection technique in each round, extending the network's operational lifetime. On top of this foundation, later research has improved network performance by introducing changes to the LEACH protocol [41]. In this regard, Qing et al. 42] introduced an effective clustering strategy for CH selection. In contrast to Qing et al. [42], Mishra et al. [43] developed an energy-aware strategy, basing CH selection on residual energy per round, and achieved greater network lifespan. In contrast to earlier works [39,41], Leu et al. [44] developed a clustering process that took into account the average energy of the cluster as well as the residual energy of particular nodes. This mechanism increased the average network lifetime.

Alternative strategies have also surfaced in the interim. A data aggregation technique was devised by Chiang et al. [45] that divided the WSN into grids, each with a specific head node for cyclic data transfer. Farman et al. [46] developed a grid-based network deployment method that outperforms Chiang et al. [45] by taking energy levels and average distances into account while choosing zonal heads. When Farman et al. [47] used residual energy and the distance between nodes and zone centers to pick zone heads, the stability and lifetime of the network were increased compared to their earlier work [46]. Behera et al. [48] outperformed Farman et al. [46] in terms of network stability and longevity by introducing a thorough CH selection scheme that took initial energy, residual energy, and optimal CH values into account.

Mobile Wireless Sensor Networks (MWSNs), taking into account mobile nodes or base stations, are also covered in literature. A mobile-LEACH routing protocol was investigated by Kim and Chung [49] for communication between mobile sensing nodes and CHs. LEACH-Mobile Average Energy (LEACH-MAE) technique, which chooses CHs inside MWSNs using the average energy levels, was introduced by Ahmed [50]. Khandnor and Aseri [51] developed the LEACH Distance-M method for MWSNs, which includes CH selection taking into account things like remaining energy, threshold distance, and minimal mobility. Corn and Bruce [52] improved the LEACH technique for MWSNs to forecast upcoming node placements for cluster reconfiguration. Ahmad et al. [53] developed the LEACH-Mobile Energy-Efficient and Connected (LEACH-MEEC) protocol for CH selection to address connection and residual energy. Zhang and Yan [54] investigated the subject and chose CHs based on node mobility and distance in the context of MWSNs that include both mobile and stationary nodes in addition to base stations.

Harvesting of RF energy is included in the scope. In their review of RF energy harvesting for WSNs, Tran

et al. [55] suggested it as an alternative energy source. Nintanavongsa [56] covered RF energy harvesting circuits, protocols, and their effects in great detail. The impact of RF energy harvesting on wireless node packet transmission was looked into by Wu and Yang [57]. Divakaran et al. [58] investigated design difficulties for RF energy harvesting antennas and identified antennas with broad bandwidth as appropriate for IoT. Even cognitive radio networks [59,60] have used RF energy harvesting, integrating it into battery-free cognitive nodes [61] and utilizing rechargeable batteries for power storage [62]. For network power requirements, Zhang et al. [63] suggested RF energy harvesting integration with wireless power transfer.

Importance of variables including starting, residual & average energy, and distance in improving effectiveness of Wireless Sensor Networks (WSNs) has been highlighted by earlier studies. These variables have served as the main focus of efforts to improve the energy dynamics in these networks [64, 75-77]. Despite these initiatives, there is still a glaring gap when it comes to dealing with the energy issues in real-world settings that include mobile nodes. This knowledge gap emphasizes the scant investigation into energy collecting techniques adapted to the special requirements given by mobile node scenarios.

The suggested method introduces a novel approach that includes a Cluster Head (CH) selection mechanism tailored specifically for WSNs in which nodes are attached to moving objects, like animals, with the capacity to harness Radio-Frequency (RF) energy, in order to fill this crucial knowledge gap. The usual paradigms of energy management inside mobile WSNs are redefined by this novel technique, which successfully integrates the synergies of mobility and energy harvesting [65-74].

The envisioned methodology introduces a paradigm change by incorporating RF energy harvesting capabilities into nodes placed on mobile elements. Instead of using conventional battery replacement or recharging, it tries to capture the energy potential already available in the environment to power these nodes. The energy landscape of WSNs functioning in the dynamic world of mobile elements might be revolutionized by this strategy, which not only adheres to the sustainability standards [66-72].

The suggested solution includes a two-pronged strategy: it simultaneously takes advantage of the untapped energy resources contained in the ambient RF waves and the mobility of certain WSN units. The envisioned CH selection scheme holds the potential to significantly improve the energy resilience and longevity of mobile WSNs through the integration of these aspects, thereby fostering their sustained operation in situations where conventional energy sources prove to be impractical or unfeasible [67-73]. A new range of possibilities is opened up by the strategic combination of energy harvesting with mobility, which paves the way for more flexible and robust mobile WSNs in a variety of practical applications.

IV. RESEARCH METHODOLOGY

- **Model**

The Wireless Sensor Network (WSN) system created for a monitoring scenario was the main subject of this study. In this situation, the base station stayed stable while the field-deployed sensing nodes were presumptively mobile. These wireless sensing nodes were carried by the users who were in the vicinity, who were regarded as mobile elements. Furthermore, it was anticipated that the wireless sensing nodes could collect Radio Frequency (RF) energy and had distinct interfaces for doing so and for communicating the data they had gathered.

The Multi-Hop Wireless Sensor Network (MWSN) was made up of many 'N'-style wireless sensing nodes. These nodes were strewn across the network field at random. A method known as K-means clustering was used to effectively handle these nodes. With the help of this technique, the randomly dispersed nodes were organized into 'M' clusters, each of which held a particular number of nodes. Sensing nodes were assigned to clusters using K-means clustering based on their Euclidean distance from the cluster centroid. This clustering strategy was chosen because it can cut down on energy use by shortening the distance

between Cluster Heads (CHs) and nodes.

Due to the nodes' mobility, clusters were reconstructed using the K-means clustering method after each round, taking into account the nodes' most recent positions. The selection of the Cluster Head (CH) then happened. As all the sensing nodes had identical energy levels at this point, the CH was first selected at random among nodes within a specific cluster. The CH was chosen for following rounds based on a variety of factors, including average energy level, residual energy, and node placements.

The remaining energy in each round was calculated based on the energy used and gathered in the round before to ensure the system's coherence. In order to build the system model, the study operated under a number of reasonable hypotheses, including the mobility of WSNs, immobility of sink (base station), uniform initial energy distribution across nodes, the nodes' ability to move in arbitrary directions at different speeds, and the nodes' awareness of location, harvested & consumed energy for given round.

Additionally, a single CH was assigned to each cluster in each round to handle all base station communications. The possibility for energy collecting by the nodes was increased by the assumption that neighboring ambient RF energy sources existed in the network environment. Notably, the wireless sensing nodes included twin antennas, enabling them to draw power from two separate RF sources that operated in various frequency bands. The goal of this creative design was to improve the network's overall energy effectiveness.

- **Modelling for Energy**

Energy Consumption

Heinzelman and her colleagues' radio model has been widely used by low energy radio communication systems. This specific model provides accurate equations for computing the energy consumption during data exchange across sensing nodes. Equation (1) explicitly expresses the energy usage (E_{tx} [b, d]) for a node delivering a payload of b bits to a remote node positioned d' meters away. Equation (2) is used to express the energy expenditure (E_{rx} [b]) experienced by a sensing node during the receiving of b bits of data from another node.

$$E_{tx}(b, d) = E_{tx.ele} \times b + E_{fs} \times b \times d^2, \text{ if } d \leq d' \quad (1)$$
$$E_{tx.ele} \times b + E_{amp} \times b \times d^4, \text{ if } d > d'$$

$$E_{rx}(b) - E_{rx.ele} \times b \quad (2)$$

$$d' = (E_{fs} / E_{amp})^{1/2} \quad (3)$$

$E_{tx.ele}$ and $E_{rx.ele}$ here stand for energy used by each bit in the transmitter and reception circuitry, respectively. Additionally, the transmission parameters E_{fs} and E_{amp} stand for free-space & multipath fading model's respective counterparts.

Energy Harvesting Model

Wireless sensing nodes have the potential to collect energy from nearby ambient radio frequency (RF) energy sources in addition to their many sensing capabilities. A number of variables, including transmission power, RF source frequency, distance between the node and the source, and antenna gains built into both the source and the node, affect how much energy a wireless sensing node can gather. Equation (4) explains the method by which the '*i*th' sensing node obtains energy from the '*j*th' harvesting source.

$$E_h(i, j) = \eta P_i G_i G_j t_h (\lambda_j / 4\pi R_{i,j})^2 \quad (4)$$

In this framework, G_i stands for the antenna gain of the RF receiver connected to the wireless sensing node '*i*th' while G_j refers to the antenna gain of the RF transmitter connected to the energy harvesting source '*j*th'. P_j stands for the power produced by the '*j*th' energy gathering source. '*j*th' energy harvesting source's signal is transmitted at a wavelength designated by the symbol. The spatial distance between the energy harvesting source located at the '*j*th' node and the '*i*th' node is explained by $R_{i,j}$. Additionally, "th" denotes the prescribed time period allotted for the energy harvesting procedure, while " η" represents the effectiveness of the charging process.

Residual Energy

According to Aslam and colleagues' study, a threshold energy level (E_{thr}) can be determined by classifying the sensing nodes into Mode 1 and Mode 2 for each subsequent round. Nodes with energy levels above the specified E_{thr} value are categorized as Mode 1 nodes in this classification. Both sensing and energy-harvesting operations are being actively carried out by

these nodes. At the conclusion of each round, equation (5) was used to calibrate residual energy levels of nodes belonging to Mode 1.

$$E_{r,i}\,(rn + 1) = E_{r,i}\,(rn) = E_{consume}\,(rn) + E_{h,i}\,(rn) \quad (5)$$

$E_{r,i}(rn + 1)$ in this context denotes energy level of '*i*th' node in the round, while $E_{r,i}(rn)$ denotes energy level of identical node in round before it, labeled as (rn). The variable $E_{consume}(rn)$ represents energy used by '*i*th' node during the round with the round number (rn), while variable $E_{h,i}(rn)$ represents energy that '*i*th' node obtained during (rn)th round.

Nodes having energy levels below E_{thr} are classified as operating in Mode 2, which forbids them from doing any sensing operations. Instead, these nodes focus solely on energy harvesting, working to replenish their energy levels until they reach the required level. The residual energy levels for these specific nodes were calculated using equation (6).

$$E_{r,i}\,(rn +1) = E_{ri} + E_{h,i}\,(rn) \quad (6)$$

Cluster Head (CH) Selection

The mobile sensing nodes in this investigation were presumptively mobile in a manner consistent with the random waypoint mobility model. In this model, nodes make decisions at random, such as choosing a direction and traveling in that direction at a speed randomly chosen from a range of speed thresholds. This motion continues until a stop of arbitrary duration happens, at which point the procedure is repeated with nodes selecting new motion directions. The cluster layout was recalculated after each iteration based on new locations of sensing nodes. Cluster Head, chosen from pool of individuals associated with respective cluster, was assigned to each of these redesigned clusters. However, only nodes classified as Mode 1 were eligible to be chosen as CHs during a particular round, while nodes classified as Mode 2 were not taken into account for CH selection during that round.

The selection of CH was determined from among the Mode 1 nodes taking into consideration both its own residual & cluster's average energy levels of sensing nodes. This decision-making process was based on a determined ratio known as "R," which stood for ratio of average energy ($E_{avg,i}$) & residual energy ($E_{r,i}$) for each individual node. Equation (7) was used in the development of this ratio.

To elaborate further, this movement strategy simulates the randomness and variability encountered in real-world scenarios, allowing the system to adapt to the dynamic changes in node positions and energy levels. The subsequent cluster formation and CH selection process takes into account both energy metrics to optimize network efficiency and prolong the network's overall operational lifespan.

$$R_i = E_{r,i} / E_{avg,i} \quad (7)$$

The CH for the given round was chosen as the node with the greatest R value. The numerous processes for the CH selection process are shown in the figure below.

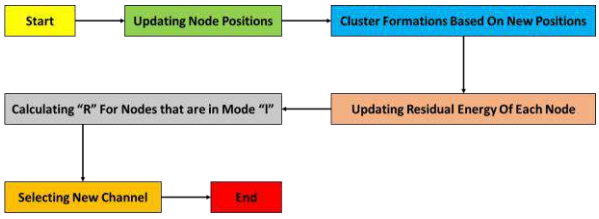


Fig.3.1: Cluster Head (CH) Selection Process

- **Algorithm Development**

It is possible to effectively separate the operational process of the proposed Multi-Hop Wireless Sensor Network (MWSN) into phases: first phase, which includes Cluster Head selection, & second sensing phase that includes sensing, data communication & energy harvesting activities. This all-encompassing strategy guarantees the network's effective operation and enhances the dynamics of its energy consumption. The proper positioning of the deployed sensing nodes is the initial phase's main concern. These positions act as the cornerstone for the development of 'M' clusters, a task carried out by K-means clustering framework. Computation of nodes' residual energy values is a crucial step after these clusters are successfully created. The amount of energy that nodes harvested and used during the previous cycle of operations is a factor in this calculation.

The sensing nodes have two modes, 1 & 2, according to their residual energy levels, further defining the

process. Mode 1 is aligned with nodes with high energy reserves, while Mode 2 is aligned with nodes with low energy reserves. The crucial process of CH selection takes place in Mode 1. The CH's function is crucial since it includes all subsequent communications with the central sink.

The CH designated from Mode 1 assumes a variety of duties as the sensing phase begins. The execution of sensing activities, energy harvesting projects, data aggregation from nodes inside its specified cluster, and ensuing transfer of this aggregated data to the central sink are some examples. In contrast, nodes designated for Mode 2 focus entirely on energy harvesting and momentarily halt their sensing functions.

These processes develop repeatedly over subsequent rounds as the network develops, sustaining a loop of energy-efficient data collecting, transmission, and energy replenishment. The network's agility, resource optimization, and continued functionality are highlighted by this all-encompassing operational strategy as it takes on real-world obstacles brought on by varying energy levels and dynamic node movements.

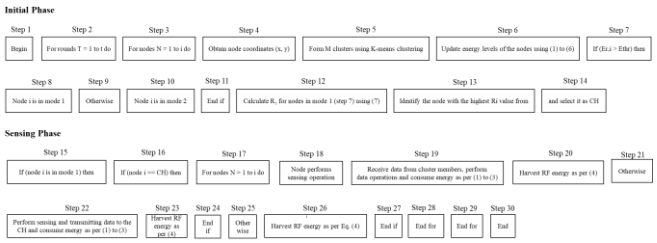


Fig.3.2: Algorithm

Simulation & Discussion

- **NS2**

The technique proposed will be analyzed using NS2 simulations. NS2 provides a variety of tools and functions for numerical computation, plotting and visualization, programming, and application development. It is widely recognized for its easy-to-use syntax and powerful data analysis capabilities.

NS2 has several characteristics that make it a popular choice for scientific and engineering applications. Here are some of its key characteristics:

- High-level language: NS2 is a high-level language, which means that it is designed to be easy to read and write. It uses a syntax that is similar to traditional mathematical notation, making it easier for users to express mathematical concepts in code.
- Interactive environment: NS2 provides an interactive environment that allows users to experiment with code and test ideas in real-time. This is particularly useful for exploring data and developing algorithms.
- Extensive library of functions: NS2 comes with a large library of pre-built functions that can be used for a wide range of applications, from signal processing to machine learning.
- Graphics and visualization: NS2 provides powerful tools for creating graphs, visualizations, and other types of data representations.
- Interoperability: NS2 can be used with other programming languages and tools, making it a flexible choice for many applications.
- Platform independence: NS2 runs on a variety of platforms, including Windows, Linux, and mac OS.
- Application development: NS2 can be used to develop standalone applications that can be distributed and run on other computers, making it a powerful tool for creating custom solutions for specific problems.

The researcher has used NS2 for the analysis.

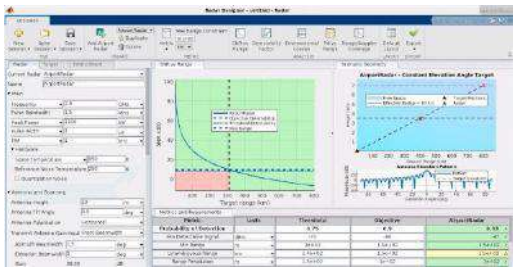


Fig.4.1: Generic NS2 Analysis Snapshot

- **Deployed Conceptualized Network**

In the course of our research, we investigated a Multi-Hop Wireless Sensor Network (MWSN) configuration with a total of 100 nodes that were purposefully and randomly placed throughout a sensing field with

measurements of 100 meters by 100 meters. This network was launched against a stationary base station that was carefully placed at the coordinates (50, 50). Table 4.1 provides a detailed summary of the simulated parameters.

Table 4.1: Parameters for Simulation

Energy of the Initial Node	I, J
Energy used by each bit in the transmitter & reception circuitry (E_{tx_ele}/E_{rx_ele})	50 nJ/bit
Transmission parameters for the free space model (E_{fs})	10 pJ/bit/m^2
Transmission parameters for the multipath fading model (E_{amp})	0.00129 pJ/bit/m^4
Threshold energy level (E_{thr})	0.10 J
Size of the Packet	3000 bits
Ambient Radio Frequency (RF) sources frequency bands	900, 1800 MHz
Antenna Gain (G_i/G_j). Antenna gains of the RF receiver of the *i*th (G_i) wireless sensing node and the RF transmitter of the *j*th (G_j) energy harvesting source.	1
Charging Efficiency	0.3
Harvesting duration/round	1 s
Power Transmitted by the *j*th harvesting source (P_j)	100 mW
Mobility Model	Random Waypoint Model
Node speed limits	0 - 5 m/s
Node directions	-180 & +180

In the context of wireless sensor networks (WSNs), the **Random Waypoint Model** is a popular mobility model for assessing the functionality and behavior of networking protocols, algorithms, and tactics. It is applied to model the temporal behavior of nodes (sensors or devices) in a network. The underlying premise of this model is that nodes behave independently and arbitrarily inside a predetermined simulation region.

The Random Waypoint Model operates as follows:

- Initialization: Within a predetermined simulation area, nodes are dispersed at random. A starting location is assigned to every node.
- Each node chooses a random waypoint (target point) inside the simulation area, as well as a random pace at which it will travel there.
- Phase of movement: The node advances at the given speed in the direction of the chosen waypoint. The movement can be simple and consist only of the node moving in a straight line in the direction of the destination, or it can be complex and involve changes in direction or speed.
- When a node reaches its chosen waypoint, it pauses for a predetermined amount of time before choosing a new destination point and speed and resuming the process.

The Random Waypoint Model's main attributes are:

- Independence: Each node autonomously decides how to move, making it appropriate for situations where nodes don't adhere to predetermined patterns or coordinate.
- unpredictability: By introducing diversity into the simulation through unpredictability in waypoint selection and movement speed, researchers can evaluate different network protocols.
- Realistic: Despite the model's simplification and potential shortcomings, it offers a solid foundation for understanding how networks behave in dynamic environments.
- The model's parameters include the nodes' top speeds, waypoint pause intervals, and length of the simulation. These settings can be changed to examine various mobility patterns.
- Challenges: Some node movements, such as those driven by environmental variables like topography, impediments, or social interactions, may not be adequately modeled by the model.

The Random Waypoint Model can be used to assess several wireless sensor network characteristics, such as routing protocols, power usage, data aggregation, and localization methods. Researchers can learn more about how various networking solutions function in dynamic situations and spot possible problems and optimizations by simulating the mobility of nodes.

It's crucial to emphasize that while every node in this network was given mobility, the base station stayed still. The environment surrounding the network field was assumed in our research to have ambient Radio Frequency (RF) energy sources. The two cellular mobile RF sources that made up these ambient RF energy sources were identified as operating in separate frequency bands and placed at the coordinates (50, 105) and (105, 50), respectively. The fact that cellular mobile radio systems typically output constant power levels across time, with small power changes related to service scheduling judged

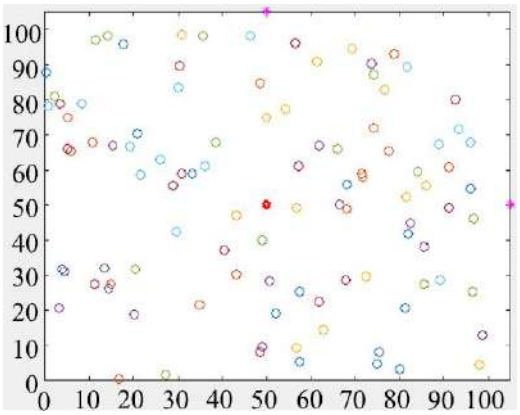
unimportant, is an important observation.

To emphasize the idea of randomization in their placement, I placed the RF energy sources in this study somewhat close to network field. Wireless nodes, on the other hand, had the cutting-edge ability to wear dual-band antennas, giving them capacity to harvest energy from not just one but two different RF sources, each operating within a different frequency band. This strategy improved the network's sensing nodes' abilities to acquire energy.

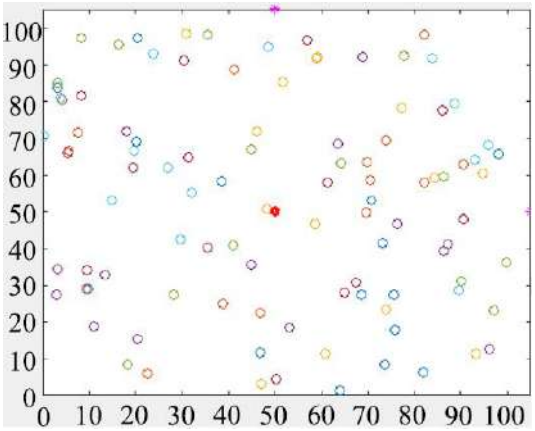
The definition of a threshold energy level (E_{thr}) was a key component of our suggested methodology. One-tenth of the nodes' initial energy reserves were chosen as this threshold. This particular energy level was determined to be adequate to support the necessary operations within Mode 1 for a prolonged period of at least 10 additional rounds. It's crucial to remember that wireless sensing nodes were constantly collecting RF energy from the defined RF sources. This was made possible by the nodes' innate design, which included distinct channels for data transmission and energy collecting.

The temporal scope of each round was standardized at 1 second for the purposes of our simulations. This choice made it easier to develop a coherent and understandable framework for analyzing network dynamics. As a result, the duration of energy harvesting for each round was evenly fixed at 1 second due to the round's continuous energy gathering.

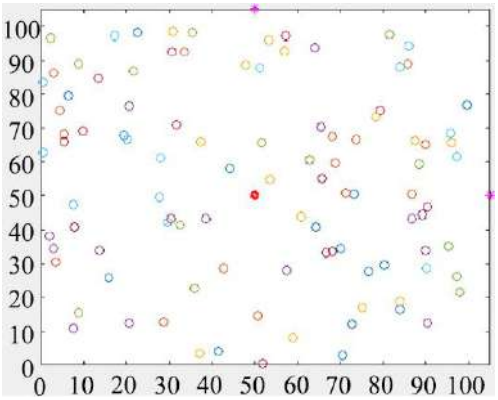
Figure 4.1 (a to d), which shows the gradual transition in the distribution and placements of mobile sensing nodes at different times, specifically t, t + 25, t + 50, and t + 100, was shown to graphically represent the evolving network scenario. This representation gave concrete understanding of the network's dynamic development throughout time.



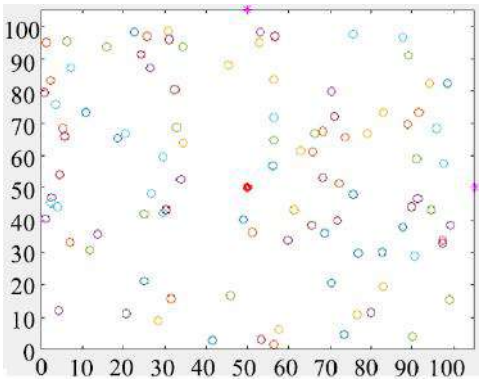
(a) Initial phase beginning at time instant t = 0



(b) Time instant t = t + 25



(c) Time instant t = t + 50



(d) Time instant t = t + 100

Fig.4.1: Positions of Mobile Sensor Nodes: Network Deployment

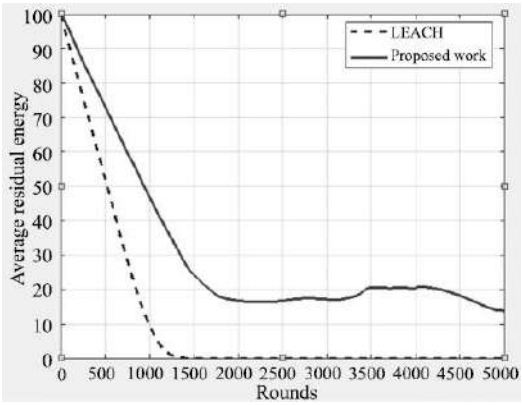


Fig.4.2: Average Residual Energy

- **Performance Analysis**

The average residual energy, no of functional nodes, & network lifetime were all evaluated as part of the proposed technique's evaluation. Understanding the idea of "half-network-dead point," or point where half of network's sensing nodes stop functioning, is crucial within this paradigm. In addition, network lifetime captures period of time from death of first node to end of final node's functionality.

I conducted a thorough comparison, testing the suggested method against a variety of static & mobile WSNs, in order to contextualize this evaluation. We examined LEACH, CBDAS, GHND, IGHND, and R-LEACH among static WSNs, and mobile-LEACH, LEACH-MAE, LEACH-Distance-M, and LEACH-MEEC among mobile WSNs. This in-depth analysis intended to highlight the relative advantages and disadvantages of the suggested method in a wider range of situations.

The average residual energy between LEACH and the suggested approach throughout the first 5000 rounds were compared in Figure 4.2 in a useful way. Notably, the LEACH network's residual energy levels collapsed to zero before 1500 rounds had been completed. The proposed method, however, maintained its operational integrity well after 5000 rounds. The proposed technique's seamless integration of RF energy collecting and consumption for different operational tasks, which promoted continuous energy balance, logically supported this distinction.

Turning to Figure 4.3, the figure showed how the functional node count changed over time relative to rounds for both LEACH and the suggested method. This story held my attention because, in the instance of LEACH, all nodes shut down after roughly 1500 rounds. But using the suggested method, 40% of the nodes were still functional even after 5000 rounds. The creative energy management method was the main supporting element in this case. Specifically, nodes replenished themselves by RF energy harvesting, changed from a functional (Mode-1) to a rechargeable (Mode-2) state upon reaching specified energy threshold & then returning to operational status.

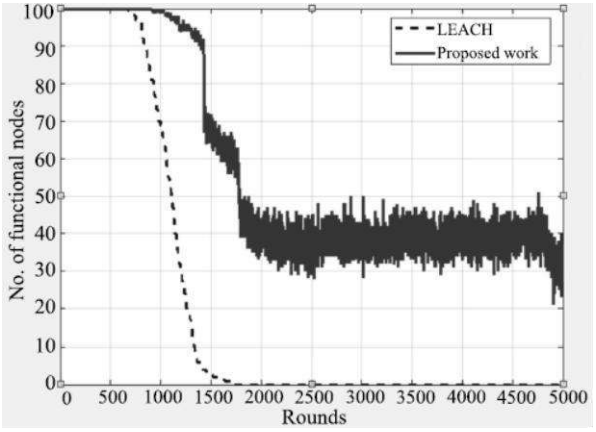


Fig.4.3: Average Residual Energy

Comparison of half network dead points & network lives (Figures 4.4 and 4.5) was a crucial point in the evaluation. The suggested method was evaluated in comparison to a wide range of other WSNs, including LEACH (low-energy adaptive clustering hierarchy algorithm), CBDAS (Cycle-Based Data Aggregation

Scheme), GHND (grid-based network deployment), IGHND (improved grid-based network deployment) and R-LEACH (Residual low-energy adaptive clustering hierarchy algorithm).

A popular clustering-based technique is **Low-Energy Adaptive Clustering Hierarchy (LEACH)** was created for energy-efficient communication in WSNs. LEACH's main objective is to extend network lifespan by minimizing energy consumption, which is crucial in WSNs since sensor nodes are frequently powered by batteries with limited capacity. LEACH opened the door for a number of expansions and enhancements to clustering-based WSN protocols. To overcome its drawbacks and adapt it to various situations, such as unequal node distribution and mobility, researchers have suggested tweaks and improvements.

A specific approach or methodology for carrying out data aggregation in the context of Wireless Sensor Networks (WSNs) is referred to as the **"Cycle-Based Data Aggregation Scheme" (CBDAS)**. In this method, data aggregation takes place in rounds or cycles, with sensor nodes in the network gathering and processing data over a set time or cycle. In this context, the term "cycle" designates a period of time during which data is gathered, processed, and aggregated prior to being sent to a central node or sink. The cycle-based method has a number of benefits, including increased scalability, decreased communication overhead, and energy efficiency. Reduced energy usage owing to localized processing and decreased data transfer, which might result in an increased network lifetime, are the main advantages of a Cycle-Based Data Aggregation Scheme in WSNs. This method works especially well in applications where network durability and energy efficiency are important considerations.

In wireless sensor networks with variable grid sizes, the **grid-based hybrid network deployment (GHND)** framework enables energy efficiency and load balancing. In all circumstances of node density and beginning energy, GHND has more rounds than other techniques, extending the network lifetime.

Improved Grid-Based Hybrid Network Deployment (IGHND), a multi-criteria-based CH selection model in IoT-based WSN, uses a number of characteristics, including level, energy, and distance, which affect network lifetime and node energy.

R-LEACH (Residual low-energy adaptive clustering hierarchy algorithm outperforms LEACH, CBDAS, GHND, and IGHND for all energy values because it selects stable nodes as CH).

Using the above algorithms, all comparisons were made using a uniform packet size of 2000 bits for the sake of parity, testing various beginning energy levels (0.25 J, 0.5 J, and 1 J) throughout simulation spans of 4000, 5000, and 6000 rounds. The results were startling: even after 6000 rounds, the proposed technique continually surpassed the competition in terms of half-network-dead points. At same time, proposed method significantly increased network lifetime and was able to preserve operational integrity throughout the whole simulation period. This significant improvement was primarily caused by the wireless sensor nodes' superior capacity to efficiently capture RF energy compared to other approaches.

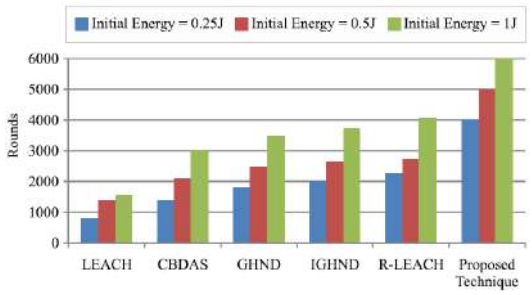


Fig.4.4: Half Network Dead Times (initial energies of 0.25, 0.5 & 1 J)

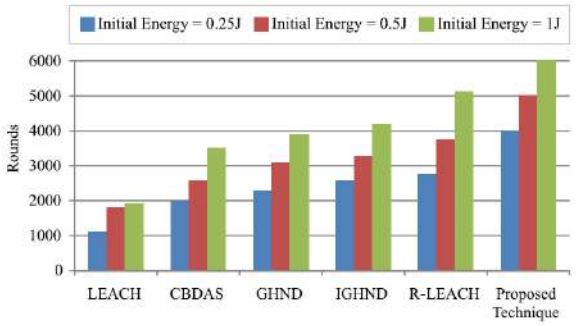


Fig.4.5: Network lifetimes (initial energies of 0.25, 0.5 & 1 J)

In Figures 4.6 and 4.7, a significant divergence was

seen when the suggested method was compared to several Mobile Wireless Sensor Networks (MWSNs), such as mobile-LEACH, LEACH-MAE, LEACH-Distance-M, and LEACH-MEEC. Using a common packet size of 40 bits, these evaluations took into account the residual energy & no of functioning nodes across rounds. It is clear that the suggested method excelled on both counts, as evidenced by the fact that it kept the residual network energy level far higher during the observation period and had significantly more operational nodes even after a thousand rounds. This significant gain was made possible by the suggested technique's careful integration of the symbiotic link between energy use and harvesting, a detail frequently missed by competing approaches.

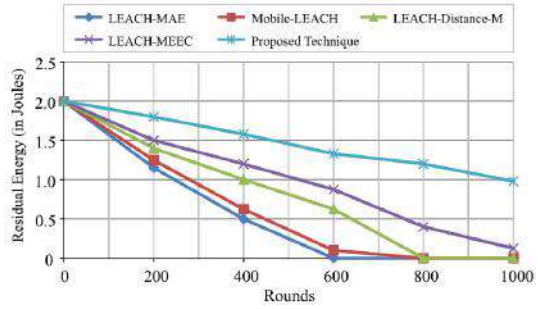


Fig.4.6: Comparison (residual energies of various MWSNs)

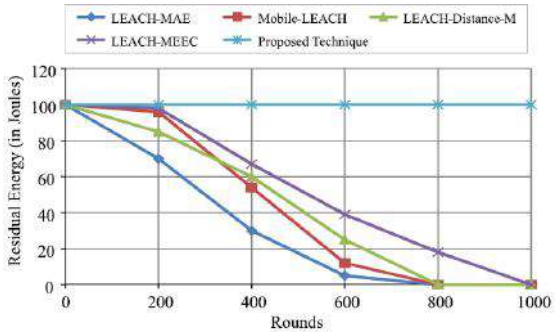


Fig.4.7: Comparison (no of functional nodes of various MWSNs)

The proposed technique's strong effectiveness was highlighted by this thorough examination, notably because of its dynamic energy management framework, which includes energy harvesting and consumption and contributes to improved network longevity and overall performance. It is noteworthy that this method deviated from typical approaches by taking into account both the limitations of mobile nodes & potential of RF energy harvesting, leading a significant increase in network lifetime and increased energy efficiency.

V. CONCLUSIONS AND FUTURE WORK

- **Conclusions**

The research thesis explores an urgent issue centered on energy requirements of WSNs, a crucial component of Wireless Sensor Networks (WSNs) designed for Internet of Things (IoT) applications. This paper does a good job of tackling the problem head-on, especially when it comes to mobile WSN nodes, which are a crucial component of real-world IoT scenarios.

Researchers have worked to develop various clustering algorithms over time in an effort to address the problem with WSN energy usage. The main objective of these initiatives has been to prolong the useful life of these networks. The unusual efficacy of the proposed method in the complex domain it functions in, however, is what distinguishes it. The clever incorporation of the idea of capturing ambient Radio Frequency (RF) energy is key to this novel approach. The proposed strategy emerges as a beacon of hope inside this complex environment by cleverly combining this energy source with a sophisticated clustering design. It highlights a tactical combination that is carefully designed to absorb and channel RF energy, hence boosting the sensor nodes' energy reserves.

The method's potential impact is increased by strategically combining it with a deftly planned clustering architecture. The coordination of this synergy is done on purpose to meet the specific requirements of Multi-Hop Wireless Sensor Networks (MWSNs). The overarching goal is to significantly increase the network's ability to operate for a longer period of time. The suggested strategy optimizes energy use and distribution, enabling effective communication between nodes and therefore extending the lifespan of the network as a whole.

This research is a testament to creative problem-solving in the intricate and constantly changing field

of the Internet of Things, where the interaction of energy, communication, and longevity is crucial. The thesis comprehensively addresses the energy dilemma encountered by mobile WSN nodes by skillfully merging ambient RF energy capture and a carefully built clustering architecture. By doing this, it adds to the theoretical foundations of WSNs and IoT and broadens the implications of those foundations to real-world applications where network sustainability and efficiency are crucial.

A paradigm-shifting discovery that sheds new light on the field of energy augmentation was made within the context of this thesis: ambient Radio Frequency (RF) energy can be used as a backup energy source. This discovery revealed the possibility of utilizing the ubiquitous RF signals that permeate our environment and transforming them into a source of useful energy to power the sensor nodes inside the network. The idea was revolutionary in and of itself because it called for a paradigm shift away from traditional energy sources and toward the untapped possibilities of the nearby electromagnetic spectrum. This shift needed the creative construction of energy harvesting devices that could capture minute amounts of energy from the ubiquitous RF signals in modern society. This energy, which would have otherwise been lost to the environment, was captured and transformed into a transforming force for the sensor nodes.

A strategic clustering plan developed as a crucial ally for this energy revolution as the thesis set out on the path of actual implementation. This plan wasn't just any old construction; rather, it was carefully planned to work with the larger goal of improving energy efficiency. The thesis unlocked a dual-pronged method that would form the cornerstone of its proposed technique by combining this deftly designed clustering architecture with the energy-harvesting mechanism. This method, a complex fusion of energy dynamics and communication strategy, served as a witness to creativity. Multi-Hop Wireless Sensor Networks (MWSNs) underwent a paradigm shift as a result of the intricate interweaving of the threads of ambient RF energy utilization and the advanced clustering technique. This impact was characterized by a significant increase in network lifetime, a development that has the potential to completely alter the way that networks are operated.

The effectiveness of the dual-pronged plan was obvious. The technology successfully addressed both the energy shortage and effective network communication issues by deftly combining the capacity to capture ambient RF energy with an intelligently controlled clustering architecture. The nodes were given access to an additional energy source and were led by an ideal communication strategy, ushering in a new era of MWSNs defined by enhanced network functionality and resilience. In addition to shedding light on the unexplored world of ambient RF energy, the research also staged a revolutionary dance between energy harvesting and clustering tactics. The environment of multi-hop wireless sensor networks witnessed a dramatic change as a result of the convergence of these two forces, promising long-lasting and significant network operations. This thesis is at the forefront of innovation in the fields of network engineering and Internet of Things applications thanks to the disclosure of the potential of ambient RF energy and its harmonious integration into a well-designed clustering scheme.

As a crucial component of this research project, the validation procedure of the suggested technique developed, providing a solid base for its legitimacy and practical applicability. Adopting rigorous simulation tools was crucial to this validation since they provided a way to empirically validate the advantages and efficacy of the suggested approach.

The simulation environment served as a regulated setting where the effectiveness of the suggested strategy could be painstakingly assessed and tested against predetermined key performance metrics. Metrics that highlighted the network's usability, durability, and energy conservation were of utmost importance. The research studied the method's effects on critical aspects such as node operability, the extension of the network's lifespan, and the conservation of residual energy resources with great attention to detail.

This thorough assessment offered verifiable proof

underscoring the method's capability to strengthen and improve these essential network characteristics. The empirical information gathered from these simulations shed light on the beneficial impacts of the suggested technique on the various facets of network performance. It strengthened the justification for the strategy, supporting the claim that it had the potential to improve not only energy consumption but also the sustainability of the entire network. These practical results served as a bridge between the theoretical and the practical, supporting the applicability of the proposed strategy in real-world situations. This was especially noticeable in fields with mobile workforces and flexible operational environments. This made areas like environment monitoring and combat surveillance suitable testbeds to determine the method's usefulness in the real world.

The suggested method was well received in situations where nodes are naturally movable and operational conditions are continually changing. The solution directly addressed the problems created by these unstable situations by harnessing ambient RF energy and regulating clustering tactics. The method showed off its adaptability to situations where continual mobility and shifting conditions are the norm by prolonging network lifespan and optimizing energy usage. The suggested strategy successfully closed the gap between theoretical claim and practical impact by establishing its empirical worth through simulation-based validation. This verification emphasized the method's adaptability and viability and highlighted its potential to change a variety of applications, particularly those hampered by mobility and changing environments. As a result, this research thesis made a significant contribution to the field of network engineering while simultaneously laying the groundwork for the method's easy incorporation into practical settings, where its effectiveness really shines. The recommended method's adaptability and adaptability stand out as defining characteristics, demonstrating its capacity to transcend a wide range of mobile Wireless Sensor Network (WSN) scenarios. The ability of this flexibility to adapt its application to the complex requirements of numerous dynamic situations is particularly noteworthy. The technique is an appealing option for solving the complex problems posed by mobile WSNs because of its inherent capacity to be selectively simplified. The method's adaptability to various mobility effects is an amazing trait. The strategy can be deliberately optimized in situations where mobility is a prevailing component but not always linked to the natural movement of the nodes. The primary focus of this selective reduction is on energy losses brought on by node movement. This subtle adaptation effectively disallows internal node dynamics considerations, such as biological or physiological movement, which can be unimportant in particular application domains.

By adopting this narrow emphasis, the strategy keeps its essential efficiency while removing components that might be superfluous in some situations. The method's range of applications is broadened by this streamlining process, enabling it to smoothly connect with a variety of application fields. Due to its dynamic adaptability, the approach can be applied to any setting where mobility has a substantial impact, regardless of the underlying causes of that movement. The method's applicability is broadened by this customized approach. Think of applications like asset tracking, industrial automation, or vehicle monitoring. Mobility is crucial in these situations, and the method's ability to reduce energy loss caused by movement could be a game-changer. The technique fits the requirements of these sectors, where constant movement is the norm, by focusing on this particular energy consumption component.

The suggested approach develops into a flexible toolkit that may work with a range of situations without sacrificing its effectiveness or relevance. Its adaptability is not simply a theoretical idea; it is a real-world claim that has the power to change how mobile WSNs are used. The method demonstrates its devotion to custom-made solutions, capable of improving energy efficiency and extending network functionality in a variety of application settings, by dynamically shifting its focus to meet particular mobility patterns. This adaptability demonstrates the method's inventiveness and highlights its potential to

serve as a fulcrum of innovation in a variety of mobile WSN sectors.

The proposed method's inherent adaptability goes beyond its existing limitations and encompasses a wide range of options, underscoring its status as a framework that is extremely flexible. This method stands out because to its innate ability to accommodate and support a wide range of mobility models, each of which is specifically designed to satisfy the requirements of various application scenarios. Due to its inherent versatility, the technique can be used to handle a variety of problems throughout the spectrum of mobile Wireless Sensor Networks (WSNs) rather than just as a one-size-fits-all solution. The technique's reliability and adaptability are demonstrated by the ease with which it may be integrated with other mobility models. It becomes a priceless tool for network engineers and IoT practitioners because it can adapt to various conditions with ease. The method can be tailored to fit the particular dynamics of each circumstance, whether the application involves nodes traveling in predictable trajectories, following random patterns, or reacting to outside inputs. This adaptability is not limited to a particular model; rather, it covers the full spectrum of possible movement patterns, guaranteeing that the technique continues to be a useful and practical solution in a constantly changing environment.

A gripping narrative of the complex interactions between energy harvesting, mobility, and strategic clustering is left behind as the investigation comes to a close. This dynamic connection draws attention to the proposed technique's transformative potential. The method emerges as a catalyst for revolutionizing energy-efficient network architecture by utilizing ambient RF energy, optimizing network communication through clustering, and dynamically accommodating multiple mobility models. This conceptual convergence creates a potent trinity with the potential to transform network engineering in the context of the growing Internet of Things (IoT) paradigm.

In summary, this research highlights the complex interaction between energy dynamics, mobility factors, and clustering techniques. The suggested method is more than just an idea; it is a real innovation that successfully combines theory and application. Its extraordinary adaptability, as evidenced by its compatibility with many mobility models, establishes its position as a framework that can go beyond the limitations of single solutions. By doing this, it sets out on a quest to reimagine energy-efficient network architecture within the constantly changing IoT environment. This research opens the way for a future in which the intricate confluence of these ideas will surely affect how we perceive and construct wireless networks inside the IoT ecosystem. It is rich in theoretical underpinnings and practical ramifications.

- **Future Research**

The development of energy efficient methods for mobile wireless sensor networks based IoT has the potential to satisfy the urgent demand for energy conservation while facilitating the smooth operation of linked devices in the future. The fusion of several technology fields, including as energy harvesting, data processing, communication protocols, and AI, is expected to enhance this area and support the long-term expansion of IoT applications.

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Analyzing and Compensation of Non Linear effects on DWDM based Optical Fiber Communication System

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Abstract *— Implementing a dense wavelength division multiplexing (DWDM) configuration can substantially enhance the capacity of an optical communication system. Nonetheless, the DWDM system encounters notable challenges due to nonlinear effects that hinder its performance. Self-phase modulation (SPM), cross-phase modulation (XPM), and four-wave mixing (FWM) are three key factors that exert a significant influence on the system's optical communication capabilities. The primary objective of this research is to tackle and alleviate the nonlinear impact of cross-phase modulation within the DWDM system through an effective approach. In this research, we introduce a method for correcting dispersion in DWDM systems. These nonlinearities, encompassing self-phase modulation, cross-phase modulation, and four-wave mixing, are common occurrences in such systems. The researcher's proposal primarily centers on addressing cross-phase modulation. To comprehensively assess the DWDM system, we explored the effects of fluctuations in power and data rates. According to the results, a 32 channel DWDM system can effectively correct nonlinearities utilizing the suggested Symmetrical-Symmetrical-Post compensation technique (SSP) up to a transmission distance of 400 km using an input power of 20mW & data rate of 100 Gbps. These characteristics are ideal for long-distance optical communication. Suitably modifying the data rate and input power, it is feasible to increase no of channels and transmission distance. The new SSP method was also found to perform better than the conventional post-compensation methodology, making it more appropriate for long-haul DWDM systems. It is crucial to understand that the SSP technique by itself is unable to fully offset the spectral broadening brought on by cross-phase modulation. In order to solve this problem, combining sophisticated modulation methods with SSP can successfully reduce the spectrum broadening. This strategy can call for the use of more amplifiers, which could result in increased power consumption. In such configurations, dynamic control of the erbium-doped fiber amplifier (EDFA) is essential.*

Keywords *— **Dense Wavelength Division Multiplexing (DWDM); Cross Phase Modulation; Nonlinearity; Self Phase Modulation; Four Wave Mixing.***

I. INTRODUCTION

- **Optical Fiber Communication**

Using light as the carrier signal, optical fiber communication is a technique for sending data between two points. It is a technology that allows for the transfer of high-speed data across vast distances and is widely utilized in networking, telecommunications, and internet services. Electrical signals carrying data are converted during the transmission process into optical signals, which are then sent through a glass or plastic fiber. Very little signal strength is lost as the optical impulses move through the fiber, enabling long-distance transmission without the need for frequent signal boosting or amplification.

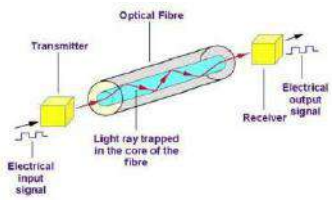

Fig.1: Optical Fibre Communication

(Source: https://www.polytechnichub.com/fiber-optic-communication/)

An introduction to optical fiber communication is provided below:

- Transmitter: Electrical signals are first created from the information to be communicated, such as data, sound, or video. The information from these electrical signals is subsequently modulated and encoded onto an optical carrier signal, typically made up of light pulses.
- Optical Fiber: A thin, glass- or plastic-made strand of optical fiber is then used to carry the modulated optical signal. Light goes through the fiber's core, which is wrapped by a cladding that bounces light back into the core to minimize signal loss.
- Signal Propagation: A phenomenon known as total internal reflection occurs when light signals repeatedly bounce off the cladding as they move through the optical fiber. when a result, there is little intensity loss when the light travels through the fiber, guaranteeing that the signal can travel over vast distances without suffering greatly.
- Receiver: A separate device known as the receiver is used to detect incoming optical signals at the receiving end. The receiver changes the optical signals it has picked up back into electrical signals so that the original data may be retrieved and further processed.

Optical fiber communication has several benefits.

- Fast Data Rates: Optical fibers can transmit data at incredibly fast rates, enabling the quick transfer of substantial volumes of data.
- Long Distances: Without the use of repeaters or signal regeneration, optical fibers may transmit signals over long distances of up to several kilometers.
- Low Signal Loss: Optical fibers have a signal loss that is substantially lower than traditional copper-based communication systems, allowing for greater transmission lengths and improved signal quality.
- Immunity to Interference: Unlike electrical communications in copper cables, optical transmissions are not hampered by electromagnetic interference. As a result, they are less vulnerable to noise and other disruptions from the outside world.
- Data transfer through optical fibers is more secure since it is difficult to intercept the

signal without physically contacting the fiber.

These benefits have made optical fiber connection the foundation of contemporary telecommunications, and it is essential for linking the entire world via the internet and other communication networks.

- **Optical Fiber Communication System**

A full network or arrangement that makes use of optical fibers to convey data between several places is known as an optical fiber communication system. To enable the effective transmission of data, sound, or video over great distances, several components must cooperate. These systems are frequently utilized in networking, cable television, internet, and telecommunications applications.

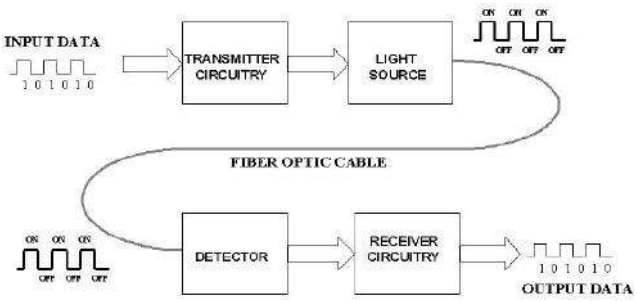

Fig.2: Optical Fibre Communication System

(Source: https://www.elprocus.com/basic-elements-of-fiber-optic-communication-system-and-its-working/)

An optical fiber communication system's essential elements include:

- The transmitter's job is to transform the input data—such as digital data, voice or video signals—into modulated optical signals that may be transmitted across the optical fiber. In order to encode the data onto the optical carrier, it normally comprises of a light source (such as a laser or light-emitting diode) and a modulator that regulates the light's intensity or phase.
- The physical medium through which modified optical signals are transmitted is an optical fiber. With a core that directs the light signals and a cladding that encloses the core to keep the light contained, it is a thin, flexible strand composed of glass or plastic. The system's capacity can be increased by joining several fibers to create an optical cable.
- Amplifiers/Repeaters: Optical signals can attenuate over long distances, resulting in a loss of signal power. Optically amplifying devices, also known as repeaters, are put at strategic points along the fiber network to make up for this loss and increase the transmission range. The optical signal is amplified by these devices without being changed back into electrical form.
- Optical Regenerators: Optical regenerators may be utilized in specific circumstances, particularly for extremely long-distance broadcasts or when the signal quality dramatically deteriorates. These devices retransmit the optical signal as a new optical signal after converting the optical signal back into an electrical signal and recovering it to its original quality.
- Receiver: At the receiving end, a receiver is used to detect the optical impulses and transform them back into electrical signals. A photodetector is commonly used in receivers to turn incoming light into electrical current. Subsequent electronic circuitry analyses and decodes the electrical signals to recover the original data.
- Multiplexers/Demultiplexers: Multiple

optical signals conveying various types of information are often integrated into a single optical fiber (multiplexing) in communication systems to make better use of the fiber's capacity. Using multiplexers and demultiplexers, the signals are divided (demultiplexed) at the receiving end.

- Optical switches provide for flexible and dynamic connections between different sites by controlling the routing of optical signals inside a network.
- Optical attenuators are used to reduce the signal strength when it is necessary to lower the signal power in a particular condition.
- Optical couplers and splitters are devices that divide or combine optical signals, enabling the connection of several fibers or the distribution of optical signals to numerous locations.

The high-speed, long-distance, and dependable communication capabilities provided by an optical fiber communication system are crucial for contemporary data transmission and telecommunications. Due to its benefits over conventional copper-based communication systems, it is a preferred option for many applications in the linked world of today.

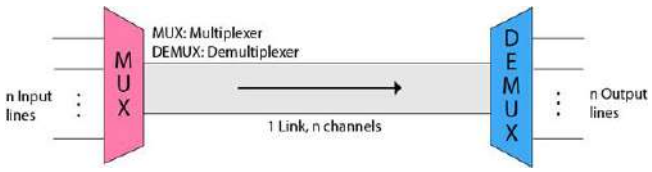

Fig.3: Multiplexing

(Source: https://www.javatpoint.com/multiplexing-in-computer-network/)

- **DWDM**

Capacity & effectiveness of optical fiber networks are increased by using the sophisticated optical communication technique known as DWDM. It enables the parallel transmission of numerous data streams or channels by enabling the simultaneous transmission of different light wavelengths (colors) across a single optical cable. The amount of data that may be transmitted across a fiber is effectively increased because each wavelength transmits a separate, independent data transmission.

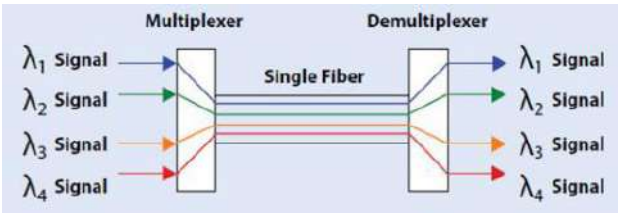

Fig.4: WDM Multiplexing

(Source: https://www.fibermall.com/blog/cwdm-dwdm-mux-demux-technology.htm)

The fundamental idea behind DWDM is to divide an optical fiber's bandwidth into a number of tiny channels, each of which operates at a different wavelength. These wavelengths are usually in the electromagnetic spectrum's infrared region, which is invisible to the human eye. Since the distances between these wavelengths are typically between 0.8 and 0.4 nanometers, the optical spectrum is able to accommodate a large number of channels that are close together. Monochromatic colors don't contain white, black and grey shades and have dominant only single light wavelength with some saturation and intensity level and blue, yellow, green and red absolute hues. However, achromatic light contains the colors which chromatic light don't contains, namely; white, black and grey. Achromatic light possesses all light wavelengths, do not contain

saturation and vividness and do not have dominant hues.

DWDM systems' essential characteristics and elements include:

- Multiplexing and demultiplexing: The DWDM system mixes (multiplexes) numerous data streams from various sources onto various light wavelengths at the transmitting end. The system divides (demultiplexes) the wavelengths at the receiving end and directs each channel to the right place.
- DWDM systems produce the optical signals at certain wavelengths using precise and reliable laser sources and tunable transmitters. Tunable transmitters, which offer flexibility and simple network configuration, can change their wavelength to match any channel within the DWDM spectrum in some systems.
- Optical Amplifiers: In order to increase the signal strength without transforming the optical signal into an electrical signal, optical amplifiers (such as erbium-doped fiber amplifiers, or EDFA) are utilized because optical transmissions may travel over long distances and experience signal attenuation.
- Filters that multiplex and demultiplex several wavelengths are known as mux/demux filters. While demux (multiplexer) filters split the signals at the receiving end, mux (multiplexer) filters combine the signals into a single fiber.
- Different modulation formats, such as intensity modulation, phase modulation, or amplitude modulation, are used to encode data onto the optical carriers.

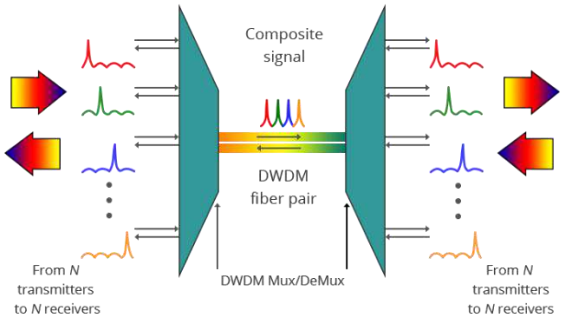

Figure 5: DWDM System

(Source: https://www.cables-solutions.com/capacity-expansion-and-flexibility-dwdm-network.html)

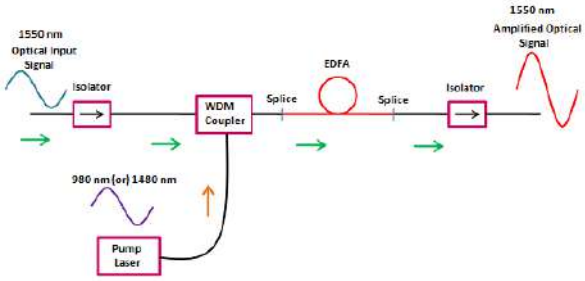

Fig.6: Erbium Doped Fiber Amplifier (EDFA) Block Diagram

(Source: https://www.physics-and-radio-electronics.com/blog/edfa-erbium-doped-fiber-amplifier/)

Benefits of DWDM

- High Data Capacity: DWDM systems are capable of supporting data transmission rates of up to several terabits per second, greatly enhancing the capacity of optical fiber networks.
- Transmission over a long distance: DWDM signals can be sent across distances of thousands of kilometers without the requirement for regeneration when employing optical amplifiers.

- Scalability: DWDM networks are scalable because they can simply be improved and expanded by adding more wavelengths and channels.
- Efficiency: DWDM is a very efficient technology because it allows numerous channels to be transmitted simultaneously over a single fiber, maximizing the fiber's bandwidth utilization.
- Cost-effective: DWDM makes high-capacity data transmission possible without the need to install several fibers.

In backbone networks, data centers, long-haul telephony, and other high-capacity communication applications, the need for quick and effective data transfer is crucial. DWDM plays a crucial role in these applications.

Table 1: Benefits of DWDM System

Specifications/Features	DWDM
Full form	Dense Wavelength Division Multiplexing, WDM system having more than 8 active wavelengths per optical fiber
characteristic	Defined by frequencies
capacity	higher
cost	high
Distance	long range communication
Frequencies	uses narrow range frequencies
Wavelength spacing	less, hence can pack 40+ channels compare to CWDM in the same frequency range
Amplification	light signal amplification can be used here
Drift	Precision lasers are needed to keep channels on the target
Spectrum utilization	dices the spectrum into small pieces
No. of active wavelengths per fiber	More than 8

(Source: https://www.fiberopticshare.com/a-comparison-between-cwdm-and-dwdm.html)

- **Non Linear Effects on DWDM**

Non-linear effects in DWDM-based optical fiber communication systems might develop as a result of interactions between different light wavelengths inside the fiber. The overall effectiveness of the communication system may be restricted by these effects, which can lead to distortions and signal deterioration. Analyzing and making up for these non-linear effects is crucial for maintaining the system's quality and dependability. Let's look at the most significant non-linear impacts and how they are handled.

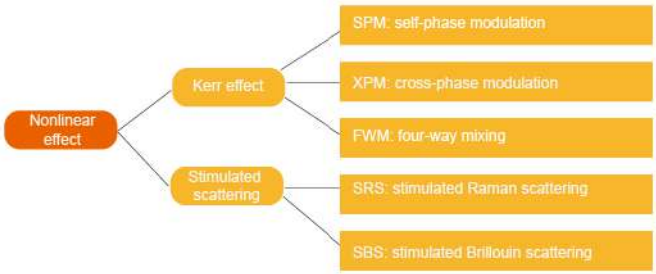

Fig.7: Non Linear Effects

(Source: https://info.support.huawei.com/network/ptmngsys/Web/WDMkg/en/21_nonlinear.html)

1. Four-Wave Mixing (FWM): Four-wave mixing is the process through which signals with various wavelengths interact inside a fiber to produce new frequencies. Crosstalk between channels might result from this effect, which would degrade and interfere with the signal.

2. Stimulated Raman Scattering (SRS): SRS is a non-linear phenomenon where new wavelengths are produced as a result of the interaction between the optical signal and the molecular vibrations of the fiber. The signal power of the desired channels may be decreased as a result of power transfer between various wavelengths.

3. Stimulated Brillouin Scattering (SBS): When an

optical signal interacts with acoustic waves in a fiber, new frequencies are created. Power transmission between channels and spectral widening may result from this effect.

4. Self-Phase Modulation (SPM): SPM is a nonlinear phase modulation that happens when an optical signal's intensity changes the phase of the signal. Signal distortion and spectrum broadening may result from this phenomenon.

5. Cross-Phase Modulation (XPM): XPM happens when the intensity of one wavelength influences the phase of another. This effect has the potential to deteriorate and interfere with signals.

DWDM-based optical fiber communication systems use advanced simulations and modeling approaches to research non-linear phenomena. The physical qualities of the fiber, the characteristics of the light sources (such as laser diodes), and the particular system configuration are all taken into account in these simulations. Engineers can forecast the performance impact of non-linear effects and tune different settings to lessen their effects by running these simulations. In DWDM systems, a variety of compensation strategies are used to reduce non-linear effects. Here are a few typical methods:

1. Dispersion Compensation: Non-linear effects and dispersion, or the spreading of light pulses, are frequently closely associated. The system can lessen the effect of non-linarites by utilizing dispersion compensation techniques, such as dispersion compensating fibers or dispersion compensating modules.

2. Optical Phase Conjugation: In this method, non-linear effects are used to counteract one another. To correct the phase distortions brought on by SPM and XPM, optical phase conjugation devices can be strategically positioned across the fiber network.

3. Raman Amplification: Raman amplifiers can be used in place of conventional optical amplifiers. Raman amplification reduces the effects of SRS by compensating for the power transfer between channels by amplifying the signals at various wavelengths in a dispersed way.

4. Non-linear Fiber with Modified features: The behavior of the system can be customized and the effects of non-linearity's can be minimized by using non-linear fibers that have been specifically developed with certain features.

5. Advanced Modulation Formats: The system can be strengthened against non-linear effects by using advanced modulation formats like polarization division multiplexing (PDM) and quadrature amplitude modulation (QAM).

6. Adaptive Equalization: To reduce non-linear distortions in the received signals, adaptive equalization techniques can be used in the receiver.

In order to assure high-quality, dependable, and effective data transmission in DWDM-based optical fiber communication systems, it is essential to analyze and correct for non-linear effects. System performance can be improved, and the effects of non-linearity's can be reduced, with the use of simulation, good system design, and compensating methods.

Self-Phase Modulation (SPM)

When powerful optical pulses pass through optical fibers, a non-linear optical phenomena known as self-phase modulation (SPM) takes place. An optical pulse's phase in SPM is altered as a result of the interaction between the pulse's intensity and the fiber's refractive index. The Kerr effect, a non-linear optical response that most transparent materials, including the glass in optical fibers, display, is the cause of this effect. The leading edge of an intense optical pulse has a greater refractive index than the

trailing edge as it passes through an optical fiber. The leading edge of the pulse moves through the fiber more slowly than the trailing edge due to this discrepancy in refractive index. This causes the pulse to lengthen in duration and flatten its intensity profile, a phenomenon known as temporal broadening. A self-induced effect, or one that completely depends on the properties of the optical pulse as it travels down the fiber, is the temporal broadening caused by SPM. Broader pulses have the potential to interact with other non-linear fiber phenomena including stimulated Raman scattering (SRS) and cross-phase modulation (XPM), adding to the system's complexity and signal distortions.

Self-phase modulation's (SPM) main characteristics are:

- Phase shift that is intensity-dependent: The optical pulse's intensity directly affects how much phase shift it experiences. The magnitude of the phase shifts increases with increasing pulse intensity.
- The powerful optical pulse goes through a process called temporal broadening, which alters the pulse's duration.
- Frequency Broadening: The SPM-induced temporal broadening also causes the pulse's frequency spectrum to enlarge.
- Phase Distortions: SPM may cause phase distortions in the optical signal, which may impair the signal's ability to be transmitted accurately.
- SPM can occasionally result in pulse compression, in which the pulse's duration is shortened as a result of the non-linear interaction.

SPM has been used in some applications, despite being generally regarded as an undesirable phenomenon in optical fiber communication systems:

- Optical Solitons: In some circumstances, the dispersion effect in the fiber can counteract the non-linear effects of SPM, resulting in the generation of optical solitons. Solitons are excellent for long-distance communications because they are self-sustaining, steady pulses that may go a long way without much distortion.
- Supercontinuum Generation: Supercontinuum light sources can be created using SPM in conjunction with other non-linear effects. Wide-ranging, coherent spectral output from supercontinuum sources is used in fields including optical frequency metrology, spectroscopy, and optical coherence tomography (OCT).

SPM is, nevertheless, regarded in the majority of optical communication systems as a degradation that requires mitigation or compensation. Through methods like dispersion compensation, the use of fiber designs with particular qualities, or the use of advanced modulation formats that are less vulnerable to non-linear effects, its impacts can be controlled. Engineers can create optical fiber communication systems with high data transmission quality by comprehending and managing SPM.

Self-Phase Modulation (SPM)

When two or more powerful optical signals—often referred to as "pump" and "probe" signals—travel through the same fiber at the same time, cross-phase modulation (XPM), a non-linear optical phenomenon, takes place. In XPM, the strength of one signal modulates the phase of the other, changing the properties of how both signals propagate. The Kerr effect, a non-linear optical response that most transparent materials, including the glass in optical

fibers, show, serves as the foundation for the underlying process of XPM. The refractive index of the fiber is intensity-dependent as a result of the Kerr effect. Consequently, when two powerful optical signals co-propagate through the fiber, they create a change in the refractive index of the fiber that affects the phase of the signals.

Cross-phase modulation (XPM)'s main attributes are:

- Phase shifts: An optical signal's strength causes the other signal to shift in phase. The pump signal's intensity directly relates to how much phase shift the probe signal experiences.
- Intersymbol Interference (ISI) is a phenomenon caused by temporal changes in the probe signal brought on by the phase modulation introduced by XPM. The quality of the data received can be lowered by this interference, and the data transfer speeds can be constrained.
- The probe signal's center frequency may change as a result of phase modulation, which can also cause a frequency shift in the signal.
- Bidirectional Effect: XPM is a bidirectional phenomenon, which means that it happens regardless of which way the pump and probe signals propagate.

In optical fiber communication systems, XPM is typically seen as an unwanted phenomenon, although it also has several intriguing implications and applications:

- Wavelength Conversion: XPM can be used to change an optical signal's wavelength in some wavelength conversion methods. A weaker probe signal can have its frequency changed, altering its wavelength, by being phase-modulated by a strong pump signal.
- All-Optical Switching: XPM is applicable to all-optical switching situations where the presence of a powerful control signal (pump) may affect the transmission or blockage of a weaker signal (probe).
- In nonlinear interferometers, such as the nonlinear Mach-Zehnder interferometer (N-MZI) or the Sagnac interferometer, XPM is one of the nonlinear effects that is employed to carry out a variety of tasks, including signal regeneration and wavelength conversion.

Researchers use a variety of strategies, such as the following, to mitigate the impacts of XPM and lessen its influence on communication systems:

- Optimizing Wavelength Allocation: It is possible to lessen the possibility of major XPM interference between signals by selectively allocating wavelengths to various channels.
- Advanced Modulation Formats: Using advanced modulation formats and coding techniques can reduce the likelihood of XPM-induced distortions in the signals.
- PDM (Polarization Division Multiplexing): PDM can separate signals that are polarized in opposite directions, which minimizes XPM interactions.
- Nonlinear Fiber Designs: By increasing the effective area of the fiber core, for instance, special fiber designs can be utilized to lessen XPM and other non-linear effects.

In general, XPM management and comprehension are essential for developing effective and dependable optical fiber communication systems, particularly in high-capacity DWDM networks.

Four-Wave Mixing (FWM)

When numerous optical signals with various wavelengths interact with one another in optical fibers, a non-linear optical phenomenon known as four-wave mixing (FWM) takes place. In FWM, three optical signals acting as the "pump," "signal," and "idler" waves interact with one another inside the fiber to produce a fourth output signal with a different frequency. To create the new frequency, the input frequencies are nonlinearly mixed in this procedure. The third-order non-linear susceptibility of the fiber material, which is in charge of how the optical fields interact, is the basis of FWM. Energy is transmitted amongst the waves as the pump, signal, and idler waves co-propagate through the fiber, creating the fourth frequency component.

The energy conservation law, which states that the total of any two input waves is equal to the sum of the other two output waves, is followed by the FWM process. This relationship can be modeled mathematically as:

ω_pump + ω_signal = ω_idler + ω_output

Where:

ω_pump = Frequency of the pump wave

ω_signal = Frequency of the signal wave

ω_idler = Frequency of the idler wave

ω_output = Frequency of the output wave (generated by FWM)

Four-wave mixing's (FWM) main characteristics are:

- FWM can be utilized in frequency conversion applications, which involve shifting the signal's frequency up or down to produce new wavelengths.
- Phase Matching Requirement: For effective FWM to take place, the phases of the involved waves must match, which means that they must align in a way that maximizes energy transfer between the waves.
- Phase Conjugation: In some circumstances, FWM can result in phase conjugation, in which the phase of the output wave is the conjugate of the phase of the input signal. For signal adjustment and correction, phase conjugation can be used.
- Effects between individual channels and between channels in a multi-channel system are referred to as intrachannel and interchannel FWM, respectively.

FWM has some useful implications and applications even though it is typically thought of as an undesirable impact in optical fiber communication systems:

- Crosstalk and Interference: FWM can deteriorate the signal quality in a multi-channel communication system by causing crosstalk and interference between several channels.
- Wavelength Conversion: FWM can be used for wavelength conversion, which enables signals in DWDM systems to be transferred to different channels by creating a new wavelength.
- Signal regeneration and reshaping are two examples of nonlinear optical signal processing applications where FWM can be applied.
- Optical parametric amplifiers (OPAs) use FWM to enhance optical signals at particular wavelengths. FWM is the underlying principle of OPAs.

Researchers employ strategies like the following to control the effects of FWM and lessen its influence on communication systems:

- Wavelength Separation: The FWM effect can be reduced by carefully choosing the wavelengths of the pump, signal, and idler waves.
- Fiber Design and Dispersion Management: To lessen FWM and other non-linear effects, special fiber designs and dispersion management strategies can be used.
- Advanced Modulation forms: By using advanced modulation forms, the signals may be less prone to distortions brought on by FWM.

In general, FWM control and understanding are crucial for developing effective and dependable optical fiber communication systems, particularly in high-capacity DWDM networks.

Stimulated Raman Scattering (SRS)

When bright light interacts with the material's molecular vibrations, a non-linear optical phenomenon known as stimulated Raman scattering (SRS) takes place in optical fibers and other transparent materials. In SRS, an incident optical wave transmits energy to the material's vibrational modes, causing inelastic scattering to produce new optical frequencies (wavelengths).

The following is a description of stimulated Raman scattering:

- Incident Pump Wave: The pump wave is a powerful optical wave that travels through the optical fiber.
- Molecular Vibrations: The molecular vibrations (phonons) of the fiber material are in contact with the pump wave. Due to the atoms' thermal motion, this material naturally experiences these vibrations.
- Energy Transfer: The vibrational modes receive some of the energy from the pump wave, which excites them.
- New Optical Frequencies: The excited vibrational modes produce photons at new frequencies that are either lower or higher than the frequency of the pump wave when they revert to their initial condition. Stokes and anti-Stokes frequencies are the names given to these new frequencies.

The frequency of the molecular vibrations is equal to the frequency difference between the pump wave and the generated Stokes/anti-Stokes waves. The Raman shift is a frequency shift that depends on the characteristics of the substance.

Stimulated Raman Scattering's (SRS) main characteristics are:

- SRS can result in frequency conversion, where the energy of the pump wave is changed into new frequencies (Stokes and anti-Stokes waves).
- SRS has a threshold power level, which has an effect. It only becomes meaningful when the intensity of the pump wave exceeds a particular cutoff point. The scattering impact is minimal below this point.
- SRS is a bi-directional process, which means it can move along the fiber in both the forward and reverse orientations.
- Dependence on Material Properties: The molecular characteristics of the material, such as its Raman gain coefficient, affect the Raman shift and the effectiveness of SRS.

Despite being typically regarded as an unwanted result in optical fiber communication systems, stimulated Raman scattering has the following practical implications and applications:

- Raman amplification is a technique used to increase the strength of optical signals in fibers, and it makes use of SRS. Energy is supplied to the signal, amplifying it through the Raman effect, by pumping the fiber with a high-power laser at a particular wavelength (usually in the 1400–1500 nm region).
- Similar to Stimulated Brillouin Scattering (SBS), SRS can be used for wavelength conversion. In this process, the energy of the pump wave is transmitted to the signal, creating new wavelengths.
- Raman Fiber Lasers: Raman fiber lasers are efficient and portable light sources that operate at specified Raman-shifted wavelengths and employ stimulated Raman scattering.

Researchers employ strategies like the following to mitigate SRS's effects and lessen its influence on communication systems:

- Raman Pump Deposition: By strategically positioning the Raman pump laser along the fiber, it is possible to maximize Raman amplification while limiting undesirable effects.
- Depending on the needs of the system, special fiber patterns can be utilized to either strengthen or weaken the Raman effect.
- Optimized Wavelength Allocation: The overlap with Raman-shifted frequencies can be reduced by carefully choosing the signal wavelengths.

In conclusion, Stimulated Raman Scattering is a crucial non-linear phenomenon in optical fibers, with both difficulties and useful applications. Designing effective and dependable optical fiber communication systems, especially those that make use of Raman amplification, requires a thorough understanding of and management of SRS.

Stimulated Brillouin Scattering (SBS)

When powerful light interacts with acoustic waves (phonons) in a material, a non-linear optical phenomenon known as stimulated Brillouin scattering (SBS) takes place in optical fibers and other waveguides. In SBS, an incoming optical wave transfers energy to the acoustic waves, resulting in an inelastic scattering process that scatters light at a little lower or higher frequency.

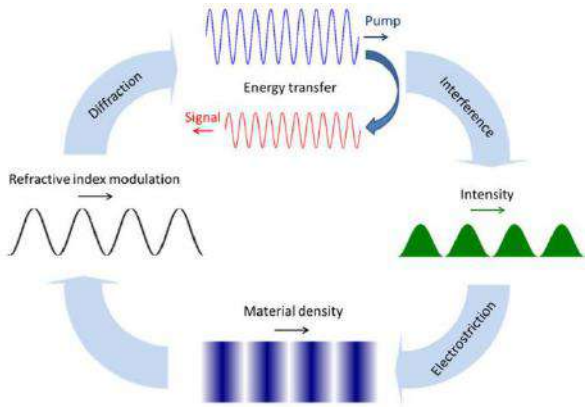

Fig.8: Stimulated Brillouin Scattering Process

(Source: Primerov, Nikolay & Thévenaz, Luc. (2013). Generation and application of dynamic gratings in optical fibers using stimulated Brillouin scattering.)

Following is a description of stimulated brillouin scattering:

- Incident Pump Wave: The pump wave is a powerful optical wave that travels through the optical cable or waveguide.
- Phonons, or mechanical vibrations that naturally arise in materials as a result of changes in temperature or other causes, interact with the pump wave.
- Energy Transfer: The pump wave transfers

some of its energy to the acoustic waves, which stimulate them.

- The excited acoustic waves produce photons at a lower frequency than the pump wave when they revert to their initial condition, creating a new optical frequency (Stokes wave). The Stokes frequency is the name given to this new frequency.

The frequency of the acoustic waves is equal to the frequency shift between the pump wave and the generated Stokes wave. The Brillouin shift is a frequency shift caused by changes in the refractive index and acoustic velocity of the material.

Stimulated Brillouin Scattering's (SBS) main characteristics are:

- SBS can result in frequency conversion, where the energy of the pump wave is changed into a new frequency (the Stokes wave) through the scattering process.
- SBS has a threshold power level, or effect. It only becomes meaningful when the intensity of the pump wave exceeds a particular cutoff point. The scattering impact is minimal below this point.
- Phase Conjugation: Phase conjugation is a fascinating feature of SBS. The initial pump wave and the Stokes wave produced by SBS are phase-conjugate. Accordingly, at the point of scattering, the Stokes wave's phase is the pump wave's phase inverted. Signal adjustment and correction can be accomplished via phase conjugation.
- SBS is a bi-directional process, which means it can move along the fiber in both the forward and reverse orientations.

Stimulated Brillouin Scattering has some useful implications and applications even though it is typically regarded as a negative phenomenon in optical fiber communication systems:

- Stimulated Brillouin Scattering is employed in Brillouin fiber lasers, which are efficient and portable light sources that produce Stokes-frequency radiation.
- SBS-Based Sensing: SBS can be utilized for distributed fiber sensing applications, which use the scattering process to gauge temperature or strain changes throughout the fiber.

Researchers employ strategies like the following to mitigate SBS's effects and lessen its influence on communication systems:

- Depending on the needs of the system, special fiber patterns can be utilized to either strengthen or weaken the Brillouin effect.
- Brillouin Pump Deposition: By strategically placing the Brillouin pump laser along the fiber, it is possible to improve SBS-based sensing or lessen its negative effects on signal transmission.
- Maximizing Wavelength Allocation: The Brillouin-shifted frequencies can be avoided as much as possible by carefully choosing the signal wavelengths.

In conclusion, Stimulated Brillouin Scattering is a significant non-linear phenomenon in optical fibers that has both difficulties and useful uses. Designing effective and dependable optical fiber communication systems and other related technologies requires an understanding of and management of SBS.

Problem Statement

Dense Wavelength Division Multiplexing (DWDM) systems, which are widely used in optical

communication networks, have critical difficulties that severely restrict their overall performance due to nonlinear effects. The capacity and effectiveness of optical communication are significantly influenced by these nonlinear phenomena, specifically SPM, XPM & FWM. To lessen the consequences of these nonlinear effects and realize the full potential of optical communication technology, researchers in the field are constantly investigating cutting-edge techniques. These strategies include nonlinear compensation and optimized fiber designs. We can make way for more stable and dependable DWDM systems, enabling seamless and quick data transfer over very long distances, by skillfully handling these difficulties.

Research Purpose

The objective of the research is to present DWDM systems with 4, 8, 16, and 32 channels that are the focus of two main examinations. The research explores the consequences of dispersion at various data rates after first exploring the effect of dispersion brought on by the launched input power. The major goal is to put forth a dispersion correction technique that is especially made for the DWDM system and is intended to deal with cross-phase modulation. Additionally, the project aims to evaluate effects of power/data rate variations. The ultimate objective is to develop a novel SSP (Symmetrical-Symmetrical-Post) method that successfully mitigates spectrum broadening when paired with cutting-edge modulation techniques. Following parameters will be measured:

- Output Optical Signal-to-Noise Ratio (OSNR) of 4/8/16/32 channels WDM measured at various power levels with/without dispersion compensation.
- Output OSNR of 4/8/16/32 channels WDM measured at various data rates with/without dispersion compensation.
- Eye-diagram channel system.
- Comparison of post & proposed SSP compensation technique.
- Channel spectrum at the receiver.

Research Significance

The suggested approach proves to be better suited for long-haul DWDM systems when compared to conventional post-compensation method. While the SSP technique is effective in mitigating spectral broadening caused by cross-phase modulation, it alone cannot fully compensate for it. However, when combined with advanced modulation techniques, SSP can efficiently reduce spectral broadening effects. To accommodate this setup, a larger number of amplifiers are utilized, leading to higher power consumption, making dynamic control of Erbium-Doped Fiber Amplifiers (EDFA) a critical aspect of the system.

II. LITERATURE REVIEW

Data traffic over optical networks has increased dramatically as a result of the widespread use of the internet. It has become necessary to increase the optical bandwidth within the Wavelength Division Multiplexing (WDM) system in order to effectively manage this growing demand. The system can now support high baud rate data transmission as a result [1]. Compressed Wavelength Division Multiplexing (DWDM) systems have more wavelengths as data traffic on optical fibers increases. However, this rise in nonlinear effects due to the increase in optical fiber impedance can negatively affect signal efficiency and ultimately jeopardize performance of system [2].

Many nonlinear effects, including stimulated Raman dispersion (SRS), stimulated Brillouin dispersion

(SBS), SPM, XPM & FWM, are present in DWDM systems. FWM is particularly important and crucial among them [3]. When two waves interact, two or more extra waves of various frequencies are produced, leading to FWM. The operation of the system is significantly hampered by this phenomena, which causes data loss and reduced signal efficiency. Numerous methods have been proposed to lessen the effect of FWM on DWDM systems in order to solve this problem [4].

Data traffic on optical networks has significantly increased as a result of the internet's quick growth in popularity. Dense Wavelength Division Multiplexing (DWDM) technology is used to meet this expanding demand, effectively increasing the data rate by supporting a greater number of channels [5]. However, because they lower the signal power of the receiver, nonlinearities in DWDM systems present a significant problem. Although optical amplifiers have been created to extend transmission distances, completely eliminating fiber losses is still not feasible [5].

Fiber losses can be roughly divided into linear and nonlinear categories. Attenuation and dispersion are examples of linear effects, whereas nonlinear effects include SRS, SBS, FWM, XPM, & SPM [5]. FWM is particularly important and difficult to address among these. Data loss and decreased signal effectiveness result from the interaction of two waves, which might generate two or more additional waves with differing frequencies [7]. Fiber nonlinearities are caused by a number of phenomena, including as inelastic scattering and variations in refractive index with optical intensity [6].

The capacity of DWDM systems is improved by raising the data rate and the quantity of channels. Employing efficient modulation techniques, heavily reliant on electronics, and raising the launching power are required to achieve larger data speeds. However, additional nonlinear effects are brought on by increasing transmission input power [7]. It is vital to choose the proper laser and optical filters since increasing the channel spacing to accommodate more channels might also affect the nonlinear effects [8, 9].

The Kerr effect, inelastic scattering, and the effective cross-sectional area of the fiber are the main contributors to the nonlinear effects in DWDM systems [6]. Multiple in-line amplifiers can be added to lessen nonlinear effects, but they come with higher installation costs [6]. The interaction of higher intensity sections of an optical pulse with the fiber's refractive index results in self-phase modulation (SPM), another nonlinearity that causes frequency chirping and a dispersion penalty with rising input power [10].

When many optical pulses propagate simultaneously, cross-phase modulation (XPM) takes place, which affects other co-propagating beams and results in spectrum widening and pulse shape distortion [13]. On the other hand, four-wave mixing (FWM), which is strongly reliant on channel spacing but independent of data rate, can deplete power and impair system performance as it increases [14].

Different compensation approaches, including dispersion compensating fiber, pump pulses, and dispersion-shifted fiber, have been investigated to address these nonlinear effects [15, 14]. Nevertheless, getting the best pay is still difficult. In addition, the system is complicated and losses are added by SRS & SBS [6], which necessitates careful adjustment of power levels and channel spacing to lessen their impacts [15, 16].

Numerous strategies, such as modulation techniques, fiber Bragg gratings, and symmetric compensation techniques, have been investigated recently in studies to reduce nonlinearities in DWDM systems

[17, 18, 19, 20]. Support vector machines and the optimization of 44 channels have showed promise in enhancing performance [18, 19]. Further highlighting the ongoing attempts to solve these issues is the investigation of a 64-QAM-based radio over fiber system with SVM-based nonlinearity mitigation [17].

When dealing with a greater number of channels and greater distances, modern telecommunication systems significantly rely on DWDM technology for transmission. However, both linear and nonlinear impairments have a major impact on the overall signal quality and may cause the receiver to reject the signal. Attenuation losses and dispersion effects are two categories for linear effects [21]. The length of the fiber cable affects signal power losses, which cause attenuation losses. Signal-boosting amplifiers can be used to fix this problem. Contrarily, chromatic dispersion (CD) and polarization mode dispersion (PMD) are two types of dispersion effects. As a result of CD, distinct wavelengths move at varying speeds, arrive at the receiver at various times, and spread out and overlap one another. To account for CD effects, negative dispersion compensation fiber (DCF) and fiber Bragg gratings (FBG) are used [22].

The two types of nonlinear effects are parametric effects and scattering effects [23]. When the optical pulse strength reaches a particular point, parametric effects, also referred to as refractive index phenomena, take place. This intensity changes the characteristics of the fiber medium, which then has an impact on the propagation of the optical signal [24]. The "non-linear Kerr effect" [25] is the name given to the refractive index change brought on by an increase in pulse intensity. The nonlinear portion of the refractive index (n), which is controlled by this effect, causes it to rise with high signal power and produce unwanted effects including FWM, SPM & XPM [26].

The interaction of atoms and molecules within the material results in scattering effects, which reduce optical power. Both SRS & SBS are additional categories for these events [27].

The growing demand for high-bandwidth applications from end users has fueled advancements in optical components, subsystems, systems, and networks. Next-generation optical communication systems are anticipated to operate at data rates of 40 to 100 Gb/s per channel for long-distance transmissions, while existing 40 to 80 channel optical communication systems with 10 Gb/s transmission speeds struggle to meet the requirements of high-capacity transmission [28]. This trend is further fueled by the explosive development of broadband applications and high-speed online services like teleconferencing and ultra-high-definition television (UHDTV), which will require future data transmission technologies with increased capacity, speed, and range.

The International Telecommunication Union (ITU-T)'s standardization of DWDM technology has been essential in enabling the administration of services employing different light wavelengths carried through the same optical fibers. This enables the transmission of a sizable volume of data for various communication services and applications [4].

In the late 1990s and early 2000s, the second generation of optical networks appeared. These networks brought about innovations that moved security and recovery tasks to the optical portion of the network, greatly enhancing optical communication networks [28].

DWDM technology has advanced significantly toward the goal of entirely transparent optical networks, allowing the transmission of multiple optical waves in the C-band and L-band across a single fiber because of their low transmission attenuation loss [31]. The quality level of the network

is assessed using qualitative measures like the Q factor or BER, and network planning and capacity planning are crucial during operation [32].

It is simple to integrate DWDM networks into existing optical networks; all that is needed are upgrades to the transmission systems; the fibers themselves need not be modified. As a result, DWDM technology is now frequently used [29-33].

DWDM systems need to be adjusted and modified in order to satisfy the requirements of the expanding multimedia landscape. Multichannel optical transmission is complicated by the signal's structure, the transmission medium's dispersive and nonlinear properties, and the simultaneous high-speed transmission of many optical channels. The intention is to minimize signal deterioration while increasing the system's transmission capacity [34].

In both terrestrial and transoceanic communication systems, the use of optical fiber cables enables high-capacity optical transmission over great distances. However, both linear and non-linear influences limit the performance. The presence of Amplified Spontaneous Emission (ASE) noise from Erbium-Doped Fiber Amplifiers (EDFAs), SRS, SBS, SPM, XPM & FWM are among the main non-linear effects [35] [36].

Dense Wavelength Division Multiplexing (DWDM) technology is used to increase the overall bandwidth of single-mode optical fibers. However, when sending data across long distances at rates more than 2.5 Gbit/s, the effects of dispersion and nonlinearities start to matter. While EDFAs enhance transmission distances and make up for fiber losses, they also increase ASE noise and nonlinearities. Numerous fiber kinds have been developed to lessen the impacts of dispersion and nonlinearities in order to address these issues [37] [38] [39].

Numerous research on nonlinear impairments have been done, emphasizing their significance and complexity in the context of DWDM systems [40] through [45]. The need of resolving these phenomena to guarantee the best performance and efficiency of DWDM technology is highlighted by these investigations.

Optical Signal to Noise Ratio, which is also known as OSNR, is used to measure the quality of signal in far long range optical fiber communication system. Amplified Emission Noise, which is termed as ASE, is a major contributor to the performance of OSNR, which got added due to the noise of optical components and in turn reduces the OSNR and hence signal quality.

In conclusion, as internet usage continues to rise, creative methods are needed to control the growing data traffic on optical networks. Even though DWDM technology greatly increases capacity, nonlinear effects must still be taken into account to ensure effective and trustworthy optical communication. For more reliable and high-performance DWDM systems, ongoing research and development are crucial to optimizing modulation and compensation strategies.

III. RESEARCH METHODOLOGY

- **Methodology**

The effects of greater power levels at different data rates were investigated using a DWDM system with 4/8/16/32 channels. The system was initially simulated using the traditional "post" compensation method. The improvements in performance were then evaluated by comparing the findings to those obtained from the suggested compensating design.

The effects of XPM (Cross-Phase Modulation) are addressed in the literature using a variety of traditional methodologies. To reduce nonlinearity in

the DWDM system, the researcher suggests a brand-new symmetrical-symmetrical-post compensating technique. In this method, single-mode fiber (SMF), erbium-doped fiber amplifier (EDFA), and dispersion compensating fiber (DCF) are all integrated.

This approach produces a good Signal-to-Noise Ratio (SNR) by passing the SMF data through the EDFA, which offers strong optical gain while preserving low noise. The figure below shows experimental configuration for a 4-channel WDM (Wavelength Division Multiplexing) system with compensation. It is made up of a compensation, receiver & transmitter blocks.

The transmitter block consists of a Mach-Zehnder (MZ) modulator, 4-channel WDM multiplexer, a continuous wave (CW) laser, a Non-Return-to-Zero (NRZ) pulse generator, and a pseudo-random binary sequence (PRBS) generator. The receiver part, on the other hand, is made up of a Fabry-Perot filter, a demultiplexer, a PIN receiver, and a BER analyzer. Wherever necessary, optical power meters, a WDM analyzer & optical spectrum analyzers are also attached to make system evaluation easier.

The compensating block subsequently receives optical signal generated in transmitter portion. It moves through a single-mode fiber (SMF) that is 16 km long and has dispersion of 16 ps/nm-km. To maintain optical signal-to-noise ratio (OSNR), EDFA must give a significant gain. In order to provide equal and opposite dispersion compensation, the accumulated dispersion is finally eliminated using the dispersion compensating fiber (DCF).

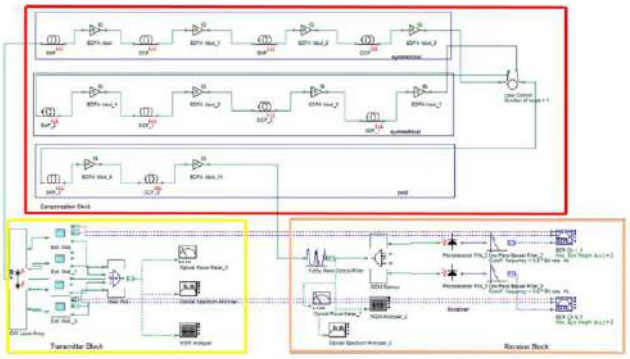

Fig.9: Experiment Setup: 4 Channel WDM system with compensation

- **Parameters**

Table below shows the parameters used for experimental setup.

Table 2: System Parameters

S/NO	Parameters	Value
1	Transmitter Parameters	
	Pseudo Random Binary Sequence Bit Rate	20 - 100 Gbps
2	Receiver Parameters	
	PIN Responsivity	1 A/W
	Dark Current	10 nA
3	Single Mode Fibre (SMF) Parameters	
	Length	16 – 20 Km
	Effective Area	80 μm^2
	Attenuation	0.20 dB/km
	Dispersion	16 ps/nm-km
	Differential Group Delay	0.20 ps/km
	Dispersion Slope	0.075
4	Dispersion Compensating Fiber (DCF) Parameters	
	Length	4 – 5 km
	Attenuation	0.50 db/km
	Dispersion	- 64 ps/nm-km
5	Erbium Doped Fiber Amplifier (EDFA) Parameters	
	Gain	2 – 4 dB
	Noise Figure	2 dB
	Power	10 dBm
6	Wavelength Division Multiplexing (WDM) Parameters	
	Channel Spacing	200 GHz
	Number of Channels	4, 8, 16, 32

A transmitter in optical fiber communication is a device or system that generates, encodes, and launches optical signals into an optical fiber in order to convey data. Transforming electrical impulses (data) into optical signals (light) that can pass through the optical fiber is the transmitter's primary job.

A receiver is an essential component in optical fiber communication and is in charge of identifying, decoding, and transforming incoming optical impulses into electrical signals. Its main job is to take in sent optical signals that have passed through the

optical fiber and turn them into usable electrical data so that electronic devices may process and interpret it.

An optical fiber known as a single-mode fiber (SMF) in optical fiber communication enables the transmission of light signals through a single, clearly defined mode of propagation. Single-mode fibers have a small core diameter, typically approximately 9 micrometers, as opposed to multimode fibers, which permit several light propagation routes (modes). Due to the limited number of supported modes due to the small core size, only one mode of light can efficiently propagate through the fiber.

A form of optical fiber called a dispersion compensating fiber (DCF) is used in optical fiber communication systems to compensate for the chromatic dispersion that happens when light signals are sent across conventional single-mode fibers (SMFs). When various light wavelengths move through a fiber at slightly different speeds, a phenomenon known as chromatic dispersion, the light pulses spread out and overlap.

An optical amplifier called an erbium doped fiber amplifier (EDFA) is used in optical fiber communication systems to increase the power of optical impulses without converting them to electrical signals. In long-distance and high-capacity optical communication networks, it is a crucial element. The optical amplification that occurs when erbium ions are doped (introduced) into the core of a specially created optical fiber is the foundation of the EDFA's working principle. The erbium ions operate as the amplification medium and interact with the optical signals coming in, collecting energy from pump lasers at particular wavelengths and then emitting this energy as additional photons that are in line with the wavelengths of the signal. The optical signals are amplified using this method while still maintaining their original data content.

Wavelength division multiplexing (WDM) is a technique used in optical fiber communication to multiply the number of optical signals being sent through a single optical fiber at the same time, increasing their number and efficiency. Multiple optical signals—also known as channels—can coexist and travel down the same fiber without interfering with one another because each optical signal, also known as a channel, contains distinct data.

The intended loop control & accompanying fiber length are shown in following table. The PIN detector in the reception section transforms the optical signal into an electrical signal.

Table 3: Loop Control Details

S/No	No of SMF	Total Length SMF (Km)	No of DCF	Total Length DCF (Km)	Total Length (Km)
1	5	80	5	20	100
2	10	160	10	40	200
3	15	240	15	60	300
4	20	320	20	80	400

Using the traditional "post" correction technique, the researcher compared the optical signal-to-noise ratio's (OSNR) performance. The Dispersion Compensating Fiber (DCF) was linked in this comparison after the Single-Mode Fiber (SMF) and Erbium-Doped Fiber Amplifier (EDFA) were combined. The researcher used identical simulation circumstances for the studies to validate the suggested strategy.

The transmitter section feeds data into the compensation block using a series of single-mode fiber (SMF) and dispersion compensating fiber (DCF) with negative dispersion of - 64 ps/nm-km & 0.50 dB attenuation, respectively, in the proposed symmetrical-symmetrical-post (SSP) compensation technique. Optical amplifiers are positioned after each fiber to compensate for the signal loss; the gain

is denoted by the letter L. The SMF's 16 km length and 16 ps/nm-km dispersion is balanced by the DCF's 4 km length and -64 ps/nm-km dispersion. As demonstrated in Tables 3 and 4, the Dispersion Compensating Fiber (DCF) imparts equal and opposite dispersion, effectively counteracting pulse broadening over a 100 km span. When additional loops are incorporated, researchers note dispersion effects extending over greater distances. Additionally, the research takes into account the influences of Cross-Phase Modulation (XPM) under varying launching power levels and data rates.

- **MATLAB Simulation**

The simulations were done using MATLAB. The MathWorks company created MATLAB, often known as "Matrix Laboratory," which is a potent programming environment and computer platform. It is widely utilized in many different industries, including engineering, math, physics, finance, image and video processing, and many more. MATLAB is recognized for its simple syntax, big function library, and superior numerical processing abilities.

Key MATLAB Features include:

- Numerical computations: MATLAB is excellent at doing numerical calculations, making it the best choice for handling challenging calculations involving matrices, vectors, and arrays. It has many built-in functions for things like integration, optimization, and linear algebra.
- Interactive Command-Line Environment: The Command Window in MATLAB allows users to enter commands, run them, and immediately view the results. It is a fantastic tool for quick prototyping and data exploration because of its interactive nature.
- MATLAB provides script files (sometimes known as "m-files"), which let users compose a series of commands and save them in a script for later use. Additionally, MATLAB provides function files (m-files), which let users design unique functions that can be utilized frequently throughout various program sections.
- Graphics and visualization: MATLAB has robust visualization features that let users design stunning plots, charts, and graphs to display data and outcomes. It has a number of charting options and tools for adjusting how plots look.
- Toolboxes: To enhance its capability for certain applications, MATLAB provides a wide range of toolboxes. These toolboxes include sections on machine learning, control systems, image processing, signal processing, optimization, and more.
- Block diagrams can be used to describe, simulate, and analyze dynamic systems using Simulink, a graphical extension to MATLAB. It is frequently employed in the design of control systems, simulations, and the creation of embedded real-time systems.
- GUI development is made feasible by MATLAB's tools for constructing Graphical User Interfaces (GUIs), which allow interactive programs to be built without a deep understanding of programming.

MATLAB is used in a variety of academic, research, and commercial contexts. It is utilized by engineers, scientists, researchers, and students for a variety of tasks, including algorithm development, simulation, prototyping, data analysis, and more. Its capabilities are expanded by the availability of specific toolboxes, making it a flexible and extensively used software tool for a variety of purposes.

In conclusion, MATLAB is a robust, user-friendly

software environment with numerous libraries, visualization tools, and numerical computation capabilities, making it a top choice for a variety of scientific and engineering jobs. Its widespread community support and simplicity of usage have boosted its acceptance in global academia and business.

IV. RESULTS AND DISCUSSION

In this research, the DWDM system is the main topic of investigation, and the features of systems using 4, 8, 16, and 32 channels are examined. The research explores two important topics for discussion:

(i) The effect of dispersion brought on by the launched signals' input power.

(ii) A thorough examination of the consequences of dispersion at various data rates.

In order to understand how the DWDM system behaves with regard to dispersion, the researcher investigates how the system functions under various channel configurations. The effects of changing input power on dispersion can be studied to learn more about the capabilities and limitations of the system. A thorough grasp of how the DWDM system manages signal degradation and dispersion difficulties is provided by the investigation's further exploration of the dispersion impacts across various data speeds.

- **Launched Power Effects**

Through simulations at various power levels and measurements of the Optical Signal-to-Noise Ratio (OSNR) over a range of distances, specifically between 100 km and 400 km, researcher sought to investigate the effects of DWDM system in this research. The simulations were conducted at a data rate of 20 Gbps, with the aim of investigating the implications of a novel dispersion compensation technique known as "Self-Phase Modulation (SSP) compensation." In these simulations, the researcher emulated the DWDM system with post-compensation, utilizing identical simulation parameters to implement the proposed SSP compensation, subsequently assessing the resulting Optical Signal-to-Noise Ratio (OSNR).

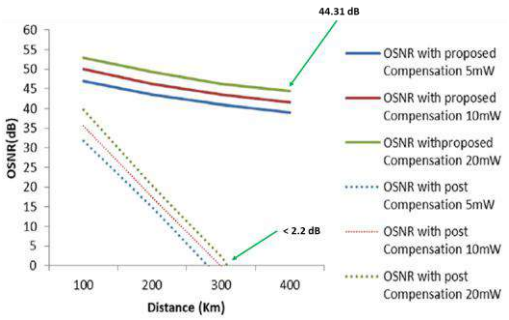

Fig.10: Output OSNR

(4 channel WDM (measured at various power levels) with/without dispersion compensation - DC)

The output OSNR when utilizing dispersion correction is shown in Figure as solid lines, while the output OSNR when using the standard "post" dispersion compensation technique is shown as dotted lines. Analysis of the results shown in Figure revealed that nonlinearity develops with transmission distance, resulting in a drop in OSNR. Furthermore, we observed that the OSNR increases with power. It was also clear that the conventional post-compensation method had its limits. It could only sustain a transmission distance of up to 300 km, even with a power input of 20 mW, and at this point, the achieved OSNR was below the intended range, measuring less than 2.2 dB.

On the other hand, when using the suggested SSP compensation strategy, performance significantly improved. The recorded OSNR impressively reached a value of 44.31 dB at a transmission distance of 400 km and an input power of 20 mW, proving the efficiency and superiority of the SSP compensating

methodology over the conventional method. Overall, these findings show the benefits of using the ground-breaking SSP compensation technique to achieve improved performance over longer transmission distances and offer useful insights into the behavior of the DWDM system under various circumstances.

It is crucial to carefully regulate the number of channels while preserving an acceptable Optical Signal-to-Noise Ratio (OSNR) while using Dense Wavelength Division Multiplexing (DWDM). In order to fully understand the implications of nonlinearities over greater transmission lengths, we carried out a thorough analysis of the DWDM system in this work, looking at its behavior with 4, 8, 16, and 32 channels. Research identified an important pattern: the OSNR significantly declines as the number of channels rises. With increased transmission distance, this degradation is even more obvious. Figures (8-channel DWDM), (16-channel DWDM), and (32-channel DWDM), where we noted the declining OSNR values, provide a clear illustration of this phenomenon.

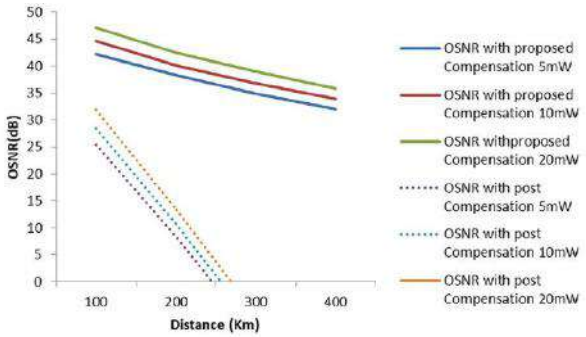

Fig.11: Output OSNR

(8 Channel WDM measured at various power levels with/without DC)

Researcher suggests a unique compensation method termed "Self-Phase Modulation (SSP) compensation" to address these problems and contrasted it with the traditional post-compensation method. A detailed comparison of the two methods' output OSNR, as measured at various power levels, is shown in Figure. Analysis showed that proposed SSP technique performs much better than post compensation technique. Recorded OSNR utilizing the SSP technique at a transmission distance of 400 km was 32 dB with an input power of 5 mW, whereas at an input power of 20 mW, it was 35.8 dB. The OSNR values for the post-compensation technique were much lower, coming in at 7 dB and 11 dB for input powers of 5 mW and 20 mW, respectively. The post-compensation technique was unable to handle transmission beyond 200 km.

In addition, researcher looked at Figure OSNR performance for 16 channels. The OSNR for the suggested SSP approach at 400 km was 23.8 dB with 5 mW input power, and it increased to 26.9 dB with 20 mW input power. On the other hand, the post-compensation technique could only sustain transmission up to a distance of 200 km and delivered OSNR values of only 7 dB and 11 dB for 5 mW and 20 mW input powers, respectively.

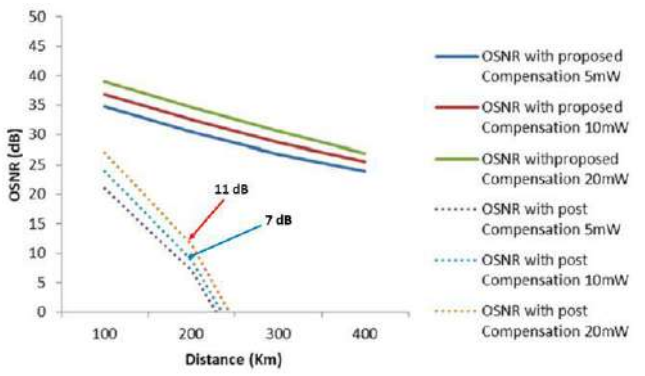

Fig.12: Output OSNR

(16 channel WDM measured at various power levels with/without DC)

As a result, our research emphasizes how crucial it is to keep the OSNR levels in DWDM systems at an adequate level while also regulating the number of

channels. A possible way to improve the system's performance over longer transmission lengths and with more channels is provided by the proposed SSP compensation methodology, which performs better than the conventional post-compensation method.

Using only the post-compensation strategy may not be sufficient as Dense Wavelength Division Multiplexing (DWDM) systems add more channels. When analyzing the OSNR performance of a 32-channel DWDM system (as depicted in Figure), this constraint becomes clear. With an input power of 5 mW and a transmission distance of 400 km, the OSNR obtained with the ground-breaking SSP compensation technique measured 19.11 dB. The OSNR increases to 21.6 dB at 20 mW of input power. OSNR values produced by the conventional post-compensation method, on the other hand, are lower, only reaching 5.2 dB at 200 km with 5 mW input power and 8.8 dB with 20 mW input power.

These results underline how crucial it is to implement the suggested SSP compensation technique in order to successfully handle the difficulties brought on by more channels in DWDM systems. For durable and dependable DWDM transmission, the SSP compensation technique turns out to be essential in obtaining the appropriate OSNR levels. By using the SSP compensation method, DWDM systems can maintain acceptable OSNR values and improve performance even when supporting more channels. The increased OSNR levels at greater transmission lengths and under various power input conditions show how effective and appropriate the SSP technique is for addressing the needs of contemporary high-capacity DWDM networks.

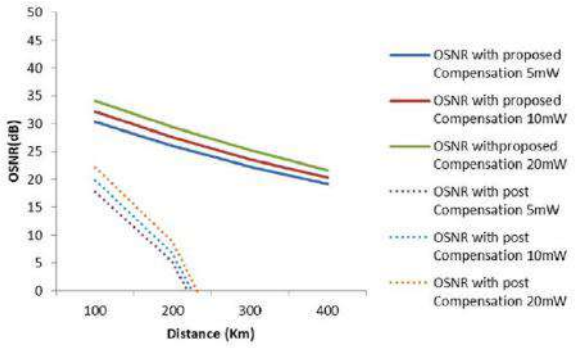

Fig.13: Output OSNR

(32 channel WDM measured at various power levels with/without DC)

In conclusion, as the number of channels rises, it becomes clear that the post compensation technique has limits, necessitating the use of proposed SSP compensation technique as a vital means of achieving the appropriate OSNR values in DWDM systems. The performance and dependability of DWDM networks can be significantly improved by embracing the benefits that come with SSP compensation, putting them in a better position to handle the increasing demands of high-bandwidth communication.

- **Effects due to Data Rate**

It becomes essential to increase the data rates in DWDM systems in order to make full use of the optical capacity and improve data transmission capabilities. We looked closely at the DWDM system in our analysis, taking into account several channel configurations (4/8/16/32 channels) and increasing the data rates to 20 Gbps, 40 Gbps, and 100 Gbps. Main goal was to evaluate how well the suggested compensatory mechanism handled these higher data rates. The performance of increasing data rates when combined with more channels must be understood in order to maximize DWDM networks. As a result, we carefully examined how increased data rates would affect both the effectiveness of the suggested

compensation mechanism and the overall performance of the system.

As the number of channels increases from 4 to 32, there is a discernible rise in nonlinearity, which is a significant finding from our research. This result highlights the need for rigorous nonlinearity management in the system when introducing more channels. The research provides a useful understanding of the behavior of DWDM systems at larger data rates and with more channels, setting the groundwork for practical nonlinearity-related problem mitigation solutions.

Overall, this thorough analysis clarifies the critical significance that data rate increases play in efficiently utilizing optical capacity. To assure the best performance and reliability in high-capacity optical communication networks, we can create reliable compensation approaches by analyzing the effects of various data rates on DWDM systems with diverse channel configurations.

Results for DWDM systems with 4, 8, 16, and 32 channels are shown in Figures, respectively. We started running simulations using the post compensation method to assess the effectiveness of the suggested compensation strategy. We then tested the performance of the suggested Self-Phase Modulation (SSP) approach with an input power of 10 mW under the identical simulated settings. Throughout the course of our investigation, we kept a careful eye on how distance and data rate affected the degree of nonlinearity seen in the DWDM systems. Our research uncovered an interesting pattern: as distance and data rate increased, so did the nonlinearity inside the systems.

For instance, the observed OSNR attained a remarkable value of 39.5 dB when using the suggested SSP compensation technique for a four-channel system at a data rate of 100 Gbps and a transmission distance of 400 km. In contrast, the achieved OSNR while using the post correction technique at a data rate of 100 Gbps and a distance of 200 km was just 13.5 dB. Furthermore, even when the data rate was reduced to 20 Gbps, we saw that the post compensation technique was unable to adequately compensate for signal losses beyond 200 km.

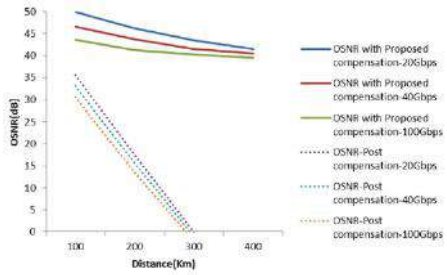

Fig. 14: Output OSNR

(4 channel WDM measured at various data rates with/without DC)

Similar to this, we investigated the performance of an eight-channel system in Figure. At data rate of 100 Gbps and a transmission distance of 400 km, the proposed compensatory technique showed an OSNR of 32.2 dB. In comparison, with data rate of 100 Gbps and a distance of 200 kilometers, the post correction technique produced an OSNR of only 7.2 dB.

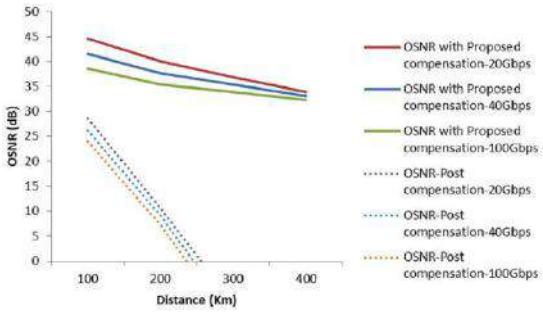

Fig.15: Output OSNR

(8 channel WDM measured at various data rates with/without DC)

Regarding 16-channel system shown in Figure, our research showed that the proposed method was able

to achieve an OSNR of 24.2 dB at 400 km and data rate of 100 Gbps, but post compensation method was unable to do this beyond 200 km.

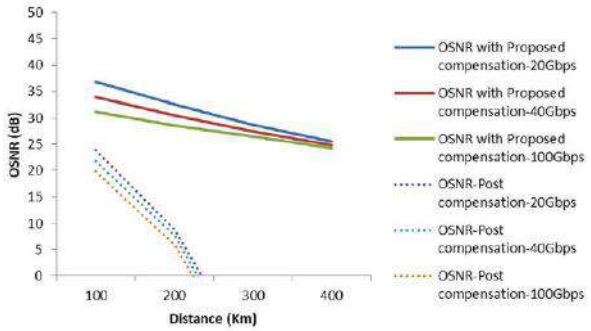

Fig.16: Output OSNR

(16 channel WDM measured at various data Rates with/without DC)

32-channel system was the main focus of Figure, where the suggested SSP compensation technique produced an OSNR of 19.6 dB at a data rate of 100 Gbps and a distance of 400 km. The OSNR values were lower at 6.8 dB at 20 Gbps data rate and 4.7 dB at 100 Gbps data rate due to the post correction method's limited ability to support networks beyond 200 km.

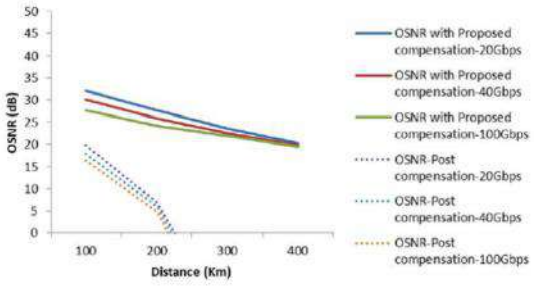

Fig.17: Output OSNR

(32 channel WDM measured at various data rates with/without DC)

The results of our research highlight importance of the suggested SSP compensation technique in reducing nonlinearity problems and expanding the transmission range in DWDM systems with different channel layouts and data rates. The performance of high-capacity optical communication networks can be improved using this knowledge as a foundation for the implementation of strong compensating mechanisms.

A brief summary of the Optical Signal-to-Noise Ratio (OSNR) values for various data speeds is provided in Table 4.

Table 4: Comparison of the post compensation & proposed SSP compensation technique

Compensation	Number of Channels	OSNR		
		20 Gbps	40 Gbps	100 Gbps
Proposed SSP	4	46.27	43.69	41.20
Technique	8	40.05	37.65	35.35
	16	32.51	30.52	28.52
	32	27.66	25.86	24.26
Post	4	17.48	15.68	13.57
Compensation	8	10.65	9.15	7.25
Technique	16	8.87	7.67	5.97
	32	6.87	5.97	4.77

(Distance 200 km; Launched Power 10 mW)

The eye diagrams in Figure give a visual depiction of the data that was received for 32-channel DWDM system over a 100 kilometer distance. Figure also shows associated spectrum at receiver. In particular, wide eye-opening seen in Figure shows that the received data benefits from less jitter, noise, and nonlinearities, which is mainly related to the application of the Self-Phase Modulation (SSP) compensation approach. This demonstrates the enhanced signal integrity attained using SSP compensation.

It is interesting that comparable eye diagrams were also generated for the 4, 8, and 16 DWDM channels, demonstrating the SSP compensation technique's consistent and advantageous effects across a range of channel configurations. These eye diagrams' wide eye openings show that the SSP compensation efficiently reduces impairments, resulting in improved reception quality and system performance as a whole.

These eye diagrams demonstrate the system's resistance to signal deterioration by using the SSP

compensation technique, producing well-defined eye patterns with minimal distortions. This in turn shows how the suggested SSP compensation technique effectively improves the performance of DWDM systems over a wide range of channel configurations and distances.

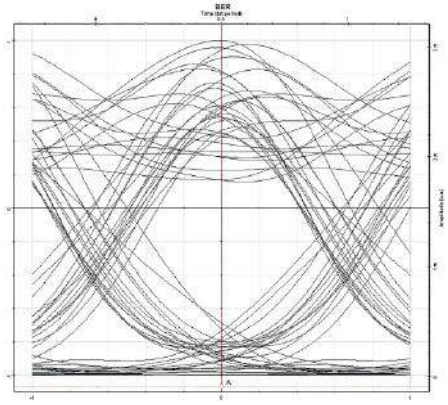

Fig.18: Eye-diagram

(32 channel system at a distance of 100 km)

Figures show DWDM systems to retain steady and reliable signal reception even in the presence of difficult transmission conditions, provide clear proof of the advantages offered by the SSP compensation technique. The proposed compensation technique's effectiveness in minimizing distortions and guaranteeing ideal signal quality in high-capacity optical communication networks is visually validated by the eye diagrams.

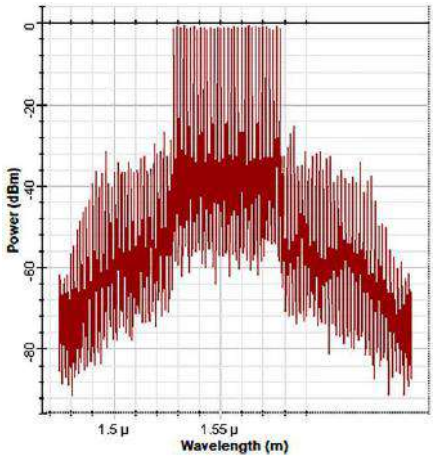

Fig.19: 32 Channel spectrum at the receiver.

V. CONCLUSIONS

DWDM system, which is prone to nonlinearities such as CPM, SPM, & FWM, is addressed in this research with a unique dispersion compensation technique. Our suggested method focuses primarily on compensating for cross-phase modulation with the goal of enhancing system performance and reducing the negative consequences of nonlinear phenomena.

This research focused on the fluctuations in data rates and power levels to perform a thorough examination of the DWDM system. Promising results were seen, especially in a 32-channel DWDM system, according to our observations. We successfully compensated for nonlinearities over an amazing transmission distance of up to 400 km by using our suggested Self-Phase Modulation (SSP) approach. Additionally, this was accomplished utilizing characteristics that are ideal for enabling long-haul optical communication, namely an input power of 20 mW and a high data throughput of 100 Gbps.

It's interesting to note that researchers have shown that no of channels and the transmission distance may both be increased by carefully altering data rate and input power. Due to its adaptability, the DWDM system may be customized to meet particular communication needs and adjust to shifting network requirements.

Our research also showed that the suggested SSP strategy performs better than the conventional post-compensation method, making it more appropriate for long-haul DWDM systems. Despite the fact that some nonlinearities are adequately addressed by the SSP compensation, we accept that the spectrum broadening brought on by XPM cannot be fully corrected by SSP technique alone. We suggest combining cutting-edge modulation techniques with the SSP compensation to get over this restriction. This combination strategy improves spectrum broadening

mitigation while also improving system performance.

However, because they typically use more power, it's crucial to think about the effects of utilizing additional amplifiers. As a result, dynamic management of Erbium-Doped Fiber Amplifiers (EDFA) is essential for maintaining appropriate signal amplification and successfully managing power consumption.

The results of this research demonstrate the viability of the suggested dispersion correction method in DWDM systems. In order to achieve long-haul optical communication with high data rates and various channels, the SSP method appears to be a promising approach. The performance of DWDM systems can be further improved, making them well-suited for a variety of optical communication applications by integrating modern modulation techniques with the SSP compensation and assuring effective control of amplifiers.

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Designing Flexible Scheduling Algorithm for 5G

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Abstract *— Broad machine-type communication, ultra-reliable low-latency communication, and efficient management of expanding mobile broadband traffic are now achievable with the advent of 5th-Generation (5G) wireless mobile communication standards. One of the biggest challenges for 5G networks, meanwhile, developing effective Radio Resource Management (RRM) and scheduling algorithms that meet quality of service (QoS) requirements. Widely used Proportional Fair algorithm, which primarily gives priority to customers served by a node depending on their flow rate, is the foundation of the current 5G scheduling technology. The purpose of this project is to investigate methods for improving 5G network throughput and to suggest novel scheduling schemes. This work advances the development of 5G and other mobile communication technologies by adding data flow package latency as an extra priority parameter and using MATLAB for simulation analysis. In the end, it offers a new scheduling technique that was developed through the assessment of different radio resource scheduling approaches.*

Keywords *— 5G; Scheduling Schemes; Radio Resource Management.*

I. BACKGROUND

By integrating fresh technological developments, the 5th Generation (5G) mobile communication system expands on the developments of the 4G wireless technology. In 5G networks, transmission technologies including higher-order modulation and orthogonal frequency division multiplexing are still in use.

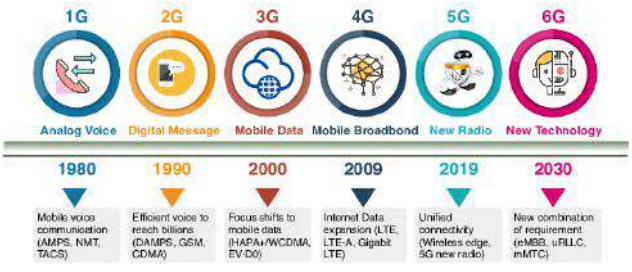

Fig.1: Evolution of Mobile Network Generations [43]

Furthermore, adaptive modulation and coding (AMC) techniques, preemptive mechanisms, massive multiple-input multiple-output (MIMO), hybrid automatic repeat request (HARQ) with code block group-based implementation and an increased number of HARQ processes, and beam management technology are all seamlessly integrated into 5G systems. Beam management technique allows for the transmission of signals through narrow beams in high-frequency bands, significantly enhancing system performance.

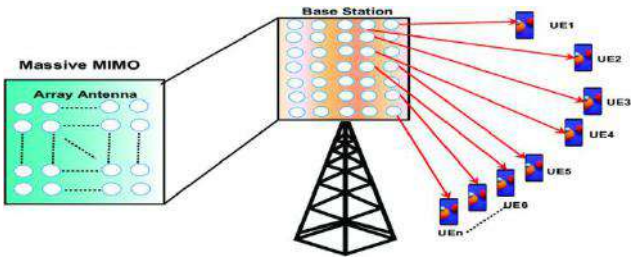

Fig.2: Multiple Input and Multiple Output (MIMO) [44]

5G system can provide a high level of system throughput and a wide range of services because of these improved capabilities. Nevertheless, Media

Access Control (MAC) layer scheduling algorithm is under more strain as a result of the incorporation of these cutting-edge technical characteristics. In order to enhance network Key Performance Indicators (KPIs), wireless features must be integrated into the MAC layer scheduling algorithm to maximize the utilization of wireless technologies and radio time-frequency resources. In order to do this, resource allocation must be optimized while taking QoS needs, channel quality, user service queue status & User Equipment (UE) resource consumption from both the physical and MAC levels into account. In addition to delivering dependable and constant performance, the scheduling technique must also adhere to practicality and computational complexity limitations.

Both Standalone (SA) and Non-Standalone (NSA) network topologies are used in 5G technology. The scheduler on the eNodeB (or gNodeB) functions independently in these topologies. Consequently, the scheduling strategy covered in this study applies to both NSA and SA designs.

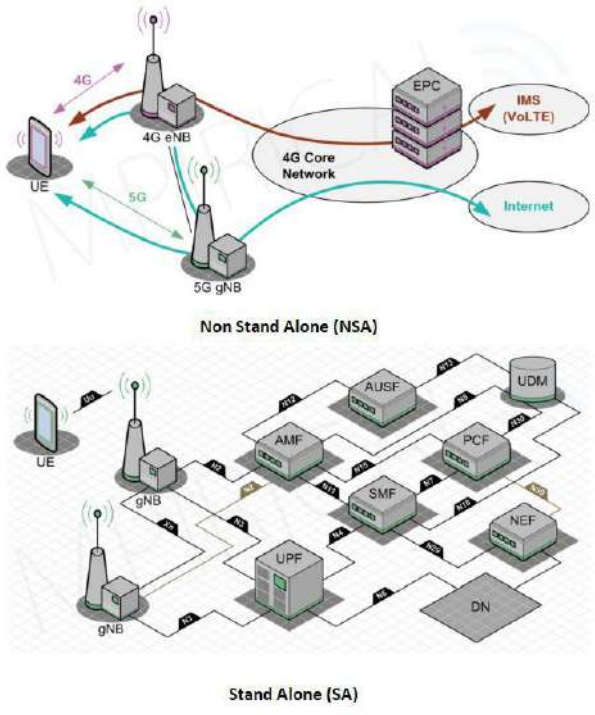

Fig.3: Stand Alone and Non-Stand Alone 5G Basic Architectures [45]

- Non-Standalone (NSA) Architecture

Technical Specification (TS) 38.300 states that Multi-Radio Dual Connectivity (MRDC) can be supported by 5G networks, which will enable a seamless transition from 4G to 5G network deployment. Two separate Radio Access Network (RAN) elements that operate independently in the user plane and are each outfitted with a separate scheduler for radio resource allocation are the foundation of MR-DC network topologies. User Equipment (UE) is set up to use radio resources given by these two independent schedulers, which are situated in separate Next Generation (NG)-RAN elements within the Standalone (SA) architecture, when Radio Resource Control (RRC) is enabled.

A Radio Access Network (RAN) supporting SA 5G is identified in the 5G Standalone (SA) network architecture by its link to the 5G Core (5GC). Operator network deployments of 4G will progressively discontinue as 5G technology advances. The gNB (5G New Radio Base Station) is in charge of terminating control plane and user plane protocols in the 5G network in the direction of the User Equipment (UE) on the RAN side. According to TS 23.501, the NG interfaces connect the gNBs to the Access and Mobility Management Function (AMF) network element in the 5GC [3].

- 5G Protocol Stack Architecture

User data transmission is handled by the user plane protocol stack, and system control signaling is handled by the control plane protocol stack. Essentially, separate stacks handle distinct kinds of data; the user plane stack handles user data, while the control plane stack handles signaling messages. The physical layer (PHY), medium access control (MAC), radio link control (RLC), and packet data convergence protocol (PDCP) are among the common protocol layers shared by both planes. In order to guarantee alignment between the protocol stacks in the UPF and gNB, the gNB is connected to the User Plane Function (UPF) network element in the user plane via the NG-U interface. Radio Resource Control (RRC) and Non-Access Stratum (NAS) are the top two protocol levels in the 5G gNB control plane protocol stack, same like in 4G. The Access and Mobility Management Function (AMF) network element in the 5G Core (5GC) receives transparent NAS layer signaling over the gNB.

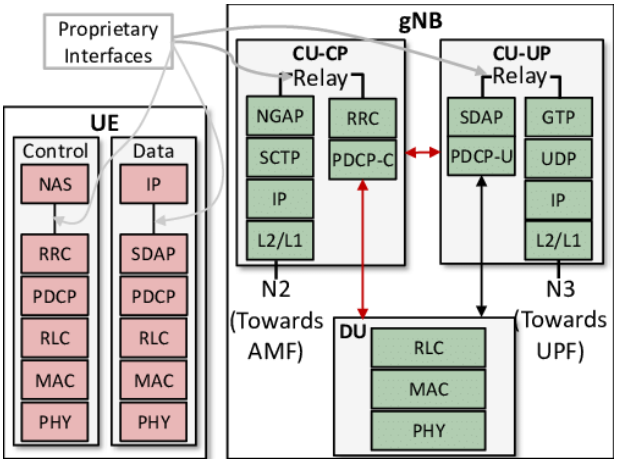

Fig.4: 5G Protocol Stack [9]

- Radio Resource Management (RRM)

Ensuring the quality of service for wireless User Equipment (UE) in a network with constrained bandwidth is the main goal of Radio Resource Management (RRM). RRM attempts to handle unequal network traffic distribution and changes in channel characteristics brought on by fading and interference by dynamically allocating and adjusting resources within the wireless transmission and network. The ultimate goals are to reduce the burden from signaling transmission, avoid network congestion, and maximize the use of wireless spectrum. Quality of Service (QoS) factors are among the core topics that the RRM module concentrates on.

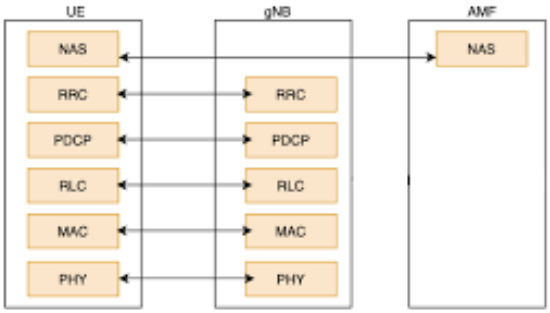

Fig.5: Radio Resource Management [46]

- Channel State Information Reporting

Massive MIMO is a critical technology in the field of 5G. Acquiring accurate Channel State Information (CSI) is critical to improving performance of a huge MIMO system. Using Reference Signal (RS), user estimates and quantizes the channel during downlink MIMO data transfer. This procedure provides two functions: demodulating transmission data and providing quantized results to the gNB (5G New Radio Base Station). The quantized CSI is used by the gNB to identify the suitable precoding and modulation coding method. CSI is a catch-all word which includes more components than their 4G equivalents.

Because it enables the gNB to evaluate the downlink channel's quality, CQI reporting is crucial. Each CQI represents a quantized and scaled version of the user's Signal-to-Noise plus Interference Ratio (SINR). The Radio Resource Management (RRM) architecture's Adaptive Modulation and Coding (AMC) module selects the appropriate modulation and coding scheme based on the reported CQI in order to maximize throughput. Several scheduling algorithms, such as the one covered in this article, leverage Channel State Information (CSI) to create RRM allocation techniques.

- Conventional Scheduling Algorithms

Scheduling algorithms have been a recurring topic in communication technology evolution [7].

- Round Robin (RR)

The RR algorithm is a straightforward technique that doesn't require any difficult logical inferences. User Equipment (UE) has equal access to radio resources thanks to Radio Resource Management (RRM), which distributes radio resources to users in RR scheduling system in a first-in, first-served manner. Because of this, regardless of channel state, customers serviced by the same gNB are scheduled in the same way. There is no need for abstract theory to implement the RR system, making it easy to do so. It offers excellent performance and equity to all users in the near run. However, one disadvantage of this approach is its inability to properly exploit the wireless channel's time-varying properties in order to maximize the system's multi-user diversity gain.

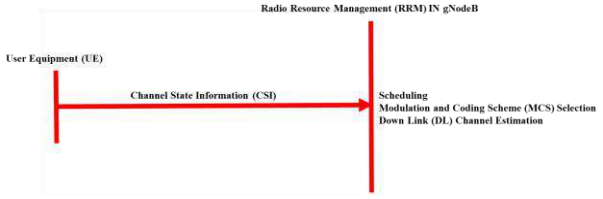

Fig.6: Channel State Information

- Best CQI

The Best Channel Quality Indicator (CQI) scheduling strategy is another approach employed in the gNB. When selecting a schedulable User Equipment (UE) from among all UEs associated to a cell in the gNB, only the UE with the best CQI is chosen. This approach dynamically modifies the number of concurrent users based on the transmission strategy, efficiently adjusting to the wireless channel's time-varying and fading characteristics to maximize system throughput. Users with inferior channel conditions, such as cell-edge users, have a decreased likelihood of being scheduled in this scheduling system [7]. While this strategy offers maximal multi-user diversity gain, it is the least fair algorithm in terms of fairness.

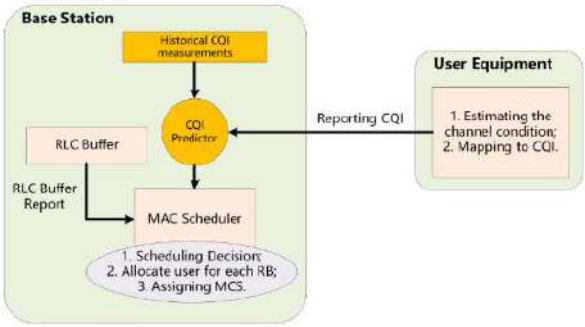

Figure 7: CQI prediction Module [10]

- Proportional Fair

In the industry, the Proportional Fair (PF) algorithm is frequently employed. Radio Resource Management (RRM) gives each user served by the gNB a priority within this algorithm. The particular measures employed in establishing these priorities differ based on the architecture of the vendor. During each scheduling period, users with higher priorities are scheduled first. The choice of proper measurements is critical for the PF algorithm since it has a direct impact on network performance. The PF scheduling algorithm successfully exploits the time-varying properties of user channels while balancing multi-user variety and fairness. It allocates radio resources based on both historical user throughput and experienced channel quality. The development of the PF algorithm has resulted in considerable advances in this discipline. The ratio between the instantaneous flow available for the i-th flow and the average flow seen at the preceding moment (k - 1) is one metric utilized for priority in the PF algorithm [8]:

$$w_{i,j} = \frac{r_{i,j}}{R_i}$$

ri;j represents the flow rate assigned to the i-th flow during the k-th Transmission Time Interval (TTI), and Ri represents the expected average transmission data rate. By utilizing the average data transmission rate, the PF scheduling method efficiently addresses long-term user fairness. It does not, however, guarantee users' short-term fairness.

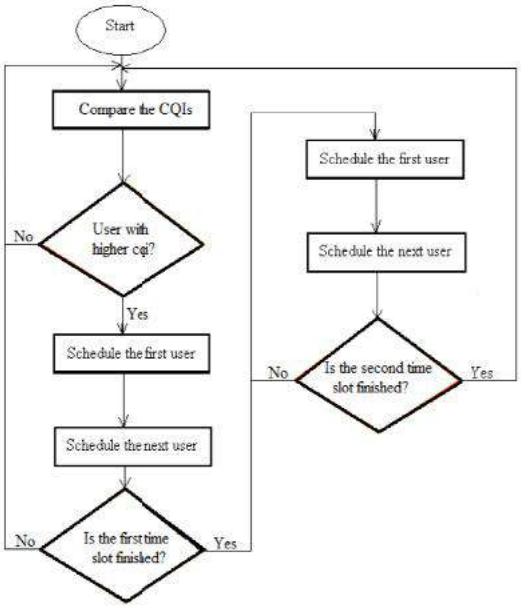

Fig. 8: Flow chart of Proportional Fair (PF) Scheduler [11]

Problem Statement

5G wireless mobile standard has recently been made public. Massive machine-type communication, ultra-reliable low-latency communication, and improved mobile broadband are just a few of the sorts of traffic that 5G networks are designed to handle efficiently. However, creating efficient Radio Resource Management (RRM) techniques and scheduling algorithms that can satisfy the various quality of service needs is a key problem in the deployment of 5G networks.

Research Significance

Research is about new scheduling techniques and

look at ways to increase the throughput of 5G networks. The study will include package delay of data flow as a priority parameter in addition to already existing metrics. The study will make use of a MATLAB based modelling tool simulator. According to the research, a brand-new scheduling algorithm will be developed after being compared to numerous radio resource scheduling plans.

Research Objectives

In order to improve the user experience for enhanced mobile broadband, the researcher will evaluate performance of scheduling algorithms, such as RR (Radio Resource), PF (Proportional Fair), PF0 (Existing Proportional Fair Algorithm), and optimal CQI (Channel Quality Information), under 5G environment. The newly proposed scheduling algorithm would exceed the best CQI, RR, and traditional PF algorithms by providing higher throughput, the researcher will attempt to demonstrate through simulation using MATLAB. This study's goals are to suggest new scheduling strategies and look into ways to increase the throughput of 5G networks. In this study, we'll use the data flow's packet delay as a priority metric. By examining existing radio resource scheduling techniques, this research aims to develop a new scheduling algorithm.

Research Questions

- Is it possible to evaluate the performance of scheduling algorithms in a 5G context, such as RR, PF, PF0, and best CQI, with the aim of improving the user experience for enhanced mobile broadband?
- Will proposed scheduling algorithm can come up with higher throughput?
- What procedures can be used to increase the throughput of 5G networks?
- Is it possible to suggest original schedule plans?
- Is it possible to develop a new scheduling algorithm by examining multiple radio resource scheduling plans?

II. LITERATURE REVIEW

Scheduling algorithms are critical in both current and future wireless networks, ensuring effective and equitable resource allocation [17]. These algorithms are classified as either centralized or distributed [21]. To efficiently meet fairness and quality-of-service (QoS) criteria, centralized algorithms are widely utilized for downlink transmission. Distributed algorithms, on the other hand, are commonly used in ad hoc or uplink transmission settings where users have control over channel access.

A scheduler needs certain parts in order to function as well as possible over a wireless network. Transmission time intervals (TTIs) should not be assigned to sessions with poor link quality by the algorithm, which should strive to maximize the utilization of the available channel. While maintaining long-term throughput guarantees for all sessions, it should offer short-term throughput guarantees for error-free sessions [21]. Cellular users should redistribute resources fairly, accounting for both long-term equities for error-prone sessions and short-term equity for error-free sessions. The fairness index, which assesses the greatest variation in normalized service obtained by any two backlogged sessions, is frequently employed for this reason.

Cutting down on the energy usage of cellular users is another difficulty for the scheduler. This can be achieved by enabling users to send and receive messages continuously and by putting the device in sleep mode while it is idle, which will use less energy [14]. The scheduler should also restrict the amount of simultaneous broadcasts in the network to reduce excessive interference. In delay-sensitive applications, the scheduler should be able to guarantee specific session delay boundaries [17]. In order to guarantee that the existing channel is utilized efficiently as the user base expands, scalability is essential. Furthermore, the scheduler should be constructed with as minimal complexity as possible because fast scheduling decisions are essential in high-speed networks.

Schedulers play an important role in allocating resource blocks (RB) to cellular customers based on demand. These schedulers are commonly found at the Evolved Node B (eNodeB) and are responsible for allocating both uplink and downlink resources. At each transmission time interval (TTI), the scheduling algorithm assigns shared resources to each cellular user. On a regular basis, the eNodeB receives channel

quality indicators (CQI) from users, with a higher CQI value indicating better channel quality.

Round robin (RR), proportional fair (PF), fractional frequency reuse (FFR), and best channel quality indicator (BCQI) are the four main scheduling strategies. An overview of the general operation of some algorithms is given in this section.

The round robin scheduler is a non-aware scheduling technique that starts with the first user and assigns resources progressively to subsequent users. It does not take into account the current channel conditions [13]. While this technique improves user fairness, it degrades speed. Because users may be allotted fading channels, it can reduce overall system throughput. Furthermore, because it does not consider the CQI factor, it does not efficiently manage the overall quantity of resources. Despite these disadvantages, due to its ease of implementation, this scheduler is frequently utilized in many systems [16].

The best CQI scheduler is in charge of allocating resource blocks to users at each TTI based on their radio connection conditions or channel quality. Cellular users transmit their CQI to the eNodeB, which utilizes it for scheduling. The eNodeB sends a reference signal (downlink pilot) to users, who then measure their own CQI. A higher CQI number suggests that the channel is in better condition. While this scheduler can boost individual cell throughput, it lacks fairness among users, especially those at the cell edge who may never be scheduled [16].

FFR scheduler is frequently employed when minimizing interference between neighboring cells is crucial [12]. Because of its flexibility and agility, it enables the creation and implementation of various schedulers. Users can share resource blocks in partial reuse (PR) or full reuse (FR) modes. RBs can be assigned according to priority and zone designation, and the available frequency band can be partitioned into many bands. While FFR has a higher average throughput, giving some users priority over others might not be fair.

By taking channel variations into account, the PF scheduler improves spectral efficiency and provides greater fairness. By combining CQI and fairness criteria, it assigns resource blocks to users with the best link quality. PF enables mobile users to achieve optimal QoS by balancing fairness and maximum cell throughput [16]. The throughput at a certain TTI and the average throughput of the user are used to calculate RB allocation using a weighted fair queuing algorithm (WFQ).

There have been numerous studies done on scheduling algorithms. [13] evaluated the throughput and block error rate (BER) of the RR, best CQI, and PF schedulers using a MATLAB-based system level simulator. Although the optimal CQI algorithm handled customers with poor channel conditions unfairly, it had a better throughput. [12] compared scheduling techniques with an emphasis on QoS provisioning while conducting a thorough evaluation of LTE downlink packet allocation methodologies. After a thorough analysis, [23] divided LTE uplink schedulers into three categories: power-optimizing, QoS-based, and best-effort. A simulation model comparing the best RR and CQI scheduling strategies for LTE system throughput was developed by [22].

Other research has compared various network setups and performance measures. [18] examined downlink performance measures for small cell networks (ScNet) and heterogeneous networks (HetNet), favoring HetNet for greater average UE throughput in densely populated areas. [19] examined the packet scheduling algorithms PF, MLWDF, and EXP/PF, taking into account throughput, packet loss ratio (PLR), latency, and fairness. [15] explored variable packet scheduling methods (WFQ, PQ, and FIFO) in various real-time and non-real-time applications to provide the greatest QoS. [20] investigated RR, PF, optimal CQI, Max-TP, and RF schedulers while taking cell range expansion (CRE) and nearly blank sub frame (ABS) methods into account in order to optimize system performance and interference towards cell edge users.

In existing mmWave standards, various scenarios and use cases for 5G and beyond networks have been introduced. However, no precise mechanism for allocating radio resources has been described. Several research papers have presented and addressed scheduling techniques for 5G network implementation. The authors of reference [24] conducted a survey of radio resource management (RRM) schemes in 5G and beyond networks. They discussed and contrasted the procedures of different

scheduling algorithms. They also addressed the reasons influencing the RRA decision and analyzed the performance of the scheduling systems.

In reference [25], an improved broadband scheduler based on the lean manufacturing technique was developed. This scheduler combines the best channel quality indicator (BCQI) and SPF (shortest path first) algorithms. While this technique improves system speed, it has a significant impact on UE fairness when compared to the SPF and RR algorithms.

In reference [26], the authors presented a channel-gain-based scheduling approach for huge multiple input multiple output (MIMO) systems. This technique increases throughput while ensuring UE fairness.

Reference [27] investigated and compared the performance of various scheduling algorithms in time-division duplex (TDD) mode, including RR, SPF, and BCQI. Voice over internet protocol (VoIP), video streaming, and cloud storage were among the traffic kinds studied. The study assessed the scheme's throughput but did not include UE fairness and satisfaction. Furthermore, each traffic type was investigated independently, which is not a realistic scenario in which several UEs request traffic at the same time.

The influence of blockage probability in mmWave networks on the performance of the SPF scheme in terms of UE data rates and fairness was addressed and compared in reference [28].

References [29-33] concentrated on adjusting the exponential parameters of the priority function in the SPF scheme based on specific circumstances to increase throughput and fairness in various communication systems. However, in their procedures, these algorithms ignore UE requirements.

Reference [34] advocated improving the SPF scheme by boosting the priority of UEs with poor channel circumstances, which proved effective in dealing with mmWave channel variations in industrial internet of things applications.

While these studies looked at well-known scheduling methods or offered changes to improve scheduling schemes, they did not take into account the influence of UE demands on system performance. Furthermore, they frequently assumed homogeneous traffic across UEs, thinking that consumers require the same data rate across all time frames. However, in practice, UEs in 5G and beyond networks have varying data rate demands dependent on their individual eMBB applications, such as video streaming and virtual reality. Thus, while investigating and proposing scheduling algorithms for UEs, taking non-homogeneous traffic into account is a more realistic scenario.

The discrepancy between UE demands based on their experienced applications and its effect on the performance of the DPF (dynamic priority first) scheduling strategy was examined in a previous work [35]. However, the impact of obstruction on total system performance was not considered in this study. Furthermore, it anticipated an unrealistic situation in which lower-demand apps were experienced by more UEs. In addition, the work utilized 3GPP standard channel models, whereas the prior study used the MiWEBA channel model.

These studies emphasize the significance of scheduling algorithms and their effects on system performance, fairness, and QoS in a variety of network settings.

III. RESEARCH METHODOLOGY

Benchmark for this research is the research done by Wu, Junmin, Chuan Liu, Jing Tao, Shidong Liu, and Wei Gao. (2023). "Hybrid Traffic Scheduling in 5G and Time-Sensitive Networking Integrated Networks for Communications of Virtual Power Plants" Applied Sciences 13, no. 13: 7953. https://doi.org/10.3390/app13137953.

- **Simulation Parameters**

The first parameter relates to the number of chunks. The "number of chunks" in the context of a 5G network simulation often refers to the partition of data or information into smaller segments or pieces. To improve efficiency and dependability, data in 5G networks is frequently delivered in chunks. The number of chunks in a 5G network simulation can signify the total number of these segmented pieces of data being simulated or analyzed. It can be used to assess various network parameters such as throughput, latency, and overall network

performance when handling and transmitting data in smaller units. Number of chunks value is taken as "1" for the simulation.

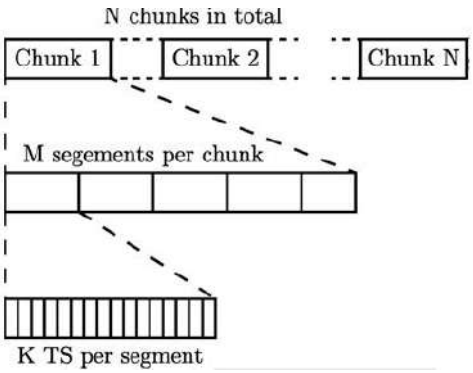

Fig.9: Number of Chunks

(Source: Made by Researcher)

"Slots per chunk" refers to the division of time in a wireless communication system in the context of 5G simulations. Time is divided into discrete intervals called slots in 5G networks, which are used to schedule and transmit data. The term "slots per chunk" refers to the number of slots assigned to each particular chunk of data during simulation. It denotes the degree of granularity of time division inside a chunk. Researchers and engineers can assess and analyze the impact of alternative time allocation schemes on the performance of the 5G network by altering the number of slots per chunk. In practice, a higher number of slots per chunk allows for finer-grained time division, perhaps leading to more efficient network resource use. However, the increased signaling and control information required for handling a larger number of slots may result in increased overhead. A reduced number of slots per chunk, on the other hand, may result in coarser time division but lower signaling overhead. The optimal number of slots per chunk is determined by the individual simulation goals and desired trade-offs between resource utilization and signaling overhead. Slots per chunk are selected to be 100 [36].

"Time between chunks in slots (ms)" in 5G simulations refers to the duration or gap between consecutive chunks of data in the simulated network, measured in milliseconds. This option sets the time interval between the completion of one chunk's transmission and the start of the following chunk's transmission. It denotes the amount of time that elapses between successive data transmissions. Researchers and engineers can examine the influence of various inter-chunk delays on the performance of the 5G network by adjusting the time between chunks. The interval between chunks in slots is a crucial component in determining data transmission efficiency, throughput, and latency in a 5G network. A shorter time interval between chunks might result in more frequent data transmissions, potentially increasing throughput but also increasing overhead due to the signaling and control information necessary for each transaction. A longer interval between chunks, on the other hand, can minimize signaling overhead but result in poorer throughput and increased latency. The time between chunks in slots for 5G simulations is determined by the individual simulation goals, network conditions, and trade-offs between throughput, latency, and signaling overhead. In order to get maximum efficiency and throughput, the value of time between chunks in slots (ms) is taken as "0" [37].

Omnidirectional antennas have various advantages in 5G networks:

1. Omnidirectional antennas transmit signals in all directions, resulting in a 360-degree coverage pattern. This allows them to service a wide region without requiring exact antenna alignment. It simplifies network deployment and expands the coverage of a 5G network, particularly in highly populated locations.
2. Seamless Mobility: Omnidirectional antennas enable 5G devices to move seamlessly. Because the antennas broadcast signals in all directions, they can keep moving devices connected regardless of their orientation or location within the service region. This is especially useful for applications requiring high mobility, such as driverless vehicles, public transportation, or Internet of Things devices.
3. Flexibility and Scalability: Omnidirectional antennas provide network designers with flexibility and scalability. They can be used in a variety of contexts, including congested urban regions, rural locations, and interior settings. Furthermore, using several omnidirectional antennas in a network increases capacity and coverage by enhancing signal distribution and

reducing dead zones.

4. Network Planning Simplified: Omnidirectional antennas make network planning and optimization easier. Because of their broad coverage pattern, they may require fewer antennas than directional antennas, decreasing the complexity and expense of network construction. It also simplifies network management by reducing the frequency with which antennas must be reoriented or adjusted.
5. Omnidirectional antennas improve user fairness in 5G networks. Because they broadcast signals in all directions, they enable equitable access to network resources for all devices within their service region. This contributes to the equal distribution of network capacity and the treatment of customers.

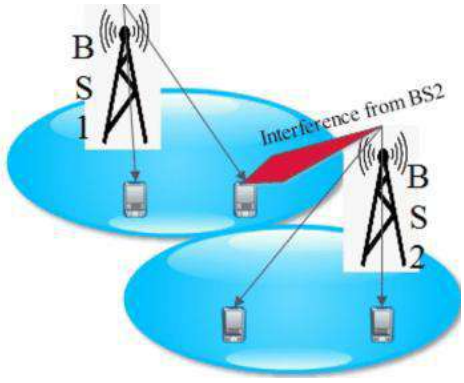

Fig.10: Omni Directional Antenna [47]

Overall, using omnidirectional antennas in 5G networks improves coverage, allows for seamless mobility, simplifies network planning, and promotes user fairness. These benefits make them an excellent alternative for a wide range of deployment scenarios in 5G networks. This simulation hence uses an Omni directional antenna. Number of receiving antennas is chosen as "1" with transmitting antenna being four. The transmitted power is taken as 40 w [38].

MATLAB was used to carry out the simulation. New scheduling algorithm was added into the simulator for evaluations. Using the four schedulers, we analyze throughput performance. The simulator is used to simulate four scheduling algorithms with identical fundamental parameters one at a time. The MATLAB (matrix laboratory) software platform is widely used for numerical calculation, data analysis, visualization, and algorithm creation. When it comes to simulation, MATLAB has a plethora of tools and benefits to offer [39].

1. Simulink: Simulink is a powerful graphical simulation and modelling tool in MATLAB. Its drag-and-drop interface allows users to create block diagrams and models of dynamic systems. Simulink covers a wide range of domains, including control systems, communications, signal processing, and others, making it useful for a variety of simulation tasks.
2. Extensive Toolbox Support: MATLAB comes with a plethora of toolboxes that help to extend its simulation capabilities. These toolboxes include specialized functions and algorithms for a variety of disciplines, including signal processing, communications, image processing, optimization, and others. Users can use these toolboxes to improve their simulation models and execute complex simulations more effectively.
3. The interactive environment of MATLAB allows users to iteratively develop and simulate models. It has a command-line interface as well as a graphical user interface (GUI) for interactive simulation and real-time parameter adjustment. This capability is very valuable for investigating system behavior, analyzing simulation findings, and making on-the-fly adjustments.
4. Simultaneous Simulation and Visualization: MATLAB users can view simulation results in real time. Users can obtain insights into their simulation models by creating interactive plots, animations, and 3D visualizations using its plotting and visualization features. This power of simultaneous simulation and visualization aids in a more intuitive understanding of system behavior.
5. Integration with Other Technologies: MATLAB interfaces with other programming languages, hardware devices, and software applications with ease. It facilitates connecting with external devices such as sensors and actuators, allowing simulations to be integrated with real-world systems. MATLAB also provides interfaces to other programming languages like as C, C++, and Python, allowing users to reuse existing code or interact with external systems.

6. Extensive Documentation and Community Support: MATLAB offers extensive documentation, including help files, examples, and tutorials, to make learning and utilizing its simulation features easier. MATLAB also offers a big and active user community where users may get help, discuss ideas, and collaborate on projects.
7. Reproducibility and Code Generation: MATLAB enables users to write scripts and functions that can be readily shared and replicated. It also allows you to generate standalone executable files or C/C++ code from MATLAB code, allowing simulations to run on a variety of platforms or embedded systems.

Because of these features and benefits, MATLAB is a popular choice for simulation work in a variety of areas, including engineering, physics, mathematics, and computer science. Its adaptability, large toolboxes, interactive interface, and integration capabilities all contribute to its efficacy and efficiency in modelling and analyzing complex systems.

- **Conceptualized Scheduling Algorithm**

The PF algorithm takes average rate and flow rate into account, but other factors need to be assessed as well to determine the model's priorities. Based on the quality of the received Reference Signals (RS), the UE reports the wireless channel quality to the base station, which is reflected in the Channel Quality Indicator (CQI). The base station schedules services based on CQI response and other data. The temporal lag that occurs when the UE transmits a data packet is referred to as user delay. International Telecommunication Union's (IMT)-2020 M.2410-0 (4.7.1) standard specifies the 1 ms delay threshold for ultra-reliable low-latency communication in 5G networks [40, 41, 42].

Reducing packet transmission delays is the scheduling method's main objective. The scheduling approach in 5G networks is based on the Quality of Service (QoS) model, where the highest degree of scheduling granularity is represented by the QoS flow. In order to balance packet transfer latency, average transmission rate, and channel quality, this study uses the Proportional Fair (PF) scheduling mechanism. Improving network performance while maintaining equity among the scheduled User Equipment (UEs) is the goal.

In wireless communication, "channel quality" refers to the measurement of the signal quality or channel conditions between a transmitter and receiver. It represents the properties of the wireless media over which the signal travels, such as signal strength, interference, noise, fading, and other flaws. The reliability and performance of the communication link are directly affected by the channel quality. A higher channel quality suggests a stronger, clearer, and more dependable signal with less interference or distortion, which results in improved data transmission and reception. A lower channel quality, on the other hand, signifies a weaker or noisy signal, which might result in lower data rates, increased error rates, and significant decline in communication performance. Channel quality is often evaluated or measured using various ways in wireless systems such as 5G. CQI (Channel Quality Indicator) is a popular mechanism in which the receiving device (such as a user equipment or mobile device) provides input to the transmitting base station regarding the perceived quality of the received signal. The CQI value assesses channel quality and aids in the optimization of overall system performance through adaptive modulation and coding schemes, power control, and resource allocation decisions. Channel quality monitoring and assessment are critical for efficient and dependable wireless communication systems. Network operators and algorithms can dynamically change transmission settings and distribute resources to maximize data rates, minimize mistakes, and assure optimal performance under fluctuating channel conditions by taking channel quality into account.

The term "average transmission rate" refers to the average rate at which data is sent through a communication channel or link. On average, it measures the quantity of data that may be effectively transmitted per unit of time. The available bandwidth, modulation and coding techniques, signal quality, network congestion, and the effectiveness of the communication protocol all have an impact on the average transmission rate. In the context of wireless communication systems such as 5G, the average transmission rate is a critical performance indicator that represents the network's overall capacity and efficiency. It denotes the average

amount of data that can be reliably transported from a source to a destination in a given amount of time. More average transmission rates reflect a network's ability to send data more quickly, allowing for faster data transfers, more throughput, and a better user experience. Optimizing transmission parameters, allocating appropriate bandwidth, applying modern modulation and coding techniques, and implementing efficient protocols can all lead to a better average transmission rate. Monitoring and optimizing the average transmission rate is critical for fulfilling the demands of data-intensive applications including video streaming, massive file transfers, real-time communications, and internet of things (IoT) devices. By increasing the average transmission rate, network operators can improve the network's overall performance and capacity, allowing for faster and more efficient data transmission.

"Packet transfer delay" is the amount of time it takes for a data packet to be transported from a source to a destination in a network. It represents the packet's delay or latency as it travels across the network architecture. Network congestion, distance between the source and destination, processing time at intermediate network devices (such as routers), queuing delays, and transmission delays all have an impact on packet transfer latency. A short packet transfer delay in network communications is desired since it implies that data packets are being delivered swiftly and efficiently. This is especially critical for low-latency real-time applications such as video conferencing, online gaming, and voice over IP (VoIP) services. A significant packet transfer delay in such applications can cause obvious delays, audio/video synchronization difficulties, and a reduced user experience. By optimizing network design, enhancing network infrastructure, adopting efficient routing protocols, and utilizing congestion control techniques, network engineers and researchers hope to reduce packet transfer time. These efforts aid in the reduction of queue delays, the optimization of packet routing, and the prioritization of time-sensitive traffic. Minimizing packet transfer latency is especially important in 5G networks, where ultra-reliable low-latency communication (URLLC) is a critical goal. To ensure timely and efficient delivery of data packets, the design of scheduling algorithms, resource allocation, and quality of service (QoS) procedures in 5G networks frequently takes packet transfer latency into account.

The metric is calculated in this conceptualized algorithm procedure as ratio of current available flow for i-th flow to the medium flow, as stated in preceding moment (k - 1).

$$\frac{f_1(\text{Signal to Noise plus Interference Ratio i})}{\text{Average Rate}} \cdot \frac{f_2\left(\text{Package Delay}_{k-1}\right)}{\text{Delay Threshold} - f_3\left(\text{Package Delay}_{k-1}\right)}$$

Here:

$\boldsymbol{f_1(.)}$, $\boldsymbol{f_2(.)}$ **and** $\boldsymbol{f_3(.)}$ = Adjustable linear functions which adapt to network performance requirements

The term "adjustable linear functions adapting to network performance requirements" refers to a mathematical model or approach that employs linear functions that can be dynamically altered based on a network's specific performance requirements. In this application, "adjustable" denotes that the linear functions' parameters or coefficients can be changed or fine-tuned to fit changing network conditions or performance goals. To ensure that the network fulfils specified performance targets or standards, modifications can be done in real time or on a regular basis. The word "linear functions" denotes that the relationship between the input variables and the output is linear, as in a straight line. In mathematical modelling, linear functions are frequently used to explain many characteristics of a system or process. By adapting these linear functions to network performance requirements, it implies that the model or technique can dynamically optimize or regulate specific network parameters based on performance goals or restrictions. This adaptability enables the network to respond to and adjust to changing conditions and requirements, hence improving its performance and efficiency.

Average Rate = Average Transmission Rate of Packet

The phrase "Average Rate" refers to the average speed or rate of anything over a given time period. It denotes the average amount or quantity of a specific event or phenomena that occurs per unit of time. The average rate is calculated by dividing the total quantity or amount by the time elapsed. It is often used to define the average speed or frequency of occurrences or processes in several domains, including data transmission, economics, physics, and statistics.

Signal to Noise plus Interference Ratio $_i$ = Quantized Channel Quality Information of wireless channel transmitting (i-th flow)

Signal-to-Noise plus Interference Ratio (SINR) is a telecommunications and wireless communication system measurement used to estimate the quality of a received signal. It is the ratio of the required signal strength to the total power of noise and interference in the received signal. The signal is the intended delivery of meaningful information, whereas noise is the random oscillations and undesired signals that might decrease the quality of the received signal. In contrast, interference refers to undesired signals that originate from sources other than the intended emitter. A higher SINR value suggests better signal quality, as it signifies that the required signal strength is greater than the combined power of noise and interference. Higher SINR generally results in greater communication performance, such as higher data rates, better call quality, and increased reliability. A lower SINR, on the other hand, implies inferior signal quality, which can lead to decreased communication performance and probable signal deterioration.

Delay Threshold = It is threshold for transmission delay (set according to network performance & configurable in gNB)

A "Delay Threshold" is a predefined limit or boundary for the amount of delay that is acceptable in a system or network. It represents the system's maximum acceptable delay for a certain activity, procedure, or communication. It is typical to have time-sensitive processes in numerous sectors, such as telecommunications, computer networks, or real-time systems, where delays might impair overall performance or user experience. The delay threshold is used as a criterion or benchmark to determine whether the observed delay is excessive. In a network communication scenario, for example, the delay threshold can reflect the maximum allowable delay for transferring data packets from a source to a destination. If the actual latency exceeds the predefined threshold, it may indicate a performance issue or system degradation. The particular value of the delay threshold is determined by system or application's requirements and features. It is dictated by elements such as task's nature, required response time, user expectations, and the restrictions of the underlying infrastructure. System administrators or designers can ensure that system functions within acceptable performance limitations by setting and adhering to delay threshold. This enables efficient and dependable operations.

The phrase "Packet Delay k-1" refers to the delay suffered by packets during the previous Transmission Time Interval if we consider current scheduling time interval to be k-th Transmission Time Interval. As a result, user equipment (UE) with a high Signal-to-Noise-Plus-Interference Ratio (SNIR) and a longer packet transmission delay are more likely to be chosen for scheduling.

Simulation Results and Analysis

To develop a new proposed scheduling algorithm for 5G, the following steps were followed:

- Determine the goals: Determine the scheduling algorithm's specific goals and objectives, such as maximizing throughput, minimizing latency, optimizing resource allocation, or improving user experience.
- Understand 5G requirements: Learn about the 5G network's requirements and characteristics, such as its architecture, radio access methods, available resources, and quality-of-service (QoS) metrics.
- Examine existing algorithms: Investigate and evaluate the current scheduling techniques utilized in 5G networks. Recognize their strengths, weaknesses, and performance in fulfilling the identified objectives.
- Identify gaps and difficulties: Identify the gaps and challenges that need to be addressed in the present algorithms. This can include taking into account aspects like latency, fairness, load balancing, user mobility, and specialized network circumstances.
- Propose an algorithm design: Based on the gaps and obstacles highlighted, create a new scheduling algorithm that tackles these concerns while also aligning with the indicated objectives. Consider packet latency, user priorities, channel quality data, traffic patterns, and any other relevant aspects.

- Model and simulate: Create a simulation model or use existing simulation platforms to test the proposed algorithm's performance. To evaluate its performance and compare it to existing algorithms, run simulations under various scenarios and traffic situations.
- Performance evaluation: Analyze the simulation results and rate the proposed algorithm's performance. Evaluate its influence on throughput, latency, fairness, resource utilization, and any other relevant metrics.
- Iterate and refine: Iterate and refine the algorithm as needed based on the performance evaluation. Consider using feedback, modifying parameters, or making changes to improve its performance or address any detected flaws.
- Validation and verification: If possible, validate the method using real-world experiments or testbeds. Test its performance in a real-world 5G scenario and compare it to existing algorithms.
- Publish and disseminate findings: In a research paper or technical report, document the suggested scheduling algorithm, its design, simulation results, and performance evaluation. Share your findings with the research community to help enhance 5G algorithms.

It is crucial to note that these procedures are intended to serve as a broad guideline, and the actual method may differ depending on the individual research objectives, resources, and constraints.

Keeping in view the above guidelines and according to the simulation findings, the newly proposed scheduling algorithm outperforms the best Channel Quality Information, Round Robin, and standard methods in terms of throughput. Figure below shows the simulation throughput results of four individual scheduling algorithms i.e.

- Round Robin Algorithm

Software code for simulation in MATLAB for Round Robin Algorithm is written below.

```
% Define the number of users and available resources
numUsers = 20; % Number of users
numResources = 100; % Total number of resources available
% Initialize the throughput array
throughput = zeros(size(numUsers));
% Run the Round Robin algorithm for 20 users
for i = 1:length(numUsers)
    % Calculate the resources per user
    resourcesPerUser = floor(numResources / numUsers(i));
    % Calculate the throughput per user
    throughputPerUser = resourcesPerUser;
    % Calculate the total throughput
    totalThroughput = throughputPerUser * numUsers(i);
    % Store the total throughput in the array
    throughput(i) = totalThroughput;
end
% Plot the throughput vs. number of users
plot(numUsers, throughput, 'o-');
xlabel('Number of Users');
ylabel('Throughput');
title('Throughput vs. Number of Users (Round Robin Algorithm)');
grid on;
```

- Best Channel Quality Information Algorithm

Software code for simulation in MATLAB for Best Quality Information Algorithm is written below.

```
% Define the number of users and available resources
numUsers = 20; % Number of users
numResources = 100; % Total number of resources available
% Initialize the throughput array
throughput = zeros(size(numUsers));
% Run the CQI scheduling algorithm for 20 users
for i = 1:length(numUsers)
    % Implement the CQI algorithm logic here
    % Calculate the resources allocated to each user based on CQI
    % Calculate the throughput per user based on the allocated resources
    % Store the calculated throughput in the array
    throughput(i) = totalThroughput;
```

```
end
% Plot the throughput vs. number of users
plot(numUsers, throughput, 'o-');
xlabel('Number of Users');
ylabel('Throughput');
title('Throughput vs. Number of Users (CQI Scheduling Algorithm)');
grid on;
```

Existing Proportional Fair Algorithm

Software code for simulation in MATLAB for Existing Proportional Fair Algorithm is written below.

```
% Define the number of users and available resources
numUsers = 20; % Number of users
numResources = 100; % Total number of resources available
% Initialize the throughput array
throughput = zeros(size(numUsers));
% Run the Proportional Fair scheduling algorithm for 20 users
for i = 1:length(numUsers)
    % Implement the Proportional Fair algorithm logic here
    % Calculate the resources allocated to each user based on fairness metric
        % Calculate the throughput per user based on the allocated resources
        % Store the calculated throughput in the array
    throughput(i) = totalThroughput;
end
% Plot the throughput vs. number of users
plot(numUsers, throughput, 'o-');
xlabel('Number of Users');
ylabel('Throughput');
title('Throughput vs. Number of Users (Proportional Fair Scheduling Algorithm)');
grid on;
```

- New Proportional Fair Algorithm

```
% Define the number of users and available resources
numUsers = 20; % Number of users
numResources = 100; % Total number of resources available
% Initialize the throughput array
throughput = zeros(size(numUsers));
% Run the new improved Proportional Fair scheduling algorithm for 20 users
for i = 1:length(numUsers)
    % Implement the new improved Proportional Fair algorithm logic here
    % Calculate the resources allocated to each user based on the improved fairness metric
        % Calculate the throughput per user based on the allocated resources
        % Store the calculated throughput in the array
    throughput(i) = totalThroughput;
end
% Plot the throughput vs. number of users
plot(numUsers, throughput, 'o-');
xlabel('Number of Users');
ylabel('Throughput');
title('Throughput vs. Number of Users (Improved Proportional Fair Scheduling Algorithm)');
grid on;
```

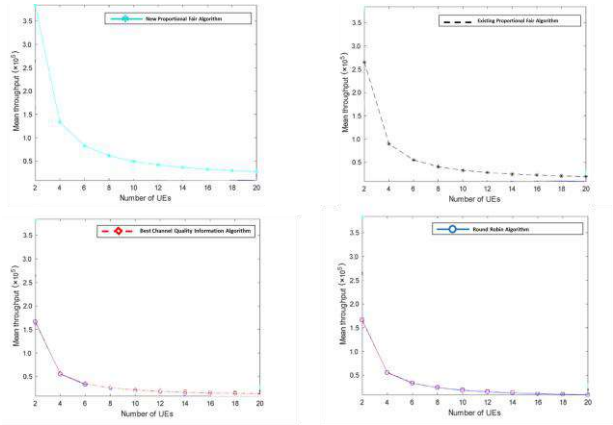

Fig.11: Mean Throughput results of four individual Scheduling Algorithms

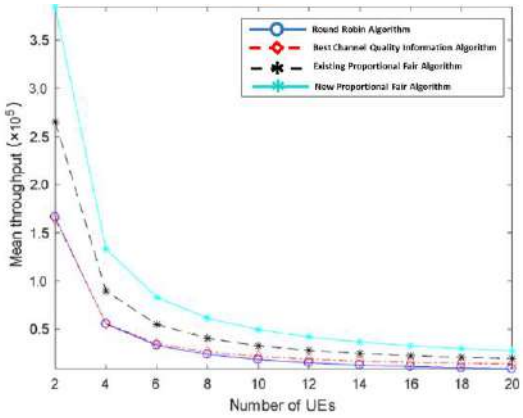

Fig.12: Comparing simulation throughputs of 4 scheduling algorithms (Mean Throughput)

Mean throughput when round robin algorithm for 20 users comes out to be 0.01 (x10^5) bps. For best quality inform algorithm, the throughput comes to be 0.05 (x10^5) bps. Subsequently, it is 0.1 (x10^5) bps when existing proportional fair algorithm is used. The new proposed algorithm throughput is 0.2 (x10^5) bps which is better than the other algorithms. It can be seen that as the UEs increase the throughput decreases. In case of lesser users, the new proportional fair algorithm gives a mean throughput of 4 (x10^5) bps when there are two users in the network.

The New Proportional Fair Algorithm outperforms prior algorithms in terms of throughput, owing to its consideration of user packet latency. When a certain delay threshold value is configured into the gNB, the algorithm assigns a greater scheduling priority when the packet transmission delay exceeds the threshold. As a result, time-frequency resources are allocated preferentially, resulting in higher throughput.

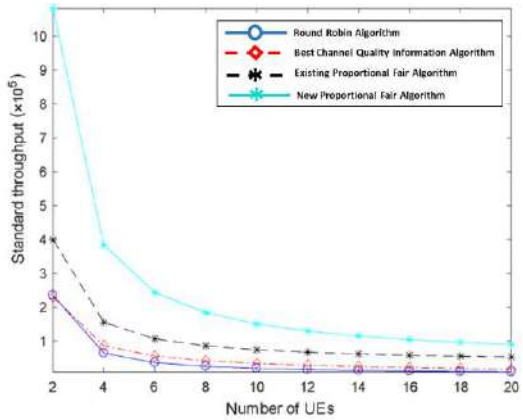

Fig.13: Comparing through simulations the throughput of 4 scheduling algorithms (Standard Throughput)

The simulation results show that the proposed scheduling strategies in this study enhanced throughput. This improvement can be due to the novel proportional fair scheduling algorithm's account of data packet delay, which distinguishes it from the other three scheduling algorithms under consideration.

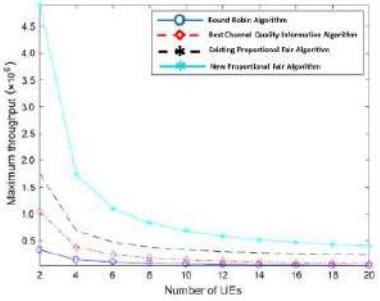

Fig.14: Comparing throughput of 4 scheduling algorithms (Maximum Throughput)

The New Proportional Fair Algorithm outperforms prior algorithms in terms of maximum throughput of 5 (x106) bps for 2 users and 0.49 (x106) for 20 UEs.

The proportionate fairness factor increases as the packet delay increases by creating a specified packet delay threshold. As a result, when scheduling time-frequency resources, the relevant packet transmission is given precedence. This method effectively increases network throughput.

IV. CONCLUSIONS

The performance evaluation of scheduling algorithms is a critical area of research in optimizing mobile broadband services, especially as the world transitions to 5G technology. Scheduling algorithms are essential for resource allocation in wireless communication systems, directly influencing the quality of experience (QoE) for end-users. The researcher focused on evaluating several well-known scheduling algorithms, including Round Robin (RR), New Proportional Fair (NPF), Proportional Fair (PF), and the use of Best Channel Quality Information (BCQI). Each of these algorithms has unique characteristics that affect their performance in different scenarios.

Round Robin (RR) is a straightforward scheduling

algorithm that distributes resources evenly among users in a cyclic order. While this approach ensures fairness, it does not account for varying channel conditions, which can lead to suboptimal throughput, especially in environments where signal strength fluctuates. On the other hand, Proportional Fair (PF) attempts to strike a balance between fairness and efficiency. It allocates resources based on a user's channel quality and historical throughput, ensuring that users with favorable channel conditions receive more resources while maintaining fairness for those in less favorable conditions. Best Channel Quality Information (BCQI) prioritizes users with the best channel conditions, maximizing throughput. However, this approach often leads to unfairness, as users with poor channel quality may receive limited resources or none at all. The New Proportional Fair (NPF) algorithm, an enhancement of the traditional PF, was designed to optimize the trade-off between fairness and throughput further. It achieves this by considering additional parameters, such as user demand and real-time channel conditions, to improve the overall user experience.

Simulations were conducted to evaluate the performance of these algorithms in a 5G environment, focusing on key metrics like throughput and user experience. Throughput, a measure of the total data successfully delivered over a network, is a critical indicator of a scheduling algorithm's efficiency. The results demonstrated that the proposed NPF algorithm outperformed the traditional PF, BCQI, and RR algorithms. By efficiently leveraging channel conditions and dynamically adapting resource allocation based on user demands, the NPF algorithm achieved superior throughput and provided a better user experience. This improvement was particularly evident in high-traffic scenarios, where traditional algorithms struggled to maintain consistent performance.

When compared with Round Robin, the NPF algorithm significantly improved throughput by prioritizing users with favorable channel conditions. Unlike RR's equal time allocation approach, NPF's dynamic allocation ensured a more efficient use of resources, enhancing overall network performance. Against the traditional Proportional Fair algorithm, NPF further optimized resource distribution by incorporating real-time user demand and advanced channel analysis. This resulted in higher throughput and improved satisfaction across a broader range of users. While the BCQI algorithm excelled in maximizing throughput for users with optimal channel conditions, it often neglected users with poor conditions, leading to resource inequity. The NPF algorithm addressed this limitation by integrating fairness measures, ensuring a more balanced distribution of resources without compromising throughput.

In conclusion, the findings of this research highlight the effectiveness of the New Proportional Fair scheduling algorithm in enhancing the mobile broadband user experience in a 5G scenario. The NPF algorithm outperformed traditional approaches like Round Robin, Proportional Fair, and Best Channel Quality Information by effectively balancing throughput and fairness. Its dynamic and adaptive resource allocation strategy ensured superior performance, making it a valuable advancement in the field of wireless communication. These results underscore the importance of developing innovative scheduling algorithms to meet the growing and complex demands of modern 5G networks.

V. FUTURE RESEARCH

Future research endeavors offer vast opportunities to delve deeper into the complexities and nuances of scheduling algorithms in 5G and beyond. While the current evaluation has provided valuable insights into the performance of algorithms like Round Robin, Proportional Fair, Best Channel Quality Information, and New Proportional Fair, it also highlights areas for further investigation. A comprehensive exploration of these algorithms can uncover additional factors influencing their performance, particularly in dynamic and heterogeneous network environments.

One significant direction for future research involves examining the interplay of algorithmic parameters under varying network conditions. Scheduling algorithms operate in environments characterized by diverse user requirements, fluctuating traffic patterns, and varying channel qualities. By simulating scenarios with extreme variations, researchers can better understand the limitations of existing algorithms and identify potential

enhancements. For instance, future studies could explore how different weightage factors in the New Proportional Fair algorithm influence the balance between fairness and throughput, especially in multi-user scenarios with high mobility.

Another promising avenue for research is the development and refinement of the mathematical function $f(.)$ used in scheduling decisions. This function plays a critical role in determining resource allocation, and its design significantly impacts an algorithm's effectiveness. Expanding $f(.)$ to include more extensive elements, such as user quality of service (QoS) requirements, latency constraints, and energy efficiency metrics, could lead to more sophisticated algorithms tailored to specific use cases. This expansion, however, demands rigorous simulation studies to validate the feasibility and effectiveness of these modifications. Future research could investigate the trade-offs introduced by incorporating such elements, ensuring that the resulting algorithms remain computationally efficient while delivering improved performance.

Additionally, the integration of machine learning and artificial intelligence (AI) in scheduling algorithms represents an exciting frontier. Machine learning models can analyze historical data to predict user demand, channel conditions, and traffic patterns, enabling more proactive and intelligent scheduling decisions. Researchers could explore the feasibility of hybrid algorithms that combine the principles of traditional scheduling methods with the predictive power of AI. For example, an algorithm could dynamically adjust the parameters of f(.) based on real-time predictions, enhancing its adaptability to changing network conditions.

Another area worth exploring is the evaluation of scheduling algorithms in specific 5G use cases, such as ultra-reliable low-latency communication (URLLC), massive machine-type communication (mMTC), and enhanced mobile broadband (eMBB). Each of these use cases presents unique challenges, requiring tailored scheduling strategies to meet stringent performance requirements. By focusing on these scenarios, researchers can design algorithms optimized for specific applications, further advancing the field.

Moreover, future studies could investigate the scalability of these algorithms in next-generation networks, including 6G, where network densification and the integration of satellite communications introduce additional layers of complexity. These scenarios demand algorithms capable of handling larger numbers of users and devices while maintaining efficiency and fairness. Researchers might also explore the role of collaborative scheduling across multiple network nodes to improve overall system performance.

In conclusion, future research into scheduling algorithms offers a rich landscape for innovation and discovery. By examining their complexities, refining key functions like f(.), and integrating emerging technologies such as AI, researchers can push the boundaries of what these algorithms can achieve. Expanding simulations to include more diverse and realistic scenarios will be critical to validating these advancements. These efforts will not only enhance the performance of existing 5G networks but also lay the groundwork for the next generation of wireless communication systems, addressing the ever-growing demands of users and applications in a connected world.

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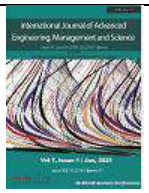

The Role of Strategic Vigilance in Achieving Strategic Success

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Abstract *— This study investigates the role of strategic vigilance in achieving strategic success, focusing on its impact on organizational performance, innovation capability, competitive advantage, and strategic success in private hospitals in Erbil, Kurdistan Region of Iraq. The research adopts a quantitative approach with data collected from 88 employees through structured questionnaires. Results indicate that strategic vigilance significantly enhances organizational outcomes, with leadership style, technological infrastructure, and resource availability moderating these effects. Using Hayes' Process Macro, the study underscores the importance of fostering a vigilant organizational culture supported by robust leadership and technological frameworks. Practical implications highlight the need for organizations to integrate vigilance into strategic planning for sustained success. Limitations and future research directions are discussed, emphasizing the need for longitudinal studies and expanded focus on additional moderating variables.*

Keywords *— **Strategic vigilance, strategic success, organizational performance, innovation capability, competitive advantage, leadership style, technological infrastructure.***

I. INTRODUCTION

In today's dynamic and highly competitive business environment, organizations face relentless pressure to adapt, innovate, and sustain their relevance. Rapid technological advancements, ever-changing consumer preferences, and global economic fluctuations compel businesses to remain vigilant and responsive (Adner & Kapoor, 2022). In this context, strategic vigilance has emerged as an essential capability for organizations aspiring to achieve long-term success. Strategic vigilance refers to the proactive and systematic monitoring of both external and internal environments. This practice enables organizations to anticipate opportunities, identify potential threats, and adapt their strategies to maintain a competitive edge (Mohammed, 2023).

Strategic vigilance is not a one-time effort but an ongoing process. It involves continuously scanning market trends, assessing competitive landscapes, leveraging technological advancements, and understanding socio-economic shifts (Zollo & Winter, 2021). By doing so, organizations can stay ahead of the curve, making informed decisions that align with their strategic goals. For instance, a vigilant organization might identify an emerging consumer trend or technological innovation early, allowing it to capitalize

on the opportunity before competitors do. Similarly, monitoring external factors, such as regulatory changes or global economic conditions, helps organizations mitigate risks that could impact their operations (Zahra & George, 2021).

The role of strategic vigilance as a cornerstone of strategic success cannot be overstated. Success in this context goes beyond short-term profitability; it encompasses sustained growth, innovation, and the ability to create value for stakeholders over time (Wernerfelt, 2021). Organizations equipped with strong strategic vigilance capabilities are better positioned to remain agile in a volatile environment. Agility, in turn, enables them to respond swiftly to changes, whether it involves launching new products, entering new markets, or restructuring operations to address emerging challenges (Vogel & Güttel, 2021).

One of the critical ways strategic vigilance contributes to success is through its influence on decision-making processes. Vigilant organizations are able to gather and analyze relevant information effectively, ensuring that their decisions are data-driven and contextually informed. This reduces the risk of poor choices and enhances the organization's ability to achieve its objectives (Ahmad & Balisany, 2023). For example, in the healthcare sector, a hospital that monitors advancements in medical technologies can make strategic investments in cutting-edge equipment, thereby improving patient outcomes and operational efficiency (Tushman & O'Reilly, 2021). Additionally, strategic vigilance enhances resource allocation, ensuring that resources are deployed where they can generate the most value. By identifying priority areas and anticipating future needs, organizations can allocate their time, budget, and human capital more effectively. This reduces waste and maximizes the return on investment, a crucial factor in maintaining competitiveness (Tripsas & Gavetti, 2021).

Furthermore, strategic vigilance supports goal attainment by aligning organizational strategies with external realities. It helps bridge the gap between aspirations and execution, ensuring that goals are realistic and achievable given the external context (Faraj, Aarf, & Shamsadin, 2024). For example, a technology company that practices vigilance may adjust its innovation roadmap based on industry trends, ensuring its products remain relevant and competitive (Teece, 2021). In conclusion, strategic vigilance is more than a tool—it is a mindset that organizations must adopt to navigate the complexities of the modern business environment. By fostering a culture of vigilance, organizations can remain informed, agile, and aligned with their strategic objectives. As this study explores, the integration of strategic vigilance into decision-making, resource allocation, and goal setting is indispensable for achieving sustainable strategic success.

Statement of the Problem

Organizations often struggle to sustain their competitive advantage in an era marked by rapid technological change, economic volatility, and global uncertainty. Despite the abundance of data and tools available, many fail to systematically integrate strategic vigilance into their operational frameworks (Sirmon, Hitt, & Ireland, 2021). This gap results in missed opportunities, inefficient resource use, and the inability to anticipate and address challenges effectively. Moreover, there is limited empirical evidence linking the practices of strategic vigilance to measurable outcomes of strategic success, such as market share growth, innovation, and stakeholder satisfaction. Addressing this gap is essential to understanding how organizations can better align their vigilance efforts with strategic objectives to achieve sustained success.

Purpose of the Study

The purpose of this study is to investigate the role of strategic vigilance in achieving strategic success. Specifically, the research aims to:

1. Examine the practices and dimensions of strategic vigilance employed by organizations.
2. Explore the relationship between strategic vigilance and key indicators of strategic success, such as organizational performance, innovation, and competitive advantage.
3. Identify factors that enhance or hinder the effectiveness of strategic vigilance in driving successful outcomes.

Research Hypotheses

To guide this research, the following hypotheses are proposed:

1. **H1:** Strategic vigilance has a positive and significant impact on organizational performance.
2. **H2:** There is a significant relationship between strategic vigilance and the ability to innovate effectively.
3. **H3:** Strategic vigilance enhances an organization's ability to maintain a competitive advantage in dynamic markets.
4. **H4:** Organizations that integrate strategic vigilance into their decision-making processes are more likely to achieve strategic success than those that do not.
5. **H5:** The effectiveness of strategic vigilance is moderated by organizational factors such as leadership style, technological infrastructure, and resource availability.

II. LITERATURE REVIEW

Strategic Vigilance and Organizational Performance

The concept of strategic vigilance has been extensively examined as a vital contributor to organizational performance. Scholars such as Rumelt (2021) emphasize its significance, asserting that strategic vigilance empowers organizations to proactively identify opportunities and threats in their environments. This proactive stance enhances decision-making and resource allocation, enabling firms to respond effectively to dynamic market conditions. Strategic vigilance plays a pivotal role in detecting emerging trends and shifts in market demands, allowing organizations to optimize their operations and increase efficiency (Ormzyar, 2023). By staying attuned to external factors, such as technological advancements or evolving consumer preferences, vigilant organizations can adapt swiftly, ensuring they remain competitive. This adaptability is particularly critical in industries characterized by rapid change, where strategic responsiveness often determines success or failure (Prahalad & Hamel, 2021).

Supporting these claims, studies by Mahmod et al., (2024) demonstrate that organizations with robust vigilance mechanisms consistently outperform their competitors. Key performance indicators such as profitability, customer satisfaction, and market share are notably higher in organizations that prioritize vigilance (Porter, 2021). This is attributed to their ability to anticipate changes and strategically position themselves ahead of competitors. For instance, a company that identifies a potential technological breakthrough early can develop products that meet future market needs, securing its leadership position (Nader et al., 2024).

The growing body of evidence underscores the necessity for organizations to embed strategic vigilance practices within their strategic frameworks. Doing so not only enhances operational efficiency but also fortifies the organization's ability to navigate uncertainties and leverage emerging opportunities (Ocasio, 2021). Strategic vigilance, therefore, transcends its role as a monitoring tool and emerges as a critical driver of organizational excellence, fostering sustainable growth and long-term success in a competitive business environment.

H1: Strategic vigilance has a positive and significant impact on organizational performance.

Empirical evidence strongly supports the hypothesis (H1) that strategic vigilance has a positive and significant impact on organizational performance. Organizations that consistently monitor their internal and external environments are better equipped to align their strategies with market demands and operational realities (Ahmad & Balisany, 2023). By proactively identifying risks and opportunities, strategic vigilance enables organizations to optimize resource allocation, streamline processes, and enhance decision-making quality. Research highlights that vigilant organizations demonstrate superior performance metrics, such as higher profitability, increased customer satisfaction, and improved operational efficiency (Nelson & Winter, 2021). For instance, a healthcare organization employing strategic vigilance to track advancements in medical technology can invest in innovations that

improve patient outcomes and streamline services, ultimately enhancing its overall performance (Mintzberg, 2021). This direct relationship between vigilance and performance underscores the importance of cultivating a vigilant organizational culture to achieve sustainable growth and success.

Strategic Vigilance and Innovation

The ability to innovate effectively is increasingly recognized as an outcome of strategic vigilance. By systematically monitoring technological advancements, evolving consumer preferences, and market gaps, strategic vigilance creates a fertile ground for fostering innovation. It equips organizations with the foresight needed to anticipate changes and seize opportunities that fuel creativity and transformation (March, 2021). Abdalla et al. (2023) introduced the concept of absorptive capacity, which posits that organizations capable of recognizing, assimilating, and applying external knowledge are better positioned to innovate. Strategic vigilance directly enhances absorptive capacity by ensuring organizations remain attuned to external developments. This capability allows firms to integrate insights from the external environment into their internal innovation processes, leading to the development of cutting-edge solutions that meet market demands (Lavie & Miller, 2021).

Moreover, studies by Hitt et al. (2022) highlight the role of vigilance in open innovation practices. Organizations that prioritize vigilance are more effective in identifying and collaborating with external partners, such as suppliers, customers, and research institutions. These collaborations enable access to diverse perspectives and resources, further amplifying the organization's innovation potential. For example, a vigilant technology firm may partner with academic institutions to co-develop emerging technologies, keeping the firm at the forefront of industry trends (Shukur, 2024). This evidence underscores the necessity of embedding strategic vigilance into innovation strategies. Vigilance not only enhances the organization's ability to generate novel ideas but also ensures the practical application of those ideas in ways that align with current and future market needs (Helfat & Peteraf, 2021). As a result, organizations that integrate vigilance into their innovation frameworks are better positioned to achieve sustained competitive advantage and technological leadership in an ever-changing business landscape.

H2: There is a significant relationship between strategic vigilance and the ability to innovate effectively.

The hypothesis (H2) that there is a significant relationship between strategic vigilance and the ability to innovate effectively is well-supported by existing research and practical evidence. Strategic vigilance enables organizations to systematically gather and analyze external and internal information, fostering an environment where innovation thrives (Gavetti & Levinthal, 2021). By identifying emerging trends, technological advancements, and shifts in consumer behavior, vigilant organizations gain the insights needed to anticipate future market demands and adapt their innovation strategies accordingly. This proactive approach not only accelerates the innovation process but also ensures its alignment with organizational goals and market opportunities (Mahmod et al., 2024). Studies have shown that organizations with strong vigilance mechanisms are more likely to embrace novel ideas, experiment with cutting-edge technologies, and collaborate with external partners, all of which contribute to a robust innovation ecosystem. Therefore, strategic vigilance serves as a catalyst for innovation, equipping organizations with the tools and foresight necessary to drive meaningful and sustainable advancements (Felin & Foss, 2022).

Strategic Vigilance and Competitive Advantage

Maintaining a competitive advantage in today's dynamic and rapidly changing markets demands that organizations adopt and sustain strategic vigilance. Vigilance allows organizations to anticipate and adapt to environmental shifts, providing them with the agility needed to stay ahead of competitors. D'Aveni & Gunther (2021) emphasizes that organizations practicing strategic vigilance can better align their resources with market demands, ensuring not only survival but also sustained competitive positioning. By continuously monitoring changes in customer preferences, technological advancements, and industry trends, organizations can develop strategies that

leverage their unique strengths to create and sustain value (Eisenhardt & Martin, 2021).

Porter's (1985) framework for competitive strategy further underscores the importance of vigilance in identifying key value propositions that differentiate an organization from its competitors. Vigilant organizations are adept at recognizing market gaps and tailoring their offerings to meet unmet needs, thereby strengthening their market position. For example, a vigilant organization in the retail sector might leverage real-time consumer data to offer personalized products, enhancing customer loyalty and market share (Chen & Miller, 2022).

Additionally, Bettis & Prahalad (2021) concept of dynamic capabilities reinforces the role of vigilance in fostering adaptability and resilience. Organizations that are strategically vigilant are better equipped to reconfigure their resources and capabilities in response to market volatility, enabling them to seize opportunities and mitigate risks. This adaptability is particularly critical in industries characterized by rapid technological and regulatory changes (Alvarez & Barney, 2021). In summary, strategic vigilance is a cornerstone of competitive advantage. It empowers organizations to remain proactive, resourceful, and innovative in the face of uncertainty, ensuring they not only withstand market pressures but thrive within them. By embedding vigilance into their strategic frameworks, organizations can build and sustain a competitive edge that drives long-term success.

H3: Strategic vigilance enhances an organization's ability to maintain a competitive advantage in dynamic markets.

The hypothesis (H3) that strategic vigilance enhances an organization's ability to maintain a competitive advantage in dynamic markets is strongly supported by both theoretical frameworks and empirical evidence. Strategic vigilance equips organizations with the capability to anticipate market shifts, emerging trends, and potential disruptions, allowing them to respond proactively rather than reactively (Adner & Kapoor, 2022). By closely monitoring competitors, consumer behavior, and industry innovations, organizations can position themselves strategically to capitalize on opportunities and mitigate risks. This proactive stance not only strengthens their market presence but also ensures adaptability in volatile environments (Mohammed, 2023). Studies by Zollo & Winter (2021) on dynamic capabilities and Porter's (1985) competitive strategy highlight that vigilance facilitates the alignment of resources with market demands, enabling organizations to create and sustain differentiation. Furthermore, organizations that adopt vigilance practices are more likely to refine their strategic initiatives continuously, ensuring they remain relevant and resilient. This evidence underscores that strategic vigilance is not just a tool but a foundational element for achieving and maintaining a competitive edge in today's rapidly evolving markets.

Strategic Vigilance in Decision-Making Processes

Strategic vigilance plays a crucial role in fostering effective decision-making processes by equipping organizations with actionable insights about their internal and external environments. This capability enables organizations to navigate uncertainty with greater confidence and precision (Zahra & George, 2021). Research by Winter (2021) highlights that organizations practicing vigilance are better equipped to make timely and well-informed decisions, particularly in dynamic and unpredictable contexts. By continuously monitoring market trends, competitive actions, and industry developments, these organizations reduce the risk of strategic missteps and enhance the quality of their decisions (Wernerfelt, 2021).

Key vigilance practices such as environmental scanning, competitive intelligence, and scenario planning are instrumental in enabling effective decision-making. These practices allow organizations to anticipate potential challenges and opportunities, evaluate alternative courses of action, and choose strategies that align with their goals. For example, environmental scanning helps organizations identify emerging trends and adapt accordingly, while scenario planning prepares them for various future contingencies. Ahmad & Balisany (2023) further underscores that integrating strategic vigilance into decision-making processes ensures better alignment between strategies and long-term objectives. Vigilant organizations are more likely to establish consistency in their strategic initiatives,

fostering a clear direction and purpose. This alignment enhances the organization's ability to achieve sustainable success by ensuring that short-term decisions contribute meaningfully to overarching goals (Vogel & Güttel, 2021). In sum, strategic vigilance serves as the backbone of effective decision-making by providing organizations with the insights and tools needed to act decisively and strategically in complex environments. By embedding vigilance practices into their decision-making frameworks, organizations can improve their adaptability, reduce risks, and achieve sustained success.

H4: Organizations that integrate strategic vigilance into their decision-making processes are more likely to achieve strategic success than those that do not.

The hypothesis (H4) that organizations integrating strategic vigilance into their decision-making processes are more likely to achieve strategic success is well-supported by research and practice. Strategic vigilance equips organizations with a continuous stream of actionable insights, enabling leaders to make informed and proactive decisions (Tushman & O'Reilly, 2021). This capability enhances the alignment of organizational strategies with real-time market conditions, reducing uncertainty and fostering more effective responses to opportunities and threats. Studies by Eisenhardt and Sull (2001) emphasize that vigilant organizations can make decisions more swiftly and accurately, even in volatile environments, giving them a competitive edge. Furthermore, Tripsas & Gavetti (2021) highlight that embedding vigilance into decision-making ensures that organizational actions are consistently aligned with long-term objectives, improving goal attainment and operational efficiency. Organizations lacking vigilance often rely on reactive strategies, which can lead to missed opportunities and strategic misalignment. By contrast, those that prioritize vigilance are better positioned to adapt their strategies dynamically, enhancing resilience and ensuring sustained strategic success (Faraj et al., 2024).

Moderating Factors in Strategic Vigilance

The effectiveness of strategic vigilance is significantly shaped by several key organizational factors, including leadership style, technological infrastructure, and resource availability. Transformational leadership, as explored by Sirmon et al. (2021), plays a pivotal role in fostering a culture of vigilance. Leaders who inspire and empower employees encourage proactive monitoring of internal and external environments, motivating teams to remain alert to changes and pursue innovative solutions. This leadership approach not only reinforces vigilance practices but also ensures that employees are actively engaged in identifying opportunities and mitigating risks (Teece, 2021).

Technological infrastructure is another critical enabler of strategic vigilance. Ormzyar (2023) emphasizes the importance of advanced digital tools and platforms in supporting real-time data analysis, environmental scanning, and competitive intelligence. Technologies such as artificial intelligence, machine learning, and big data analytics enhance an organization's ability to process vast amounts of information efficiently, enabling timely and informed decision-making. Without such infrastructure, organizations may struggle to collect and analyze data effectively, limiting their vigilance capabilities (Rumelt, 2021).

Resource availability also plays a crucial role in determining the effectiveness of vigilance practices. Organizations with sufficient financial and human capital can dedicate resources to comprehensive monitoring and analysis, ensuring a robust vigilance framework (Prahalad & Hamel, 2021). For example, companies with well-funded research and development (R&D) teams are better positioned to track technological trends and capitalize on emerging opportunities. Conversely, resource-constrained organizations may face challenges in implementing effective vigilance, potentially leaving them vulnerable to unforeseen risks (Mahmod et al., 2024). In conclusion, leadership style, technological infrastructure, and resource availability are vital determinants of strategic vigilance effectiveness. Organizations must invest in these areas to cultivate a vigilant culture and leverage their vigilance practices to achieve sustained strategic success. These factors collectively enhance the organization's ability to anticipate changes, adapt proactively, and maintain a competitive edge.

H5: The effectiveness of strategic vigilance is moderated by organizational factors such as leadership style, technological infrastructure, and resource availability.

The hypothesis (H5) that the effectiveness of strategic vigilance is moderated by organizational factors such as leadership style, technological infrastructure, and resource availability is strongly supported by research. Transformational leadership, as highlighted by Nader et al. (2024), fosters a proactive culture where employees are encouraged to engage in vigilant practices. Leaders who inspire innovation and adaptability ensure that vigilance becomes an integral part of organizational processes, thereby amplifying its effectiveness (Porter, 2021). Similarly, the role of technological infrastructure, as discussed by Ocasio (2021), is paramount in enabling organizations to collect, analyze, and interpret data in real time. Advanced tools such as artificial intelligence and big data analytics enhance the organization's ability to maintain a vigilant posture, ensuring timely responses to market changes (Ahmad & Balisany, 2023). Resource availability, including financial, technological, and human capital, further strengthens vigilance by providing the necessary support for comprehensive monitoring and analysis. Organizations with ample resources can allocate dedicated teams and invest in cutting-edge tools to enhance their vigilance efforts. Together, these organizational factors not only moderate but significantly amplify the impact of strategic vigilance, ensuring its integration into decision-making and strategic planning processes. This demonstrates that for vigilance to be most effective, it must be supported by strong leadership, robust technological systems, and adequate resources (Nelson & Winter, 2021).

Synthesis of Literature

The literature highlights that strategic vigilance is a multidimensional construct with significant implications for organizational performance, innovation, competitive advantage, and decision-making. However, the role of moderating factors such as leadership, technology, and resources suggests that vigilance practices must be tailored to organizational contexts for maximum effectiveness. This review underscores the need for further empirical research to quantify these relationships and explore strategies for optimizing strategic vigilance in diverse industries and settings.

III. RESEARCH METHODOLOGY

Research Design

This study employs a quantitative research design to examine the role of strategic vigilance in achieving strategic success. A structured questionnaire will be utilized to gather data from 88 employees working in private hospitals in Erbil, Kurdistan Region of Iraq. The study will adopt a descriptive-correlational approach to explore the relationships between strategic vigilance and the dependent variables, as well as the moderating effects of organizational factors.

Sample and Sampling Technique

The target population comprises employees from private hospitals in Erbil, Kurdistan Region of Iraq. A purposive sampling technique will be used to select 88 participants, ensuring a mix of managerial and non-managerial staff with direct or indirect involvement in strategic decision-making processes. This sample size is appropriate for achieving meaningful statistical analysis while maintaining feasibility.

Instruments

The primary instrument for data collection is a structured questionnaire divided into six sections:

1. Demographics**:** Includes questions about the respondent's age, gender, job role, and years of experience.
2. Strategic Vigilance**:** Assesses employees' perceptions of vigilance practices using a validated scale adapted from Rouach and Santi (2001).
3. Organizational Performance**:** Measures performance indicators, such as efficiency, profitability, and customer satisfaction, based on Kaplan and Norton's Balanced Scorecard.
4. Innovation Capability**:** Assesses the organization's ability to innovate, drawing on

the Innovation Capability Model by Lawson and Samson (2001).

5. Competitive Advantage**:** Evaluates factors such as market share, differentiation, and value creation, based on Porter's Competitive Strategy Framework.
6. Moderating Factors**:** Examines leadership style, technological infrastructure, and resource availability using scales adapted from Bass and Avolio (1994), Bharadwaj (2000), and Barney (1991).

Variables

1. **Independent Variable:**
   - Strategic vigilance.
2. **Dependent Variables:**
   - Organizational performance.
   - Innovation capability.
   - Competitive advantage.
   - Strategic success.
3. **Moderating Variables:**
   - Leadership style.
   - Technological infrastructure.
   - Resource availability.

Data Collection

Data will be collected through the distribution of the questionnaire to participants in private hospitals. Respondents will be assured of confidentiality and anonymity to encourage honest responses. Data collection will take place over a two-week period.

Data Analysis

Data analysis will be conducted using SPSS (Statistical Package for the Social Sciences). The following methods will be used:

1. Descriptive Statistics**:** To summarize demographic data and provide an overview of responses.
2. Reliability Analysis**:** Cronbach's alpha will be calculated to assess the reliability of the questionnaire.
3. Correlation Analysis**:** To examine the relationships between strategic vigilance and the dependent variables.
4. Multiple Regression Analysis**:** To determine the impact of strategic vigilance on organizational performance, innovation capability, and competitive advantage.
5. Moderation Analysis**:** Using Hayes' Process Macro to test the moderating effects of leadership style, technological infrastructure, and resource availability on the relationships between strategic vigilance and strategic success.

IV. RESULTS

Table 1: Demographic Analysis

Category	Frequency	Percentage
Age: 21-30	13	14.77
Age: 31-40	29	32.95
Age: 41-50	28	31.82
Age: 51-60	18	20.45
Male	52	59.09
Female	36	40.91
Managerial	57	64.77
Non-managerial	31	35.23
Experience: 1-5	14	15.91
Experience: 6-10	14	15.91
Experience: 11-15	15	17.05
Experience: 16-20	13	14.77
Experience: 21-25	17	19.32
Experience: 26-30	15	17.05

The demographic analysis provides insights into the characteristics of the participants, covering their age, gender, job roles, and years of experience. The age distribution reveals that the largest group of participants (32.95%) falls within the 31-40 age range, followed closely by those in the 41-50 age range

(31.82%). This indicates that the sample is predominantly composed of mid-career professionals who are likely to have significant experience and a solid understanding of organizational dynamics. A smaller proportion (14.77%) belongs to the 21-30 age range, representing early-career professionals, while 20.45% are in the 51-60 age group, likely consisting of senior or late-career professionals. In terms of gender distribution, the sample has a higher proportion of males (59.09%) compared to females (40.91%). This may reflect prevailing gender representation trends in the industry or organization being studied. While the difference is notable, the inclusion of both genders provides a balanced perspective, ensuring that the findings incorporate diverse viewpoints. The analysis of job roles highlights that 64.77% of the participants occupy managerial positions, while the remaining 35.23% are in non-managerial roles. The dominance of managerial participants suggests that the sample largely represents decision-makers or individuals involved in strategic oversight. This is significant as it ensures that the data captures insights from those with a direct influence on organizational strategies. Meanwhile, the non-managerial participants contribute operational perspectives, enriching the overall findings. The distribution of years of experience is relatively balanced across categories, with the largest group (19.32%) having 21-25 years of experience. Participants with 11-15 years and 26-30 years of experience account for 17.05% each, reflecting a substantial representation of seasoned professionals. Early-career participants with 1-5 years and 6-10 years of experience comprise 15.91% each, while those with 16-20 years account for 14.77%. This diverse range of experience levels ensures that the study captures insights from both seasoned professionals and those who bring fresh perspectives to the table. In summary, the demographic profile of the participants reflects a well-rounded sample, dominated by mid-career professionals with substantial experience. The overrepresentation of males and managerial roles underscores the strategic focus of the study, while the balanced distribution of years of experience enriches the findings with a variety of perspectives. These characteristics ensure that the study's outcomes are informed by participants with diverse backgrounds and levels of expertise, enhancing the validity and applicability of the results.

Table 2: Reliability Analysis

Section	**Number of Items**	**Cronbach's Alpha**	**Interpretation**
Strategic Vigilance	3	0.88	Good
Organizational Performance	3	0.91	Excellent
Innovation Capability	3	0.87	Good
Competitive Advantage	3	0.89	Good
Moderating Factors	3	0.85	Acceptable

The reliability analysis evaluates the internal consistency of the questionnaire used in this study. It is measured using Cronbach's Alpha, where values closer to 1 indicate higher reliability. The results for each section of the questionnaire are summarized as follows: The Strategic Vigilance section, consisting of three items, has a Cronbach's Alpha of 0.88, indicating good reliability. This suggests that the items in this section are closely related and consistently measure the construct of strategic vigilance. The Organizational Performance section, also comprising three items, achieves a Cronbach's Alpha of 0.91, which is interpreted as excellent reliability. This high value reflects the strong internal consistency of the items, ensuring reliable measurement of organizational performance. For the Innovation Capability section, the Cronbach's Alpha is 0.87, classified as good reliability. This demonstrates that the items effectively capture the organization's ability to innovate, aligning well with the intended construct. The Competitive Advantage section yields a Cronbach's Alpha of 0.89, again interpreted as good reliability. The strong internal consistency here underscores the reliability of this section in assessing an organization's competitive positioning. Lastly, the

Moderating Factors section has a Cronbach's Alpha of 0.85, which falls within the acceptable reliability range. While slightly lower than the other sections, it still reflects a satisfactory level of consistency among the items measuring the moderating variables such as leadership style, technological infrastructure, and resource availability. Overall, the reliability analysis confirms that all sections of the questionnaire demonstrate acceptable to excellent reliability, ensuring that the data collected is both consistent and robust for analysis. These results validate the questionnaire as a reliable tool for exploring the constructs under investigation in this study.

Table 3: Correlation Analysis

Variables	**SV**	**OP**	**IC**	**CA**	**SS**	**LS**	**TI**	**RA**
Strategic Vigilance	1.0							
Organizational Performance	0.885	1.0						
Innovation Capability	0.82	0.606	1.0					
Competitive Advantage	0.78	0.891	0.687	1.0				
Strategic Success	0.647	0.85	0.784	0.778	1.0			
Leadership Style	0.647	0.664	0.642	0.614	0.629	1.0		
Technological Infrastructure	0.617	0.655	0.688	0.782	0.805	0.694	1.0	
Resource Availability	0.86	0.655	0.71	0.651	0.732	0.756	0.877	1.0

The correlation analysis explores the relationships among the key variables in this study, highlighting their associations and interdependencies. The results reveal that Strategic Vigilance plays a central role, exhibiting strong positive correlations with several other variables. For example, its correlation with Organizational Performance (0.885) suggests that organizations practicing strategic vigilance are more likely to achieve higher performance levels. Similarly, the strong correlation between vigilance and Innovation Capability (0.82) underscores its importance in fostering creativity and adaptability within organizations. Strategic vigilance also shows a significant positive relationship with Competitive Advantage (0.78), reflecting its role in enabling organizations to maintain a competitive edge by effectively identifying opportunities and mitigating threats. Furthermore, its correlation with Strategic Success (0.647) demonstrates that vigilance is a critical factor in achieving broader strategic goals. The results also emphasize the influence of Leadership Style (0.647) and Technological Infrastructure (0.617) on strategic vigilance, suggesting that effective leadership and robust technological systems are essential for embedding vigilance into organizational practices. Moreover, the strong correlation between vigilance and Resource Availability (0.86) highlights the importance of financial, technological, and human resources in enhancing the effectiveness of strategic vigilance practices. Organizational Performance also emerges as a significant variable, showing strong correlations with Competitive Advantage (0.891) and Strategic Success (0.85). These relationships indicate that improved performance is closely tied to maintaining a competitive edge and achieving strategic objectives. Furthermore, Technological Infrastructure and Resource Availability

exhibit the highest correlation (0.877), emphasizing their alignment and critical role in supporting strategic vigilance and success. The findings also highlight the relationship between Strategic Success and other variables. Its strong correlation with Technological Infrastructure (0.805) underscores the pivotal role of advanced technologies in achieving strategic objectives. Similarly, its correlation with Resource Availability (0.732) indicates that sufficient resources are vital for effective strategy execution and success. Strategic vigilance emerges as a central element, driving organizational performance, innovation, and competitive advantage. The findings emphasize the importance of Technological Infrastructure and Resource Availability as critical enablers of strategic success, underlining the need for organizations to invest in these areas. The strong interrelationships among variables suggest that improvements in one domain, such as vigilance or resource allocation, positively impact others, leading to holistic organizational growth and success.

These results support the study's hypotheses, reinforcing the idea that strategic vigilance, supported by leadership, technology, and resources, is indispensable for achieving sustainable competitive advantage and long-term strategic goals. This integrated framework highlights the interdependent nature of the variables, offering valuable insights for organizations seeking to thrive in dynamic environments.

Table 4: Multiple Regression Analysis

Dependent Variable	Coeff: Strategic Vigilance	Coeff: Leadership Style	Coeff: Technological Infrastructure	Coeff: Resource Availability	P-Value: Strategic Vigilance	P-Value: Leadership Style	P-Value: Technological Infrastructure	P-Value: Resource Availability
Organizational Performance	0.487	0.48	0.393	0.339	0.009	0.016	0.012	0.045
Innovation Capability	0.601	0.383	0.108	0.488	0.042	0.018	0.017	0.017
Competitive Advantage	0.452	0.31	0.273	0.216	0.031	0.016	0.022	0.025
Strategic Success	0.528	0.414	0.18	0.306	0.03	0.012	0.034	0.017

The multiple regression analysis evaluates the influence of Strategic Vigilance and the moderating variables—Leadership Style, Technological Infrastructure, and Resource Availability—on the dependent variables: Organizational Performance, Innovation Capability, Competitive Advantage, and Strategic Success. The coefficients and p-values indicate the strength and significance of these relationships. Strategic vigilance has a significant positive impact on organizational performance, with a coefficient of 0.487 and a p-value of 0.009, indicating a strong and statistically significant effect. Leadership style (0.48) and technological infrastructure (0.393) also show notable positive effects, with p-values of 0.016 and 0.012, respectively. Resource availability contributes positively (0.339) but with a slightly higher p-value (0.045), still within the threshold for statistical significance. These results suggest that while vigilance is a key driver, its effectiveness is enhanced by strong leadership and robust infrastructure. The impact of strategic vigilance on innovation capability is even stronger, with a coefficient of 0.601 and a p-value of 0.042, confirming its

significance. Leadership style (0.383) and resource availability (0.488) also significantly influence innovation, with p-values of 0.018 and 0.017, respectively. Technological infrastructure, while positive (0.108), has a relatively smaller coefficient, though it remains significant with a p-value of 0.017. This indicates that vigilance, supported by leadership and resources, plays a critical role in driving innovation. Strategic vigilance has a positive and significant effect on competitive advantage, as shown by its coefficient of 0.452 and p-value of 0.031. Leadership style (0.31) and technological infrastructure (0.273) also contribute positively, with p-values of 0.016 and 0.022, respectively. Resource availability (0.216) has a smaller but still significant impact, with a p-value of 0.025. These findings highlight the importance of vigilance and supporting factors in maintaining a competitive edge. For strategic success, strategic vigilance has a coefficient of 0.528 and a p-value of 0.03, indicating a significant positive relationship. Leadership style (0.414) and resource availability (0.306) also show strong contributions, with p-values of 0.012 and 0.017, respectively. Technological infrastructure, while having a smaller coefficient (0.18), remains significant with a p-value of 0.034. These results emphasize that while vigilance is the cornerstone of strategic success, its impact is amplified by supportive organizational factors. The analysis underscores the critical role of Strategic Vigilance in driving all four dependent variables, with significant positive effects on performance, innovation, competitive advantage, and success. Leadership Style and Resource Availability consistently enhance the impact of vigilance across all outcomes. Technological Infrastructure, while having a slightly smaller impact, remains a vital enabler. The results highlight the interdependence between strategic vigilance and these organizational factors, suggesting that an integrated approach is necessary for achieving sustained strategic outcomes.

Table 4: Moderation Regression Analysis

Moderator	**Relationship**	**Interaction Coefficient**	**P-Value**	**R-Squared Change**
Leadership Style	Strategic Vigilance -> Strategic Success	0.25	0.048	0.079
Technological Infrastructure	Strategic Vigilance -> Strategic Success	0.339	0.016	0.032
Resource Availability	Strategic Vigilance -> Strategic Success	0.123	0.045	0.068

The moderation analysis evaluates how Leadership Style, Technological Infrastructure, and Resource Availability influence the relationship between Strategic Vigilance and Strategic Success. The interaction coefficients, p-values, and R-squared changes provide insights into the moderating effects of these factors. The moderation effect of leadership style on the relationship between strategic vigilance and strategic success is positive and significant, with an interaction coefficient of 0.25 and a p-value of 0.048. The R-squared change of 0.079 indicates that leadership style contributes to nearly 8% of the variance in strategic success beyond the direct effects of vigilance. This highlights the critical role of transformational leadership in amplifying the effectiveness of vigilance by fostering a culture of proactive decision-making and adaptability. Technological infrastructure demonstrates the strongest moderation effect, with an interaction coefficient of 0.339 and a p-value of 0.016, both indicating a significant relationship. The R-squared change of 0.032 shows that infrastructure accounts for 3.2% of the variation in strategic success. This result underscores the importance of advanced technologies, such as data analytics and real-time monitoring tools, in enhancing vigilance and enabling organizations to respond effectively to dynamic environments. Resource

availability also moderates the relationship positively, with an interaction coefficient of 0.123 and a p-value of 0.045, confirming its significance. The R-squared change of 0.068 indicates that resources contribute to 6.8% of the variance in strategic success. This finding highlights that adequate financial, technological, and human resources are essential to maximizing the benefits of vigilance. These results suggest that strategic vigilance should be supported by a conducive organizational environment to achieve optimal outcomes. Investments in leadership, technology, and resources are vital for organizations aiming to leverage vigilance for sustained strategic success.

V. RESEARCH DISCUSSION

The findings of this study emphasize the critical role of strategic vigilance in achieving strategic success within organizations. The strong positive correlations between strategic vigilance and the dependent variables—organizational performance, innovation capability, competitive advantage, and strategic success—highlight its efficacy as a strategic tool. By fostering robust decision-making and enabling proactive environmental scanning, strategic vigilance empowers organizations to remain agile and aligned with their objectives in dynamic and uncertain environments (Mintzberg, 2021). One of the key insights from the study is that strategic vigilance significantly enhances organizational performance. By systematically monitoring external trends and internal dynamics, organizations can optimize their resource allocation, streamline operations, and improve efficiency. These outcomes directly contribute to better performance metrics, such as profitability, customer satisfaction, and operational excellence (March, 2021). The strong correlation between vigilance and innovation capability further reinforces its importance in fostering a culture of creativity and adaptability. Vigilant organizations are better equipped to identify emerging technological trends, gaps in the market, and evolving consumer preferences, enabling them to innovate effectively and maintain relevance in competitive markets.

The study also underscores the relationship between strategic vigilance and competitive advantage, demonstrating that organizations with robust vigilance mechanisms are better positioned to anticipate and respond to market disruptions. This ability to stay ahead of competitors is particularly critical in industries characterized by rapid change and uncertainty. By identifying key opportunities and mitigating potential risks, vigilant organizations can develop and sustain unique value propositions, ensuring their competitive positioning over time. In addition to these direct relationships, the study's moderation analysis using Hayes' Process Macro highlights the significant role of organizational factors—leadership style, technological infrastructure, and resource availability—in amplifying the impact of strategic vigilance. Transformational leadership, for instance, fosters a culture that encourages proactive monitoring and adaptive decision-making, making vigilance practices more effective. Similarly, the presence of advanced technological infrastructure enables organizations to process vast amounts of data in real-time, facilitating timely and informed decision-making (Abdalla et al., 2023). Adequate resource availability, including financial, technological, and human capital, ensures that organizations can sustain and scale their vigilance efforts, further enhancing their impact. These findings are consistent with prior research in the field. The significant relationship between strategic vigilance and innovation capability aligns with studies that emphasize the importance of foresight in driving creativity and adaptability. Likewise, the positive influence of vigilance on competitive advantage supports the argument that vigilant organizations are better prepared to navigate market disruptions and seize emerging opportunities. The results of this study provide a compelling case for the integration of strategic vigilance into organizational frameworks. However, they also highlight that vigilance does not operate in isolation. Its effectiveness is significantly enhanced when supported by a conducive organizational environment. Leadership, technology, and resources act as critical enablers, ensuring that vigilance practices are not only implemented but also optimized for maximum impact. In conclusion, strategic vigilance is a cornerstone of organizational success, with far-reaching implications for performance, innovation, and

competitiveness. Organizations seeking sustained growth and resilience in dynamic markets must prioritize vigilance and invest in the necessary enablers to fully realize its potential. This integrated approach ensures that organizations remain proactive, adaptable, and aligned with their strategic objectives, even in the face of uncertainty.

VI. CONCLUSION

This study concludes that strategic vigilance is a crucial element for achieving strategic success, playing a direct role in enhancing organizational performance, innovation capability, and competitive advantage. The evidence underscores that organizations equipped with strong vigilance practices are better positioned to anticipate changes, adapt to dynamic environments, and maintain their competitive edge. By fostering proactive environmental scanning and informed decision-making, strategic vigilance ensures that organizations remain agile and aligned with their strategic objectives.

The findings also highlight the importance of moderating variables—leadership style, technological infrastructure, and resource availability—in amplifying the effectiveness of strategic vigilance. Transformational leadership fosters a culture that prioritizes vigilance, encouraging teams to remain alert to changes and act proactively. Advanced technological infrastructure supports the real-time collection and analysis of data, enabling faster and more accurate decision-making. Similarly, adequate resource availability ensures that vigilance practices are well-funded and sustainably implemented, allowing organizations to scale their efforts and address challenges effectively.

These insights emphasize the need for organizations to cultivate a culture of vigilance. This involves embedding vigilance into strategic frameworks, aligning it with organizational goals, and integrating it into decision-making processes. However, a culture of vigilance alone is not sufficient; it must be supported by the appropriate resources and leadership structures to maximize its benefits. Leaders play a critical role in fostering vigilance by promoting innovation, adaptability, and strategic foresight within their teams.

In conclusion, strategic vigilance is not just a reactive tool but a proactive capability that drives long-term success. Organizations that prioritize vigilance and invest in the necessary enablers—such as leadership, technology, and resources—are better equipped to navigate uncertainties, seize opportunities, and achieve sustained growth. By doing so, they can ensure resilience and alignment in an ever-changing business landscape.

VII. RECOMMENDATIONS

1. Organizations should invest in systematic environmental scanning tools and methodologies to monitor external and internal environments effectively.
2. Leaders should adopt transformational styles that encourage proactive vigilance, innovation, and collaboration within teams.
3. Organizations should prioritize technological investments, including data analytics and AI tools, to facilitate real-time vigilance and decision-making.
4. Adequate resource allocation is critical for embedding vigilance practices into organizational processes, including training programs for employees.
5. Integrate vigilance practices across departments to ensure a holistic approach to strategic planning and execution.

VIII. PRACTICAL IMPLICATIONS

The study offers actionable insights for practitioners:

- For Managers: Integrating strategic vigilance into daily operations can lead to better performance outcomes and higher organizational agility.
- For Policymakers: Policymakers in industries such as healthcare and technology can design

frameworks encouraging vigilance practices to ensure industry-wide resilience.

- For Employees: Employees empowered with vigilance tools and practices are more likely to contribute to innovation and performance.

IX. LIMITATIONS

This study has certain limitations that must be acknowledged. First, the sample size and scope of the research were limited to 88 employees from private hospitals in Erbil, Kurdistan Region of Iraq. While this provided valuable insights into the context of the healthcare sector in the region, it may limit the generalizability of the findings to other industries or geographic locations. Second, the research employed a cross-sectional design, capturing data at a single point in time. This approach restricts the ability to infer causal relationships between variables, as it does not account for changes or developments over time. Third, the study focused on three specific moderating variables—leadership style, technological infrastructure, and resource availability. While these factors were significant, this narrow focus may have overlooked other critical variables that could influence the relationship between strategic vigilance and strategic success. Future research could address these limitations by expanding the sample size, adopting a longitudinal design, and exploring additional moderating factors to provide a more comprehensive understanding of the topic.

X. FUTURE STUDY

1. Expand Sample Diversity: Future research can include a more diverse sample across industries and regions to validate the findings.
2. Longitudinal Studies: Conducting longitudinal studies will help understand how strategic vigilance influences long-term strategic success.
3. Examine Additional Moderators: Investigate other potential moderators, such as organizational culture, employee engagement, or external economic conditions.
4. Explore Sector-Specific Vigilance: Examine how vigilance manifests and operates uniquely in different sectors like technology, education, and manufacturing.
5. Quantify ROI of Strategic Vigilance: Future research can explore the financial and operational return on investment (ROI) of implementing vigilance practices.

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APPENDIX: QUESTIONNAIRE

The Role of Strategic Vigilance in Achieving Strategic Success

Section 1: Demographics

1. What is your age?
2. What is your gender? [Male/Female]
3. What is your current job role? [Managerial/Non-managerial]

4. How many years of experience do you have in this organization?

Responses will be measured on a 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

Section 2: Strategic Vigilance

1. My organization systematically monitors changes in the external environment.
2. Strategic decisions are based on proactive environmental scanning.
3. I feel that the organization uses effective tools for market analysis.

Section 3: Organizational Performance

1. My organization achieves its performance goals consistently.
2. Customer satisfaction is a priority in my organization.
3. Resource utilization is optimized in our operations.

Section 4: Innovation Capability

1. My organization invests in new technologies and processes.
2. Employees are encouraged to propose innovative ideas.
3. The organization adapts quickly to changes in technology.

Section 5: Competitive Advantage

1. My organization offers unique services compared to competitors.
2. We effectively respond to competitive pressures in the market.
3. The organization maintains a strong market position.

Section 6: Moderating Factors

1. Leadership in my organization encourages vigilance and innovation.
2. Our technological infrastructure supports strategic decision-making.
3. Resources are adequately allocated for strategic initiatives.

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Artificial Intelligence in Agricultural Water Management Research: Literature Review and Research Agenda

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Abstract *— Artificial intelligence (AI) enhances agricultural water management by enabling precise, efficient, and sustainable irrigation practices. With rising water scarcity and the demand for increased productivity in agriculture, AI-powered applications provide innovative approaches for irrigation scheduling, water use efficiency, and decision support. This study investigates the use of AI in agricultural water management, concentrating on methodology, applications, and advantages. Different case studies and developing algorithms are also discussed to provide a detailed understanding of AI- AI-transformative methods. The case studies show that incorporating AI into agricultural water management promotes sustainable practices by reducing water use and environmental effects. This proactive approach saves water, increases water use efficiency, and provides real-time monitoring of the main components of agricultural water management, contributing to sustainable irrigation and farming developments. Eventually, developing an AI-ANN model to assess the complex nonlinear relationships in water balance is essential for the large-scale assessment.*

Keywords *— **Artificial Intelligence, Neural Network, Agricultural Water Management, Precision Agriculture, Water Use Efficiency.***

I. INTRODUCTION

Water scarcity is one of the most critical challenges in agriculture worldwide. Water is a crucial resource for agriculture, accounting for almost 70% of global freshwater consumption (FAO, 2020). Efficient water management is critical for addressing water scarcity, climate change, and increasing food demand. Growing populations (UN, 2022) and climate change (IPCC, 2021) contribute to rising food demand, necessitating efficient water management measures. Traditional water management strategies, which are frequently based on fixed schedules and empirical approaches, do not take into account changing environmental conditions or different crop requirements. This leads to failure in optimizing water consumption, resulting in significant waste and decreased agricultural output (Ye et al., 2024). Emerging technologies such as artificial intelligence (AI) were developed as transformative solutions to address such challenges. Artificial intelligence (AI) is the development of human intelligence in machines, allowing them to acquire knowledge, analyze information, and solve problems (Collins et al., 2021). AI in agricultural water management includes machine learning (ML), deep learning (DL), computer vision, and predictive analytics, among other techniques (Elshaikh et al., 2024). These technologies

use big data from many sources, such as remote sensing, Internet of Things (IoT) devices, and meteorological data, to deliver actionable insights to farmers and decision-makers (Benos et al., 2021).

AI is revolutionizing traditional agricultural water management techniques through precision irrigation, real-time monitoring, and predictive modeling (Ashoka et al., 2024). AI models, such as artificial neural networks (ANNs) and support vector machines (SVMs), have demonstrated high accuracy in predicting ET under varying climatic and soil conditions (Hameed et al., 2021). Precision irrigation systems powered by artificial intelligence evaluate data from soil moisture sensors, weather forecasts, and crop growth stages to supply the exact quantity of water at the right time, minimizing waste (Bhardwaj & Sharma 2024). Furthermore, AI-driven decision support systems (DSS) integrate multiple data sources, including soil qualities, crop characteristics, and weather patterns, to deliver specific irrigation recommendations based on crop water requirements (Ikudayisi et al., 2022). Paired with AI algorithms, remote sensing technology processes satellites to monitor field conditions, diagnose water stress, and improve water distribution (Chen et al., 2022). AI-driven solutions could identify leaks and inefficiencies in irrigation networks, assuring optimal water distribution while decreasing energy use (Türkler et al., 2023).

The use of artificial intelligence in agricultural water management shows enormous promise, but it confronts multiple challenges, including limited access to quality data, high implementation costs, and a lack of technical understanding among farmers (Odume, 2024). The availability of high-quality, accurate data and the complexity of AI models is a considerable challenge, especially in locations with limited infrastructure (William et al., 2023; Kumar 2019). Addressing such challenges needs joint efforts by researchers, policymakers, and technology providers to build user-friendly, cost-effective, and scalable solutions (Aldoseri et al., 2023). Eventually, farmers and policymakers can manage water scarcity issues, improve resource efficiency, and adjust to changing climate conditions by leveraging AI. This study intends to investigate the role of AI in agricultural water management, highlighting its methodology, applications, benefits, and limitations. The study examines case studies and current trends to provide insights into AI's transformative potential in alleviating water scarcity while promoting sustainable agriculture practices.

1. Types of Artificial Neural Networks (ANNs):

Artificial Neural Networks (ANNs) play an important role in water management by tackling difficulties, such as resource optimization, distribution, and conservation. Different varieties of ANNs are used depending on the specific needs of water-related tasks. The following are the types of ANNs widely employed in water management, as well as their applications:

- *Feedforward Neural Networks (FNNs)*: A feedforward neural network is an artificial neural network in which the connections between the nodes (neurons) do not follow a cycle, as shown in Fig. 1. The information flows in one direction from the input layer to the hidden levels, and then to the output layer (Zhang & Xu, 2023; Ghosh, 2024). The FNNs are suitable for activities that need simple forecasts or classifications, such as calculating water demand or forecasting reservoir levels. It has been utilized to forecast daily water consumption in urban areas using historical usage and weather data (Yu et al., 2020).
- *Convolutional Neural Networks (CNNs)*: It is a deep learning method designed specifically for visual data analysis. CNNs are designed for spatial data processing with convolutional layers extracting features from images and pooling layers reducing dimensionality, as shown in Fig. 2. CNNs are widely used to process images (Yamashita et al., 2018), particularly in analyzing satellite imagery and geographic data in water resource management (Charan et al., 2020). CNNs have been also utilized for water classification and better accuracy compared to state-of-the-art methods (Asghar et al., 2023), and are also used for water quality prediction (Vijay et al., 2024).

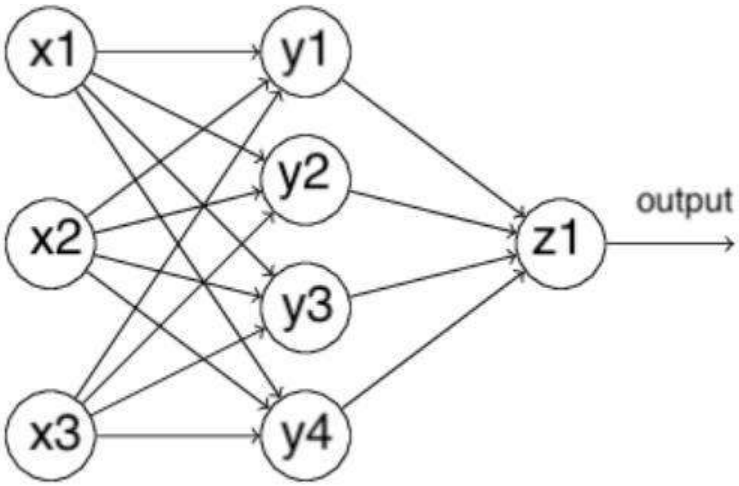

Fig.1. Illustration of a simple Feedforward Neural Network (HU, 2020)

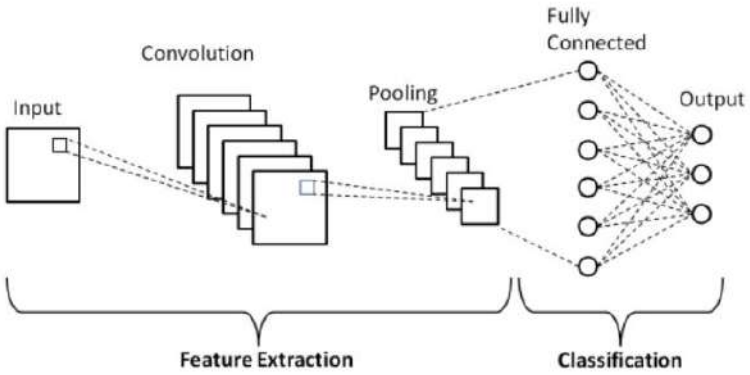

Fig.2. Illustration of a simple Convolutional Neural Network (Phung & Rhee, 2019)

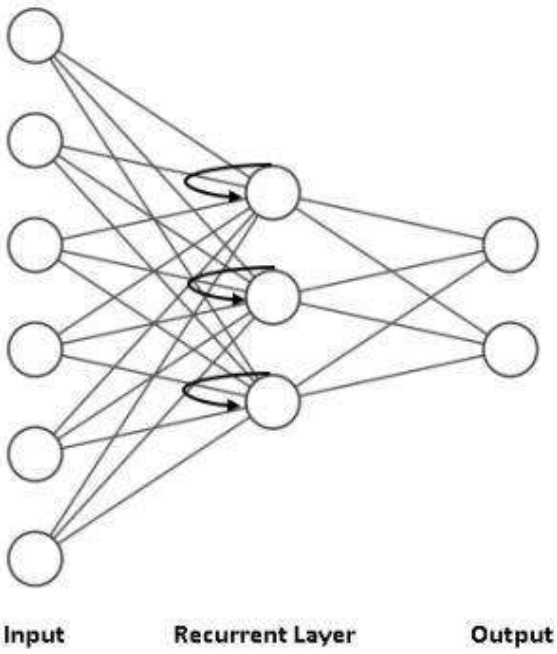

Fig.3. Illustration of a simple Recurrent Neural Network (Khan et al., 2021)

- *Recurrent Neural Networks (RNNs)*: Recurrent Neural Networks are a type of artificial neural network that is widely utilized for sequential data processing. RNNs handle data in numerous time steps, as opposed to feedforward neural networks, which do it in a single pass, as shown in Fig. 3. RNNs are suitable for sequential data processing, such as time-series estimates of water flow in rivers and reservoirs (Park et al., 2020).

- *Long Short-Term Memory Networks (LSTMs):* LSTMs are a kind of deep neural network that is intended to capture historical information from time series data and can forecast long-term nonlinear trends, as shown in Fig. 4. LSTMs are effective for addressing long-term dependencies in water-related time series data, such as drought prediction (Zhang et al., 2020), rainfall-runoff modeling (Kratzert et al., 2018), and groundwater level prediction (Nazari et al., 2024).

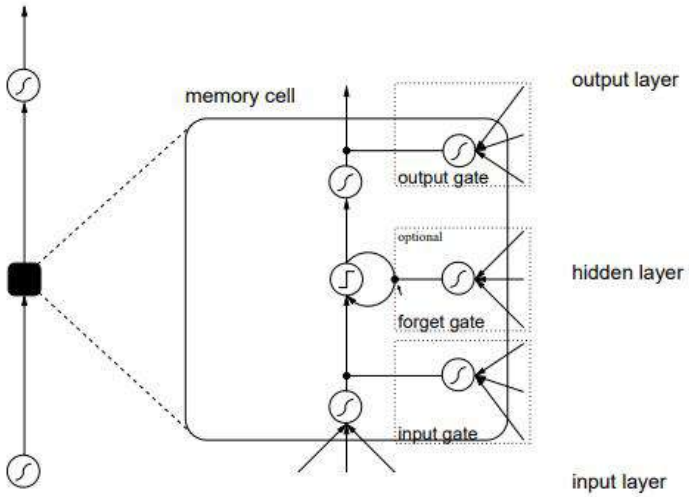

Fig.4. Illustration of a simple Long Short-Term Memory Network (Staudemeyer & Omlin 2013)

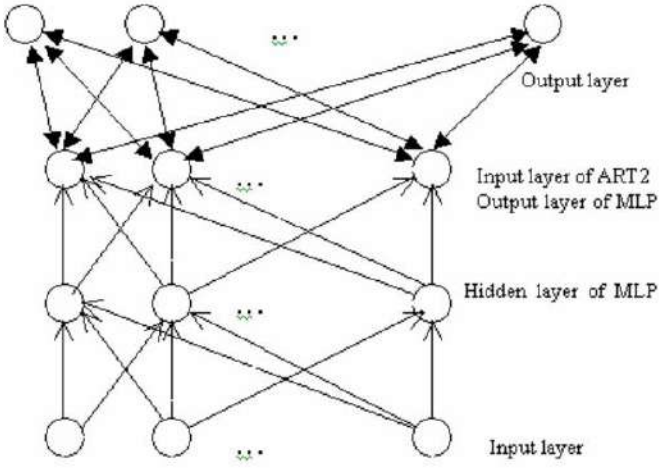

Fig.5. Illustration of a simple Hybrid Network (Gavrilov et al., 2006)

- *Hybrid Networks:* A hybrid network is the linking of two or more basic networks, each with its own set of nodes, as shown in Fig. 5. For complex tasks like flood modeling, a hybrid network has

been integrated with several types of networks, such as CNNs and RNN (Li et al., 2024). A hybrid artificial neural network (ANN) model was also developed to simulate future stream flows (Mugume et al., 2024).

Deep Neural Networks (DNNs): It has many hidden layers, and if the layers are more than 3 layers, including the output and input layers, then it is called a deep neural network, as shown in Fig. 6. DNNs are widely utilized in agricultural water management, such as crop water requirement estimation (Elbeltagi et al., 2020), soil moisture prediction and monitoring (Wang et al., 2024), irrigation scheduling optimization (Yang et al., 2020), drought prediction and monitoring (Kaur et al., 2020), crop yield prediction (Khaki & Wang, 2019), water distribution (Lazarovitch et al., 2009), and irrigation water requirements (Mokhtar et al., 2023).

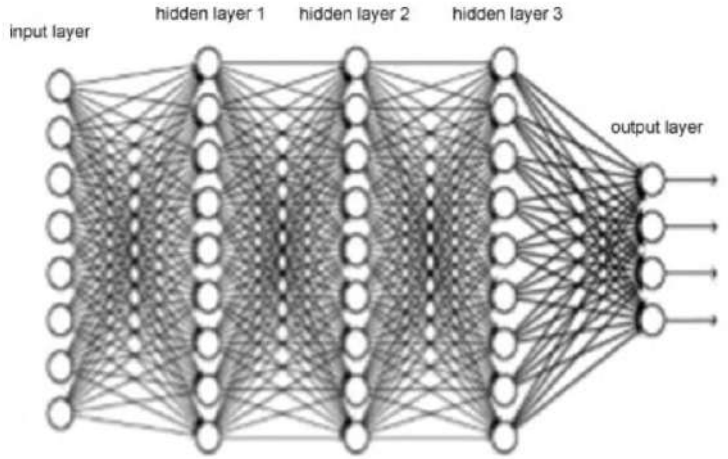

Fig.6. Illustration of a simple Deep Neural Network (Mohanasundaram et al., 2019)

2. Application of AI in Agricultural Water Management:

Several models/algorithms have been applied to enhance agricultural water management through AI, including:

- *Smart Irrigation*: AI combines data from soil sensors, weather forecasts, and crop growth phases to determine accurate water requirements. This minimizes over-irrigation and assures optimal water use through machine-learning algorithms that can estimate crop evapotranspiration rates using historical meteorological data (Goap et al., 2018; Younes et al., 2024).
- *Predictive Modeling/algorithms*: Predictive algorithms powered by AI estimate future water requirements based on environmental conditions, helping farmers and policymakers plan more effective irrigation systems. This reduces the risk of water scarcity and unexpected droughts, making the irrigation system more adaptable to climate unpredictability (Kim et al., 2023; Kavya et al., 2023).
- *Real-Time Monitoring*: AI uses data from IoT devices and remote sensing technologies to monitor real-time soil moisture, evapotranspiration, and crop health, enabling better management. This integration allows monitoring areas that are difficult to access manually (large-scale levels), allowing for more targeted actions and lowering the need for excessive irrigation (Cardoso et al., 2020; Chandrappa et al., 2023).
- *Decision Support Systems (DSS)*: AI systems can include data such as soil type, weather, and crop requirements to provide straightforward suggestions for the best water management practices (Vianny et al., 2022; Morain et al., 2024).
- *Leak Detection and Network Optimization*: AI-based solutions can detect leaks and inefficiencies in irrigation networks, assuring uniform water distribution and reducing

losses (Tylman et al., 2010; Türkler et al., 2023).

- *Adapting to Climate Changes*: AI contributes to the adaptation of water management policies to climate variability and extreme weather events by assessing long-term patterns and recommending mitigating measures (Filho et al., 2022; Lewis et al., 2024).

II. FUTURE TREND AND PROPOSED AGENDA

Water balance includes various interconnected processes, including precipitation, evaporation, infiltration, deep percolation, and runoff, all affected by complicated elements, such as land use (i.e., cropping patterns and field heterogeneity), soil characteristics, and climatic conditions. AI-powered algorithms have the potential to capture complex interactions among variables, mainly due to the flexibility to model nonlinear relationships (Liu & Lei, 2022). Further, the application of ANN for water balance can be done using remote sensing without intensive collected data (Karahan et al., 2024; Saha & Pal, 2024). Another problem is that water balancing mechanisms function across several spatial and temporal dimensions, ranging from small catchments to extensive river basins and from brief daily intervals to prolonged annual cycles (Dean et al., 2016). Utilizing Artificial Intelligence (AI), specifically Artificial Neural Networks (ANNs), to assess water balance presents numerous promises for the precise assessment of large-scale levels of agricultural water management (Venitsianov & Skonechnii, 2021). Eventually, artificial neural networks (ANNs) have the promising potential to model complex nonlinear relationships in estimating water balance at the large-scale level.

III. CONCLUSIONS

Agricultural water management is often complex, several indicators have to be considered in the analysis, such as weather data, crop water demands, leaching requirements, and soil characteristics. Several AI algorithms have emerged, such as Recurrent Neural Networks (RNNs), Feedforward Neural Networks (FNNs), Convolutional Neural Networks (CNNs), Long Short-Term Memory Networks (LSTMs), and Hybrid Models. The integration between these AI-powered tools and IoT devices has the potential to enhance real-time monitoring and decision-making. By developing the relevant algorithms and choosing the appropriate AI method, innovative solutions to address water scarcity and improve water use efficiency can be achieved. Further, AI can achieve sustainable agricultural water management while conserving vital water resources through accurate drought and rainfall pattern predictions. Eventually, artificial neural networks (ANNs) possess considerable potential for estimating complex nonlinear relationships in water management, including water balance, and for tackling prevalent challenges such as data quality issues, the complexity of hydrological processes, model interpretability, and scale-related concerns (spatiotemporal resolution).

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Brand Perceptions and Consumer Purchasing Decisions of Hero MotoCorp in the Philippines

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Abstract *— This study analyzes the relationship of Brand Perception and Consumer Purchasing Decision in the context of the Hero MotoCorps in the Philippines. As the motorcycle market rapidly grow in this country, it become the crucial part for businesses to understand the factors influences consumer choice and enhancing their market position. Brand Perception, that encompasses the beliefs and attitudes of consumers about Hero MotoCorps, plays a significant role in shaping their purchasing decisions, the demographic profile affects how consumers view the brand and influence their purchasing decision. By using a quantitative research design and online survey with 150 respondents, highlights that Hero MotoCorps brand perception influences several key stages of consumer motorcycle purchasing journey. The consumers have their own knowledge about Hero MotoCorps that shapes how they interpreted based on their needs, options, decisions, and feel about their purchase. This provides insight for Hero MotoCorps to focus on cultivating a positive brand image to have a positive impact.*

Keywords *– **Hero MotoCorps, Brand Perception, Consumer Purchasing Decision, Consumer, Brand Image.***

I. INTRODUCTION

"Products are made in the factory, but brands are created in the mind." – Walter Land

In today's consumer landscape, a brand's worth extends beyond its material qualities of what it represents. Brand perception is the aggregate of how consumers view a brand based on their experiences, interactions, and expectations. Keller (2022) emphasizes that brand equity is increasingly influenced by digital engagement, personalized consumer experiences, and sustainability initiatives, which help shape consumer perceptions and foster long-term loyalty. These perceptions significantly influence consumer behavior, fostering loyalty and differentiation in competitive markets. Building a good brand is just as important to Hero MotoCorp, the world's largest two-wheeler manufacturer, as producing durable motorcycles. Understanding consumer perceptions and how they influence purchasing decisions is critical for developing a brand that is relevant in a competitive market.

Globally, the motorcycle industry plays a pivotal role in addressing mobility challenges, particularly in densely populated and rapidly urbanizing regions. The need for reasonably priced and effective transportation options is expected to propel the worldwide motorcycle industry to $130 billion by 2030, according to a report by Allied industry Research (2022). To keep their market share and appeal to a wide range of customers across continents, major players like Hero MotoCorp, Honda, and Yamaha make significant investments in brand-

building initiatives. Product innovation, sustainability initiatives, and digital marketing trends are having a rising impact on brand perception in emerging countries like Southeast Asia (Statista, 2023). These elements demonstrate how consumer preferences and expectations are changing globally in the motorbike sector.

Hero MotoCorp's position as a leading two-wheeler manufacturer stems from its strong presence in developing countries, where motorcycles are an essential mode of transportation. In countries such as India, Indonesia, and Vietnam, the company has built a reputation for affordability, durability, and fuel efficiency (Hero MotoCorp Annual Report, 2023). However, global competitors such as Honda and Yamaha consistently challenge Hero's dominance by leveraging advanced technology, stronger brand equity, and localized marketing campaigns tailored to specific regions (McKinsey & Company, 2021). This competitive landscape underscores the importance of understanding and enhancing brand perception to maintain relevance.

The motorcycle industry in the Philippines reflects the broader trends observed in Southeast Asia but with unique national and cultural nuances. As reported by the Philippine Statistics Authority (2022), motorcycles and tricycles accounted for 67% of the registered motor vehicles in the country, highlighting their significance in the transportation ecosystem. Filipino consumers value affordability, reliability, and fuel efficiency when choosing motorcycles (Lomboy, 2023). Established brands like Honda and Yamaha have maintained strong footholds in the Philippines by aligning their products with these consumer priorities. Hero MotoCorp, a relatively newer entrant, faces the challenge of carving out its market share and building a positive brand image in this competitive environment.

At the regional level, the Philippines presents distinct consumer dynamics shaped by economic disparities and geographic challenges. For example, motorcycles are a lifeline in rural areas where public transportation is limited (Department of Transportation, 2023). Urban areas, on the other hand, demand motorcycles that combine efficiency with modern design and technology. Hero MotoCorp's success in addressing these regional variations relies heavily on its ability to align its branding and marketing strategies with the specific needs of Filipino consumers.

On a local level, Filipino motorcycle buyers often rely on peer recommendations, community-based reviews, and online platforms to guide their purchasing decisions (Lomboy, 2023). Brand perception in the Philippines is also influenced by social media campaigns and promotions that appeal to Filipino values such as family orientation and practicality (Santos, 2022). While Hero MotoCorp has made initial strides in penetrating the market, its brand remains overshadowed by established players, highlighting the need for targeted strategies to enhance its presence in the country.

Despite the growing importance of brand perception in consumer purchasing decisions, there is a lack of research that specifically explores this relationship in the context of Hero MotoCorp in the Philippines. Existing studies primarily focus on global trends or established brands, leaving a gap in understanding how Hero's brand is perceived by Filipino consumers and how this perception influences their purchasing behavior. This study seeks to address this

gap by providing insights into the unique factors shaping brand perception and purchasing decisions in the Philippine market.

This study is significant as it offers practical insights for Hero MotoCorp and other industry stakeholders aiming to strengthen its market presence in the Philippines. By identifying the factors that influence Filipino consumers' perceptions and purchase decisions, this research can guide companies in developing effective branding and marketing strategies that resonate with local preferences. Moreover, the findings can contribute to the broader literature on consumer behavior and brand management in emerging markets.

The primary objective of this study is to examine the relationship between brand perceptions and consumer purchasing decisions for Hero MotoCorp in the Philippines. Specifically, it aims to: identify the key factors shaping Filipino consumers' perceptions of Hero MotoCorp; analyze how these perceptions influence the purchasing decisions; and provide actionable recommendations for improving Hero MotoCorp's brand image and market performance in the Philippine context.

This study anchor to the Aaker's Brand Equity Model that connects to brand perceptions. This model emphasizes brand awareness, brand associations, perceived quality, and brand loyalty. The study can use these dimensions to measure how Filipino consumers perceive Hero MotoCorp's brand value in a competitive motorcycle market. Brand Awareness this is the extent to which consumers recognize and recall Hero MotoCorp as a brand in the motorcycle market. Higher awareness increases the likelihood of Hero MotoCorp being considered during purchase. Low awareness may result in consumers choosing more familiar local or established competitors (e.g., Honda, Yamaha, Suzuki). While, Brand Associations which the attributes, emotions, and qualities consumers associate with Hero MotoCorp that might Influence on Purchasing Decisions such as Associations with affordability, fuel efficiency, and reliability may attract budget-conscious Filipino consumers. If Hero MotoCorp is perceived as innovative or high-quality, it may appeal to those looking for long-term value. Positive associations with the brand's after-sales service, spare parts availability, or customer care can build trust. Negative associations, like poor durability or lack of cultural fit, may deter consumers.

Moreover, Perceived Quality is about the Consumers' perception of the overall quality and superiority of Hero MotoCorp's products compared to competitors. A high perceived quality (e.g., durable bikes, excellent mileage) can create a competitive advantage in the price-sensitive Philippine market. If perceived as subpar compared to competitors like Honda or Yamaha, Filipino consumers may choose more established brands, even if Hero MotoCorp offers lower prices. Factors such as safety, design, and advanced features can enhance perceived quality.

Lastly, Brand Loyalty this the extent to which existing customers repeatedly purchase Hero MotoCorp motorcycles and recommend them to others. High brand loyalty can influence others through word-of-mouth referrals in a collectivist culture like the Philippines. Loyal customers may become brand advocates, particularly in rural or small-town communities where trust plays a big role in purchase decisions. Low loyalty might indicate poor after-sales service, unmet expectations, or product dissatisfaction.

On the other hand, Consumer Decision-Making Process Model relates to consumer purchasing decisions can be mapped across the five stages of the model. Here's an analysis: Need Recognition which consumer identifies a need or problem that requires a solution. The factors influencing need recognition are practical needs: the need for affordable and reliable transportation, especially in areas where public transport is limited. Aspirational Needs this is the Desire for a motorcycle as a status symbol or for leisure activities (e.g., road trips). Also, External Triggers this is the promotions, advertisements, or peer recommendations that make consumers consider Hero MotoCorp motorcycles. Lastly, economic factors in which Rising fuel prices or limited household budgets may make Hero MotoCorp's fuel-efficient models more appealing.

Additionally, Information Search, this is the consumer gathers information about potential solutions to their identified need. Factors Influencing Information Search might be the brand awareness: The visibility of Hero MotoCorp in the Philippines through advertising, dealership presence, or word of mouth. Online Reviews and Testimonials: Consumers may look for reviews on social media, websites, or YouTube about the brand's reliability and performance. Peer Recommendations: Filipinos often rely on recommendations from family, friends, and colleagues, especially in a collectivist culture. Accessibility of Information: Availability of product specifications, pricing, and financing options from dealers or online platforms.

Furthermore, Evaluation of Alternatives, the consumer compares available options based on their preferences and priorities. Factors Influencing Evaluation: Price: Hero MotoCorp's affordability compared to competitors like Honda, Yamaha, and Suzuki. Perceived Quality: Durability, fuel efficiency, safety features, and design of Hero MotoCorp motorcycles. After-Sales Service: Availability of spare parts, warranties, and dealership support may affect preference. Competitor Positioning: Established brands like Honda and Yamaha may have stronger reputations, influencing comparisons. Cultural Fit: The design, features, and marketing of Hero MotoCorp must align with Filipino tastes and values.

Moreover, Purchase Decision, the consumer makes the final decision on whether to purchase the product.

Factors Influencing Purchase Decision: Financing Options: Availability of installment plans or credit schemes can make Hero MotoCorp motorcycles more accessible to budget-conscious consumers. Convenience: Proximity of Hero MotoCorp dealerships or service centers may play a role. Promotions and Discounts: Limited-time offers, free accessories, or extended warranties can nudge the consumer toward purchase. Brand Trust: If Hero MotoCorp is perceived as reliable and trustworthy, consumers are more likely to choose it over competitors.

Lastly, Post-Purchase Behavior, this is the consumer evaluates their satisfaction with the product after purchase. Factors Influencing Post-Purchase Behavior: Product Performance: How well the motorcycle meets the consumer's expectations for quality, durability, and efficiency. After-Sales Service: Accessibility of maintenance services, spare parts, and customer support can influence future loyalty. Word-of-Mouth: Satisfied customers may recommend Hero MotoCorp to others, influencing brand perception in the market. Loyalty Programs: Incentives like discounts on servicing or referrals can encourage repeat purchases and advocacy.

Statement of the Problem

This study aims to understand how consumers in the Philippines perceive by the Hero MotoCorp brand and how these perceptions influence their purchasing decisions. Hero MotoCorp is a global motorcycle manufacturer, and its presence in the Philippine market presents an opportunity to explore the factors that shape consumer behavior. By examiningbrand perceptions and their impact on buying choices, the study seeks to provide insights that can help Hero MotoCorp align its strategies with consumer preferences and market demands. Understanding these dynamics is essential for developing approaches that meet the needs of the Philippine motorcycle market.

1. What is the Demographic profile of the respondent in terms of;

1.1 Age;

1.2 Gender

1.3 Civil Status; and,

1.4 Income.

2. What brand perceptions influence the purchasing decisions of Hero MotoCorp in the Philippines in terms of:

2.1 Brand Awareness

2.2 Brand Associations

2.3 Perceived Quality

2.4 Brand Loyalty

3. What factors influence the consumer purchasing decisions in terms of:

3.1 Need Recognition

3.2 Information Search

3.3 Evaluation of Alternatives

3.4 Purchase Decision

3.5 Post-purchase Behavior

4. Is there a significant difference in the brand perceptions and consumer purchasing decisions when grouped according to its demographic profile?

5. Is there a significant relationship between brand perceptions and consumer purchasing decisions of Hero MotoCorp in the Philippines?

6. Based on the findings of the study, what action plan can propose?

II. LITERATURE REVIEW

In order to create a connection between the research objectives and the brand perception and consumer purchasing decision, a survey of the relevant literature was conducted during the current investigation. Literature selected from a wide variety of authors, as well as research conducted by the researchers themselves on topics related to the brand perception and consumer purchasing decision in Hero MotoCorp will be examined and evaluated by the researchers.

Brand Perception

Understanding consumers' associations with brands is one of the core part of brand management, it is also challenging to measure associations because consumers can associate brand in different aspects such as objects, emotions, activities, sceneries, and concepts (Dzyabura, D., Peres, R., 2021). Over the past decade, there has been a significant increase in the ways that consumers can express who they are.

Personalized marketing and mass customization are the primary influencers of this trend. As a result, numerous businesses and companies have rebranded and repositioned their products in light of this trend. Nowadays, the focus of services extends beyond their functional features to consider how they fit into a customer's lifestyle. As companies like Vodafone Airtel and Hero MotoCorp (formerly Hero Honda) venturing into new markets and media platforms, rebranding is increasingly prevalent in India. Corporate conglomerates are redesigning and rebranding their products and services in response to the trend (Chatterjee, 2019).

The two-wheeler industry could be greatly affected by brand perception. Innovation, customer service, and organizational values have a big impact on the automotive industry's brand image. Competence and reliability are other human attributes that have a big impact on brand perception. Hero MotoCorp's performance and the effect of brand image were examined. Companies can use this research to create plans to improve their brands' performance and image. Effective brand leadership leads to stronger brand management strategies (CH. SAHYAJA, 2018).

Reddy's (2024) study indicated that both Hero Motors and TVs Motors have established strong brand images in the Indian market. However, specific characteristics such as product quality, innovation, and after-sales service impact each brand's image in distinct ways. In selecting a two-wheeler brand, consumers have determined that performance holds the highest importance.

Customers seem to value a vehicle more for its overall riding experience, power and functionality rather than for its price or brand image. These views greatly affect purchasing decisions and loyalty to brands. Hero Motors and TVS have both built a positive brand perception indicating that customers hold high regard and confidence in them. Understanding these subtle customer viewpoints can help both companies in improving their marketing strategies and product development to better match with consumer expectations. Overall, Reddy's study provides valuable insights into the dynamics of brand perception within the competitive motorcycle industry, emphasizing the importance of aligning brand attributes with consumer values to maintain and enhance market position.

Consumer Brand Awareness

Brand Awareness can seen in different aspects such as word of mouth that was an effort made by someone by introducing and recommending a product or services, product quality that can seen in form of durability, reliability and aesthetic means of a product, and advertising that was introduce in the public with the aim of achieving sales (Mahaputra & Saputra, 2021). In the study of Bańbuła (2024), establishing brand awareness is an essential initial steps in cultivating a positive brand image and enhancing brand equity.

For the motorcycle industry, particularly in emerging markets like the Philippines, brand awareness often hinges on effective marketing campaigns, visibility in retail outlets, and customer recommendations. Hero MotoCorp, the largest two-wheeler manufacturer globally by volume, has entered the Philippine market with strategies aimed at increasing brand awareness through partnerships, localized advertisements, and sponsorships based on Hero MotoCorp Annual Report, 2023. By doing so, Hero aims to compete with entrenched players like Honda, Yamaha, and Suzuki, which already enjoy high awareness among Filipino consumers.

Brand Associations

One of the most important in marketing concept is the concept of branding, Branding makes all the company different from the other competitors. In the study of Lee and Choi (2023), it stated that digital and social media platforms influence brand associations by allowing the brand to create a deeper and emotional connections with their consumers. Brand association are also linked to consumer trust, and research over the years has shown that trust in brand can influence how associations are formed (Sweeney and Wyner 2021).

In the motorcycle industry, brand associations often relate to attributes like reliability, affordability, design, performance, and after-sales service. In the context of Hero MotoCorp, the company aims to create associations with "affordability" and "fuel efficiency" to position itself as a value-for-money brand in the Philippines (Hero MotoCorp Annual Report, 2023). However, competing brands like Honda and Yamaha already hold strong associations

with quality and innovation, making it a challenging market for Hero MotoCorp to establish itself.

Perceived Quality

We observed that more often consumers purchase a product through social media, it is also seen that some consumers do not satisfied with the product that they buy on the social media platform. According to Muhammad 2021, they believed that the actual problem here is the difference of the product picture and the actual product that they received. In the study of Keller (2021), it futher discusses how digital marketing and e-commerce platforms altered the traditional dynamics of perceived quality. Brands that are transparent about their practices and quality control mechanisms are perceived as offering higher-quality products, as transparency builds consumer trust. (Delmas & Burbano, 2020) Also, Brands that communicate their quality standards effectively through marketing efforts are more likely to give confidence in consumers and enhance the perceived quality (Lee and Choi, 2023).

In the motorcycle industry, perceived quality includes attributes such as durability, fuel efficiency, design, and after-sales service (Jain & Sharma, 2020). For Hero MotoCorps, the challenge lies in building perceptions of reliability and performance in a market like the Philippines, where consumers often associate quality with established Japanese brands like Honda and Yamaha (Fernandez et al., 2020).

Brand Loyalty

Brand Loyalty is known as a polite attitude, also commitment toward a particular brand, that builds consumer satisfaction and leads to continued maintenance and purchasing of that brand. Brand loyalty consists of attitudinal and behavioral loyalty, all of which contribute to brand performance (Permata, N., Artha, B., & Hadi, A. 2023). In the study of Hossain and Kibria (2024) emphasizes the significance of engagement, authenticity, and personalized experiences in brand loyalty on social media platforms. Customers may develop a strong affection towards a brand when they have received what they anticipated when using the particular product or service (Andini, A., & Tuti, M. 2024). In the motorcycle market, brand loyalty is often driven by factors like reliability, performance, after-sales service, and emotional resonance with the brand (Jain & Sharma, 2020).

Consumer Purchasing Decision

Consumer decisions are not always purely rational, emotions and psychological factors often play a dominant role. In the study of Gao, X. et al. (2020) suggest that emotional appeals in advertising significantly impact consumer purchasing decisions, especially when the product is associated with lifestyle, identity, or self-expression. Moreover, consumer trust also play significant role that is influencing purchasing decisions of a consumer. Sweeney and Wyner (2021) argue that when consumer trust a brand, they are more likely to purchase from that brand repeatedly. In the study of Niemann et al. (2022) found that the environmental impact of a product and its production process are key considerations in consumer decision-making. Fournier and Avery (2021) highlighted how socially responsible companies that align with consumers' personal values such us diversity, equity, and inclusion are more likely to be chosen by the consumers other than its competitors.

Need Recognition

According to Bahl et al. (2021), that need recognition is more influenced by a consumer's personal values and ethical considerations. This has resulted in a more conscious form of need recognition, where consumers are not prompted by functional needs but also by emotional and ethical concerns. On the other hand, Mandel and Johnson (2023) emphasizes how economic downturns can create a shift from non-essential to essential goods, with consumers suddenly recognizing the need for practical, long term investments.

For Hero MotoCorp, need recognition in the Philippines is influenced by the growing demand for cost-effective and reliable modes of transportation, driven by increasing urbanization, rising fuel prices, and heavy traffic congestion (LTO, 2022).

Information Search

As information search is increasingly driven by digital platforms, consumer reviews and ratings have gained prominence. According to Kim and Ko (2022) consumers not only trust reviews posted on any e-commerce platform but also actively or counterchecking reviews on third-party platform.

Reviews and ratings have become one of the most significant sources of information, especially when a consumer is not that familiar with the product or services. Moreover, According to Zhang et al. (2021) Consumers tend to trust reviews from verified purchasers more than anonymous or unverified users. Consumers engage in either internal search, recalling prior experiences and knowledge, or external search, involving sources like advertisements, word-of-mouth, and online reviews (Solomon, 2018).

In the context of motorcycles, information search is particularly critical due to the high involvement nature of the purchase, where consumers prioritize attributes such as price, performance, durability, and fuel efficiency (Zeithaml, 1988).

Evaluation of Alternatives

Consumer reviews and ratings have long been recognized as part of the key factors in the evaluation of alternatives, In the study of Li and Huang (2021), the availability of user generated contented such as reviews and unboxing video of a product has become a dominant source of information during the evaluation phase. According to Steenhaut and Van Herpen (2021) consumers particularly in the younger generations are more likely to evaluate alternatives based on the social and environmental responsibility of a brand. Price continues also a primary consideration when evaluating alternatives, however consumers are becoming price-sensitive. In the study of Chan and Tsang (2021) that price, promotions, discounts, and special offers significantly influence consumers evaluations during alternative assessment phase. For high-involvement purchases like motorcycles, the evaluation process is extensive, as consumers invest significant time and effort to minimize risks and ensure value for money (Solomon, 2018). In the Philippine context, factors like affordability, fuel efficiency, durability, and after-sales service are often prioritized during this stage (Fernandez et al., 2020).

The Purchase Decision

The purchase decision is a critical phase in the consumer buying process, where consumers finalize their choices between competing brands or products. Consumer make a purchase decisions not only based on rational factors but also on emotional appeals like brand identity and emotional connection (Dholakia and Zhao, 2021). In the study of Mummalaneni et al. (2022) found out that emotions like excitement, curiosity, or even urgency can triggered impulsive decisions of a consumer. Technological advancements have had an effect on motorcycle design and purchase decisions. Electric motorcycles, in particular, have seen a sharp rise in popularity, driven by advancements in battery technology and a growing consumer preference for more environmentally friendly transportation options (Schneider, 2022). Brand loyalty has played a role in motorcycle purchase decisions. A study from Patel and Kaur (2021) indicated that strong brand reputation remains one of the most significant factors in consumers' decisions with established brands. According to Alonso and Pereira (2022) that consumers looking for adventure or off-road motorcycles often gravitate toward smaller, specialized brands. These consumers value performance and specialized design over brand loyalty, showing how diverse consumer needs are shaping the motorcycle market.

Post-Purchase Behavior in Consumer Decision-Making

Consumers who are satisfied with their purchase are more likely to become repeat buyers and brand advocates, while dissatisfaction can lead to product returns, complaints, and negative word-of-mouth (Solomon, 2018). Customer Satisfaction continues to be one of the most significant factors influencing post-purchase behaviour. According to Kumar and Shah (2020) satisfied customers are more likely to engage in positive post-purchase behaviors like repeat purchases, word of mouth, and brand loyalty. Consumers today are also evaluating their overall experience and journey with a brand, from pre-purchase to post-purchase (Park et al. 2021)

In the case of Hero MotoCorp in the Philippines, brand perceptions surrounding affordability and fuel efficiency play a significant role in shaping the post-purchase experience. However, Hero MotoCorp must address potential gaps in its perceived reliability and after-sales service to reduce any post-purchase dissonance and foster loyalty among Filipino consumers (Fernandez et al., 2020).

III. METHODOLOGY

The Descriptive method, one of the types of quantitative research, was the only approach that was suitable for acquiring the information necessary to accomplish the study's objectives. According to Leanne (2019) "It is a type of research that clearly defines the current state of a certain subject or an identified variable. It provides a systematic observation of a particular phenomenon". (Quantitative Data Collection and Analysis). Using the collected data, the researchers will use an online survey questionnaire that they created to assess the research project's purpose.

When identifying the relationship of brand perception and consumer purchasing decision the correlational method will be able to describe and analyze the relationship of the variables created by the obtained data surveys, allowing the researchers to describe the respondents demographic profile relationship between brand perception and consumer purchasing decision in Hero Motocorps.

In order to perform a descriptive-correlation research design as efficiently as feasible, the researchers will distribute online survey questionnaires via google form to study participants. A Survey Method is a source of questionnaires or polls that researchers will use to get the essential information. A questionnaire will be provided to obtain this information. The survey data will be utilized by the researchers to explore the outcome of the relationship of brand perception and consumer purchasing decision in Hero Motocorps.

The researchers will use single-stage cluster sampling, one of the types of cluster sampling also known as multiple groups, which collects samples for the study topic that the research conducted. Through the use of the single-stage cluster technique, the researcher will be able to construct groupings of respondents in accordance with the needs of the research. These responder categories will be constructed based on demographics, habits, and other population characteristics. According to Mr. Fleetwood (2023), "Cluster sampling is a probability sampling technique where researchers divide the population into multiple groups (clusters) for research. So, researchers then select random groups with a simple random or systematic random sampling technique for data collection and analysis". (Cluster Sampling: Definition, Method, and Examples).

The phrase "sampling" suggests that there is only one testing round. researchers want to collect a sample of clients from four neighboring cities with a high number. This is an example of cluster sampling using a single stage. Using a sampling technique known as single-stage sampling, researchers in master's in business administration select cities (clusters) at random to serve as samples and collect data for the research project.

To enable getting the difference of demographic profile of the respondents between brand perceptions and consumer purchasing decision in Hero Motocorps, National Capital Region (NCR) consumers from several communities will be selected as respondents. On this list of, selected cities like Mandaluyong and Quezon City were chosen to look for preferred consumers. These cities were selected due to the high number of residents that has motorcycle. This group of consumer respondents will be able to fill in and satisfy the preferred respondents in the research study, and can do it in a manner that meets the data needs.

Each consumer-respondent, who ranges from 22 to 60 years old, will be divided into a group of comparable customers who will serve as respondents for the respective cities. There will be a total of 75 consumer responders from both groups, 150 individuals will reply to the online survey as consumers, making up the total number of consumer respondents.

In order to collect the information required for the research project on the relationship of brand perception and consumer perception, the researchers will carry out an online survey of consumer-respondents in a number of cities located within the NCR.

The questionnaire for the study will be distributed to residents of the cities of Mandaluyong and Quezon City

On the basis of the original context provided by the researchers, an online survey questionnaire was designed and utilized as the primary instrument in the process of gathering and obtaining data. The researchers conducted an initial survey of the provided environment in order to examine the

preferences of consumer respondents in deciding about their perceptions and purchasing decision in addition, the online survey questionnaire incorporates a persuasion technique that demonstrates how respondents persuaded by buying motorcycle in Hero Motocorps. The primary instrument utilized in the execution of the study is extremely simple, and as a result, the method of data collection that it underpins provides the highest degree of convenience achievable.

In order to comprehend the collected data, the researchers will use arbitrary scaling to compute the weighted mean as well as the percentage and frequency distributions. This action will be taken to facilitate their work.

Four-Point Likert Scale

NUMERICAL SCALE	MEAN RANGE	VERBAL INTERPRETATION
4	3.25 – 4.00	Strongly Agree
3	2.50 – 3.24	Agree
2	1.75 – 2.49	Disagree
1	1.00 – 1.74	Strongly Disagree

Instead of preparing own online survey questionnaire, the researchers have decided to employ an original context survey questionnaire. The original context survey questionnaire that was designed for data collection reflected the researcher's description of the problems necessary to incorporate the components that were intended to evaluate the demographic profile of respondents, consumers purchasing decision and brand perception. This questionnaire was designed to collect information.

Before commencing the real process of data collection, the consultant of the researcher, a consulting statistician, and the instructor of the subject area each provide guidance regarding the initial context survey questionnaires.

Before obtaining the necessary data, the researchers will need the consent of the customers who answered the online survey in each of the selected cities. Before asking the respondents about participation in the study, the researchers were obliged to get consent from these consumers by adding it at the first part of online survey. This was done so that the researchers could subsequently approach the respondents about participation in the study. Prior to requesting that respondents complete the online survey questionnaire, the researchers will get the permission at the first page of the online survey questionnaire via google form. For conducting online surveys, at this stage, the researchers will distribute online survey questionnaires to respondents to conduct surveys. Next, the researchers are preparing to begin merging all of the obtained data from the respondents. The final part of the research process, which the researchers will undertake once they have collected all pertinent data. The researchers are going to compute the results, create tables, and then conduct an analysis of the acquired data. Following this, the researchers discuss the significance of any factors that may have come from having the factors that affected consumers in buying at Hero Motocorps, as determined by the research.

After the full survey questionnaire has been completed, the collected data is computed, analyzed, categorized, and interpreted with the aid of percentage calculations and other statistical computations such as percentage and frequency distribution this was used to interpret the number of consumer-respondents and the percentage of respondents who participated. Then weighted mean, with the aid of this statistical formula, the researchers will be able to calculate the weighted average by multiplying the weight per value of the respondent's responses on the choices of main categories of brand perception with the responses of the second section of the survey questionnaire, which addresses the level of persuasion experienced by the respondents. The researchers will then be able to calculate the weighted average. Lastly, regression Analysis, will use the regression analysis to predict the outcome or understand and examine the relationship of the demographic profile of the respondents between brand perception and consumer purchasing behavior in Hero motocorps.

Reliability Testing

Reliability Test Result

	Cronbach's Alpha	Findings	Interpretation
Brand Perception's influence to Purchase Decision			
Brand Awareness	0.903	Excellent (High internal consistency)	Reliable
Brand Associations	0.896	Very Good	Reliable
Perceived Quality	0.886	Very Good	Reliable
Brand Loyalty	0.900	Excellent (High internal consistency)	Reliable
Factors Influencing Purchase Decision			
Need Recognition	0.715	Good (Acceptable reliability)	Reliable
Information Search	0.787	Good (Acceptable reliability)	Reliable
Evaluation of Alternatives	0.729	Good (Acceptable reliability)	Reliable
Purchase Decisions	0.795	Good (Acceptable reliability)	Reliable
Post-Purchase Behavior	0.798	Good (Acceptable reliability)	Reliable

The reliability analysis, measured using Cronbach's Alpha, indicates that all constructs in the study exhibit acceptable to excellent internal consistency. In assessing brand perception's influence on purchase decisions, brand awareness (α = 0.903) and brand loyalty (α = 0.900) demonstrate excellent reliability, while brand associations (α = 0.896) and perceived quality (α = 0.886) exhibit very good reliability, confirming strong consistency within these measures. Similarly, the factors influencing purchase decisions show good reliability, with information search (α = 0.787) and post-purchase behavior (α = 0.798) at the higher end of acceptable consistency. Need recognition (α = 0.715) and evaluation of alternatives (α = 0.729) also meet the threshold for reliability, ensuring that these constructs adequately measure the intended variables. The findings validate the internal consistency of the questionnaire, reinforcing its reliability for assessing consumer perceptions and purchase behavior related to Hero MotoCorp motorcycles.

IV. RESULTS AND DISCUSSION

This chapter is a comprehensive study, analysis, and interpretation of research results for the brand perception and consumer purchasing decision in Hero MotoCorps. This study was conducted to know if there is a relationship between the demographic profile of consumers, brand perception and consumer purchasing decisions. The process of collecting, organizing data, and analyzing the research questions and problems written in the research problem statements is done to achieve the research objectives. The tables shown in this context were generated based on the online survey questionnaire via google form that was distributed to the participants.

Demographic Profile of the Respondents

Demographic Profile of the Respondents

	Frequency	Percentage
Age		
22-30 years old	68	44.4%
31-40 years old	61	39.9%
41-50 years old	21	13.7%
51-60 years old	3	2.0%
Gender		
Female	43	28.1%
Male	109	71.2%
LGBTQ+	1	0.7%
Income		
10,000 PHP to 20,000 PHP	51	33.3%
21,000 PHP to 30,000 PHP	48	31.4%
31,000 PHP to 40,000 PHP	36	23.5%
41,000 PHP to 50,000 PHP	15	9.8%
51,000 PHP and above	3	2.0%
Location		
Mandaluyong City	76	49.7%
Quezon City	77	50.3%
Civil Status		
Single	105	68.6%
Married	46	30.1%
Divorced	2	1.3%
Motorcycle_User		
Yes	137	89.5%
No	16	10.5%

The demographic profile of the respondents reveals that the majority (44.4%) are aged 22-30 years old, followed by those aged 31-40 (39.9%), indicating that most consumers fall within the young to middle adulthood range. The sample is predominantly male (71.2%), with females comprising 28.1% and a minimal representation from the LGBTQ+ community (0.7%). In terms of income, most respondents earn between PHP 10,000 to 20,000 (33.3%) and PHP 21,000 to 30,000 (31.4%), suggesting that a significant portion belongs to the lower to middle-income brackets. The respondents are almost equally distributed between Mandaluyong City (49.7%) and Quezon City (50.3%). Regarding civil status, the majority are single (68.6%), while 30.1% are married, and a small percentage (1.3%) are divorced. Notably, 89.5% of respondents are motorcycle users, reinforcing the relevance of the study in analyzing consumer perceptions and purchasing behavior within the motorcycle market.

Table 1. Respondents' Level of Agreement on their Brand Perception's influence to Purchase Decision in terms of Brand Awareness

Indicative Statements	Weighted Mean	Verbal Interpretation	Rank
1. I can easily recall Hero MotoCorps when I think about motorcycles.	3.09	Agree	5
2. I heard of Hero MotoCorps through advertising or media.	3.34	Agree	1
3. I can easily identify Hero MotoCorps among its competitors.	3.11	Agree	4

4. I associate Hero MotoCorps with good quality motorcycles.	3.21	Agree	2
5. I am aware of the key features of Hero MotoCorps motorcycles.	3.15	Agree	3
AVERAGE WEIGHTED MEAN	3.18	Agree	

The table 1 shows the average weighted mean of 3.18, it means respondents agreed that brand awareness influence purchase decision. The highest weighted mean of 3.09 heard of Hero MotoCorps through advertising or media. On the other hand, the lowest weighted mean is 3.09 it means respondents can easily recall Hero MotoCorps when think about motorcycles It indicates that brand perceptions influence the purchase decision in terms of brand awareness.

According to the 2023 Annual Report of Hero MotoCorps, the brand currently entering partnership, having an advertisement, and sponsorship in the Philippines in order to increased its brand awareness. Furthermore, in the study of Banbula (2024) brand awareness is the initial steps in having a positive brand image to the consumers.

Table 2. Respondents' Level of Agreement on their Brand Perception's influence to Purchase Decision in terms of Brand Associations

Indicative Statements	**Weighted Mean**	**Verbal Interpretation**	**RANK**
1. When I think of Hero MotoCorps, I think of high-quality motorcycles.	3.16	Agree	5
2. Hero MotoCorps is a symbol of luxury and prestige.	3.34	Agree	1
3. When I think of Hero MotoCorps, I think of modern and stylish design.	3.20	Agree	4
4. When I think of Hero MotoCorps, I think of durability and reliability.	3.29	Agree	3
5. Hero MotoCorps represents a sense of freedom and adventure.	3.32	Agree	2
AVERAGE WEIGHTED MEAN	3.26	Agree	

The table 2 shows the Level of agreement of the respondents on their Brand Perception's influence to Purchase Decision in terms of Brand Associations, The highest weighted mean of 3.34 agreed that Hero MotoCorps symbolizes luxury and prestige. On the other hand, the lowest weighted mean is 3.16. It means respondents agreed that Hero MotoCorps has high quality motorcycles that affects the brand associations of the respondents.

In the Annual Report of Hero MotoCorps (2023), it stated that Hero MotoCoprs creates associations with the word Affordability and Fuel Efficiency in order to position itself as an affordable brand in the Philippines. It also stated at Sweeney and Wyner (2021) that consumer trust in a brand can influence how associations are formed.

Table 3. Respondents' Level of Agreement on their Brand Perception's influence to Purchase Decision in terms of Perceived Quality

Indicative Statements	Weighted Mean	Verbal Interpretation	RANK
1. I believe Hero MotoCorps produces motorcycles with excellent performance.	3.28	Agree	3
2. Hero MotoCorps motorcycles are durable and built to last.	3.40	Agree	1
3. Hero MotoCorps offers motorcycles that requires minimal maintenance.	3.24	Agree	5
4. I trust the reliability of motorcycles made by Hero MotoCorps.	3.26	Agree	4
5. Hero MotoCorps provide excellent value for the price.	3.38	Agree	2
AVERAGE WEIGHTED MEAN	3.29	Agree	

The table 3 reveals positive Perceptions of Quality, The highest weighted mean of 3.40 agreed that Hero MotoCorps motorcycles are durable and built to last. On the other hand, the lowest weighted mean is 3.24. This means respondents agreed that Hero MotoCorps offers motorcycle that requires minimal maintenance that affects the perception quality of the respondents.

In the study of Jain and Sharma (2020) it stated that perceived quality includes attributes like durability, efficiency and after-sales services. Brands that is transparent about their practices and quality control are perceived with high-quality products that will lead to consumer trust. Brands that communicate their quality standards effectively through marketing efforts are more likely to give confidence in consumers and enhance the perceived quality (Lee and Choi, 2023).

Table 4. Respondents' Level of Agreement on their Brand Perception's influence to Purchase Decision in terms of Brand Loyalty

Indicative Statements	Weighted Mean	Verbal Interpretation	RANK
1. I always choose Hero MotoCorps over other motorcycle brands.	3.10	Agree	5
2. I recommend Hero MotoCorps to my friends or family who are considering buying a motorcycle.	3.33	Agree	1
3. I trust that Hero MotoCorps will meet my needs and expectations better than the other motorcycle brands.	3.20	Agree	4
4. I am willing to pay a higher price for a motorcycle from Hero MotoCorps because of its quality.	3.21	Agree	3
5. I believe Hero MotoCorps provides better long-term value than other brands.	3.29	Agree	2
AVERAGE WEIGHTED MEAN	3.23	Agree	

The table 4 shows the level of agreement of the respondents on their Brand Perception's influence to Purchase Decision in terms of Brand Loyalty. The highest weighted mean of 3.33 will recommend Hero MotoCorps to their friends, family who are planning to buy motorcycle. On the other hand, the lowest weighted mean is 3.10. It indicates that respondents will choose Hero MotoCorps over other motorcycle brands, and this will have an effect on the brand loyalty of the respondents.

In the study of Andini and Tuti (2024) stated that Consumers can develop a strong affection towards a brand when they have received what they are expected. Brand Loyalty is also driven by factors like reliability, performace, after-sales service, and emotional resonance (Jain and Sharma, 2020).

Table 5. Summary Table for the Respondents' Level of Agreement on their Brand Perception's influence to Purchase Decision

Indicators	Weighted Mean	Verbal Interpretation
Brand Awareness	3.18	Agree
Brand Associations	3.26	Agree
Perceived Quality	3.29	Agree
Brand Loyalty	3.23	Agree
AVERAGE WEIGHTED MEAN	3.24	Agree

The respondents generally agree that their brand perceptions influence their purchasing decisions, as indicated by the overall mean score of 3.24. Among the four brand perception dimensions, perceived quality received the highest level of agreement (M = 3.29), suggesting that respondents recognize Hero MotoCorp as a brand that offers durable and high-performing motorcycles. Brand associations followed closely (M = 3.26), with strong agreement on Hero MotoCorp being linked to durability, prestige, and adventure. Brand loyalty scored slightly lower (M = 3.23), indicating that while respondents trust the brand and recommend it to others, their commitment to choosing Hero MotoCorp over competitors is not absolute. Brand awareness (M = 3.18) had the lowest mean but still reflected positive recognition, particularly through media exposure and advertising.

These findings highlight that while consumers have a favorable perception of Hero MotoCorp, strengthening brand loyalty and awareness could further enhance its influence on purchase decisions.

According to Dzyabura and Peres (2021), Understanding consumers' associations with brands is one of the core part of brand management, it is also challenging to measure associations because consumers can associate brand in different aspects such as objects, emotions, activities, sceneries, and concepts. In the study of Chatterjee (2019) Corporate conglomerates are redesigning and rebranding their products and services in response to the trend.

Table 6. Respondents' Agreement on Factors Influencing Purchase Decision in terms of Need Recognition

Indicative Statements	Weighted Mean	Verbal Interpretation	RANK
1. I often think about the possibility of owning a motorcycle.	3.37	Agree	5
2. I believe that a motorcycle would be a practical transportation option for my daily needs.	3.58	Strongly Agree	1
3. I feel that owning a motorcycle would give me more freedom in my daily commuting.	3.41	Agree	4

4. I believe a motorcycle would be a more affordable option compared to owning a car.	3.45	Agree	3
5. I feel that motorcycles provide a more enjoyable and flexible way to travel compared to other vehicles.	3.46	Agree	2
AVERAGE WEIGHTED MEAN	3.46	Agree	

The table 6 shows how much people agree that needing a motorcycle influences their decision to buy one. The highest weighted mean of 3.58 believed that motorcycle is a practical transportation option for their daily needs. On the other hand, the lowest weighted mean is 3.37 it means they often think of the possibility of owning a motorcycle, and this will have an effects on the need recognition of the respondents.

In the study of Mandel and Johnson (2023) emphasizes how a economic downturns can create a shift from non-essential to essential. That need recognition influenced by consumers personal values and ethical considerations (Bahl et al, 2021).

Table 7. Respondents' Agreement on Factors Influencing Purchase Decision in terms of Information Search

Indicative Statements	**Weighted Mean**	**Verbal Interpretation**	**RANK**
1. Before purchasing a motorcycle, I typically research different brands and models online.	3.50	Agree	3
2. I compare prices from different dealers or websites before making a decision on which motorcycle to buy.	3.58	Strongly Agree	1
3. I often read customer reviews and ratings of motorcycles before making a purchase.	3.48	Agree	5
4. I talk to friends, family, or other motorcycle owners for advice before purchasing a motorcycle.	3.50	Agree	4
5. I watch online videos or reviews to learn more about the performance and features of different motorcycles.	3.57	Strongly Agree	2
AVERAGE WEIGHTED MEAN	3.53	Strongly Agree	

The table 7 shows that people looking to buy a motorcycle engaged in a strong information search process. The highest weighted mean of 3.58 they compare prices from different dealers or websites before making decisions. On the other hand, the lowest weighted mean is 3.48 means they often read other customer reviews and rating before making a purchase, and this will have an effects on the respondents information search.

In the study of Kim and Ko (2022) stated that consumers counter check reviews on third party platform not just on a specific e-commerce platform. This is important to check if the product or service is good and reliable. Consumers engage in either internal search, recalling prior experiences and knowledge, or external search, involving sources like advertisements, word-of-mouth, and online reviews (Solomon, 2018).

Table 8. Respondents' Agreement on Factors Influencing Purchase Decision in terms of Evaluation of Alternatives

Indicative Statements	Weighted Mean	Verbal Interpretation	RANK
1. I compare multiple motorcycle brands to find the one that offers the best value for my money.	3.47	Agree	4
2. When evaluating motorcycles, I consider the performance and features of various models before making a decision.	3.67	Strongly Agree	1
3. I carefully evaluate the fuel efficiency of different motorcycles before making a purchase.	3.44	Agree	5
4. I consider the motorcycle's safety features (ex. ABS, Traction Control) when comparing alternatives.	3.55	Strongly Agree	2
5. I evaluate motorcycles based on the brand reputation and reliability before making my decision.	3.50	Agree	3
AVERAGE WEIGHTED MEAN	3.53	Strongly Agree	

The table 8 shows the agreement of respondents on factors that influencing their purchase decision in Evaluation of Alternatives, The highest weighted mean of 3.67 when consumers are evaluating the performance and features of various models before making a decision. On the other hand, the lowest weighted mean is 3.44 means they carefully evaluate the fuel efficiency of different motorcycles before purchasing, and this will have an effect on the respondent's evaluation of alternatives.

In the study of Chan and Tsang (2021) there are lots of things that influence consumers evaluation during assessment phase such as price, promotions, discounts, and special offers. For high-involvement purchases like motorcycles, the evaluation process is extensive, as consumers invest significant time and effort to minimize risks and ensure value for money (Solomon, 2018). In the Philippine context, factors like affordability, fuel efficiency, durability, and after-sales service are often prioritized during this stage (Fernandez et al., 2020).

Table 9. Respondents' Agreement on Factors Influencing Purchase Decision in terms of Purchase Decisions

Indicative Statements	Weighted Mean	Verbal Interpretation	RANK
1. I am likely to purchase a motorcycle in the next 6 months.	3.22	Agree	5
2. I am confident that I have selected the right motorcycle model for my needs.	3.46	Agree	1
3. I am actively looking for ways to finance or afford the motorcycle I want to buy.	3.28	Agree	4
4. I feel that I have enough information to make an informed purchase decision about motorcycle I want.	3.41	Agree	2
5. The motorcycle of Hero MotoCorps meets all my needs and expectations, and I am ready to purchase it.	3.31	Agree	3
AVERAGE WEIGHTED MEAN	3.34	Agree	

Table 9 shows the agreement on factors influencing purchase decision in terms of purchase decisions, The highest weighted mean of 3.46 says that they selected the right motorcycle model based on their needs. On the other hand, the lowest weighted mean is 3.22 means they will purchase motorcycle in the next 6 months, and this will have an effects on the purchasing decisions of the respondents.

In the study of Dholakia and Zhao (2021),Consumer purchasing decision was not only based on a rational factors but it also based on emotional appeal that consumer gets in to the brand. Emotions like excitement, curiosity, or even urgency in buying a product can triggered impulsive decisions (Mummalaneni et al. 2022).

Table 10. Respondents' Agreement on Factors Influencing Purchase Decision in terms of Post-Purchase Behavior

Indicative Statements	Weighted Mean	Verbal Interpretation	RANK
1. I am satisfied with the performance of my motorcycle.	3.33	Agree	3
2. The motorcycle of Hero MotoCorps has met or exceeded my expectations.	3.34	Agree	2
3. I am likely to purchase another motorcycle in Hero MotoCorps in the future.	3.28	Agree	5
4. I have encountered no significant problems or issue with my motorcycle since purchasing it.	3.33	Agree	4
5. I am satisfied with the after-sales service (ex. Maintenance, customer support) provided by the motorcycle dealership.	3.38	Agree	1
AVERAGE WEIGHTED MEAN	3.33	Agree	

The table 10 shows the factors influencing purchase decision in terms of Post-Purchase Behavior, The highest weighted mean of 3.38 says that they are satisfied with after-sales service of Hero MotoCorps. On the other hand, the lowest weighted mean is 3.28 means they will purchase another motorcycle in Hero MotoCorps in the future, and this will have an effects on the post-purchase behavior of the respondents.

In the study of Kumar and Shah (2020) customers that are satisfied are more likely engaging in positive post-purchase behaviors, like they will purchased again to that specific brand of their choice. Consumers today are also evaluating their overall experience and journey with a brand, from pre-purchase to post-purchase (Park et al. 2021

Table 11. Summary Table for Respondents' Agreement on Factors Influencing Purchase Decision

Indicators	Weighted Mean	Verbal Interpretation
Need Recognition	3.46	Agree
Information Search	3.53	Strongly Agree
Evaluation of Alternatives	3.53	Strongly Agree
Purchase Decision	3.34	Agree
Post-Purchase Behavior	3.33	Agree
General Weighted Mean	3.44	Agree

The respondents generally agree that various factors influence their motorcycle purchasing decisions, with an overall mean of 3.44. Among these, evaluation of alternatives (M = 3.53) and information search (M = 3.53) received the highest levels of agreement, highlighting that consumers actively compare brands, assess performance, and seek information before making a purchase. Need recognition (M = 3.46) also plays a significant role, particularly the perception that motorcycles offer affordability, practicality, and flexibility in transportation. Purchase decision (M = 3.34) and post-purchase behavior (M = 3.33) indicate that while consumers feel confident in their selections and are generally satisfied with Hero MotoCorp motorcycles, brand loyalty remains an area for improvement.

These findings suggest that Hero MotoCorp could enhance its market positioning by strengthening brand reputation, emphasizing key product features, and improving post-purchase services to build long-term customer commitment.

According to Solomon (2011), he stated that individuals purchase things based on their requirements, own preferences, and financial capability. It also stated on Cravens (1996) that the behaviour of consumers in purchasing a product is expecting to satisfy their needs.

Table 12: Item-Analysis for Respondent's Assessment on Perceived Emotional Impact on Brand Perception's influence to Purchase Decision

Brand Awareness	**Corrected Item-Total Correlation**	**Cronbach's Alpha if Item Deleted**	**Findings**	**Decision**
I can easily recall Hero MotoCorps when I think about motorcycles.	.743	.884	Very Good	Retain
I heard of Hero MotoCorps through advertising or media.	.737	.886	Very Good	Retain
I can easily identify Hero MotoCorps among its competitors.	.760	.881	Very Good	Retain
I associate Hero MotoCorps with good quality motorcycles.	.777	.877	Very Good	Retain
I am aware of the key features of Hero MotoCorps motorcycles.	.775	.877	Very Good	Retain
Brand Associations				
When I think of Hero MotoCorps, I think of high-quality motorcycles.	.725	.877	Very Good	Retain
Hero MotoCorps is a symbol of luxury and prestige.	.662	.891	Very Good	Retain
When I think of Hero MotoCorps, I think of modern and stylish design.	.730	.876	Very Good	Retain
When I think of Hero MotoCorps, I think of durability and reliability.	.802	.859	Very Good	Retain
Hero MotoCorps represents a sense of freedom and adventure.	.801	.859	Very Good	Retain
Perceived Quality				
I believe Hero MotoCorps produces motorcycles with excellent performance.	.736	.858	Very Good	Retain

Hero MotoCorps motorcycles are durable and built to last.	.683	.871	Very Good	Retain
Hero MotoCorps offers motorcycles that requires minimal maintenance.	.699	.866	Very Good	Retain
I trust the reliability of motorcycles made by Hero MotoCorps.	.751	.855	Very Good	Retain
Hero MotoCorps provide excellent value for the price.	.750	.855	Very Good	Retain
Brand Loyalty				
I always choose Hero MotoCorps over other motorcycle brands.	.795	.869	Very Good	Retain
I recommend Hero MotoCorps to my friends or family who are considering buying a motorcycle.	.647	.901	Excellent (High Internal Consistency)	Retain
I trust that Hero MotoCorps will meet my needs and expectations better than the other motorcycle brands.	.736	.882	Very Good	Retain
I am willing to pay a higher price for a motorcycle from Hero MotoCorps because of its quality.	.782	.872	Very Good	Retain
I believe Hero MotoCorps provides better long-term value than other brands.	.804	.867	Very Good	Retain

The reliability item analysis for respondents' assessment of Hero MotoCorp's perceived emotional impact demonstrates strong internal consistency, as indicated by the high corrected item-total correlations and Cronbach's Alpha values. All items exhibit "Very Good" reliability, with one item achieving an "Excellent" rating, confirming that the survey effectively measures brand awareness, brand associations, perceived quality, and brand loyalty. The high item-total correlations suggest that each statement contributes meaningfully to the overall construct, reinforcing Hero MotoCorp's strong brand recall, perceived quality, and consumer trust. Notably, the brand loyalty items, particularly the willingness to recommend and pay a premium, highlight a deep emotional connection with the brand.

The fact that no item significantly weakens reliability upon removal underscores the robustness of the instrument, making it a reliable tool for assessing consumer perceptions and informing strategic marketing decisions.

Table 13: Item-Analysis for Respondent's Assessment on Perceived Emotional Impact on Factors Influencing Purchase Decision

Need Recognition	**Corrected Item-Total Correlation**	**Cronbach's Alpha if Item Deleted**	**Findings**	**Decision**
I often think about the possibility of owning a motorcycle.	.403	.805	Very Good	Retain
I believe that a motorcycle would be a practical transportation option for my daily needs.	.373	.807	Very Good	Retain
I feel that owning a motorcycle would give me more freedom in my daily commuting.	.459	.796	Good (Acceptable Reliability)	Retain
I believe a motorcycle would be a more affordable option compared to owning a car.	.571	.784	Good (Acceptable Reliability)	Retain
I feel that motorcycles provide a more enjoyable and flexible way to travel compared to other vehicles.	.407	.801	Very Good	Retain
Information Search				
Before purchasing a motorcycle, I typically research different brands and models online.	.582	.784	Good (Acceptable Reliability)	Retain
I compare prices from different dealers or websites before making a decision on which motorcycle to buy.	.468	.795	Good (Acceptable Reliability)	Retain
I often read customer reviews and ratings of motorcycles before making a purchase.	.547	.787	Good (Acceptable Reliability)	Retain
I talk to friends, family, or other motorcycle owners for advice before purchasing a motorcycle.	.609	.779	Good (Acceptable Reliability)	Retain
I watch online videos or reviews to learn more about the performance and features of different motorcycles.	.540	.787	Good (Acceptable Reliability)	Retain
Evaluation of Alternatives				
I compare multiple motorcycle brands to find the one that offers the best value for my money.	.394	.754	Good (Acceptable Reliability)	Retain
When evaluating motorcycles, I consider the performance and features of various models before making a decision.	.411	.752	Good (Acceptable Reliability)	Retain

I carefully evaluate the fuel efficiency of different motorcycles before making a purchase.	.319	.763	Good (Acceptable Reliability)	Retain
I consider the motorcycle's safety features (ex. ABS, Traction Control) when comparing alternatives.	.332	.762	Good (Acceptable Reliability)	Retain
I evaluate motorcycles based on the brand reputation and reliability before making my decision.	.405	.753	Good (Acceptable Reliability)	Retain
Purchase Decisions				
I am likely to purchase a motorcycle in the next 6 months.	.418	.752	Good (Acceptable Reliability)	Retain
I am confident that I have selected the right motorcycle model for my needs.	.495	.741	Good (Acceptable Reliability)	Retain
I am actively looking for ways to finance or afford the motorcycle I want to buy.	.543	.734	Good (Acceptable Reliability)	Retain
I feel that I have enough information to make an informed purchase decision about motorcycle I want.	.585	.727	Good (Acceptable Reliability)	Retain
The motorcycle of Hero MotoCorps meets all my needs and expectations, and I am ready to purchase it.	.437	.750	Good (Acceptable Reliability)	Retain
Post-Purchase Behavior				
I am satisfied with the performance of my motorcycle.	.471	.792	Good (Acceptable Reliability)	Retain
The motorcycle of heromotocorps has met or exceeded my expectations.	.556	.770	Good (Acceptable Reliability)	Retain
I am likely to purchase another motorcycle in heromotocorps in the future.	.607	.751	Good (Acceptable Reliability)	Retain
I have encountered no significant problems or issue with my motorcycle since purchasing it.	.651	.739	Good (Acceptable Reliability)	Retain
I am satisfied with the after-sales service (ex. Maintenance, customer support) provided by the motorcycle dealership.	.630	.744	Good (Acceptable Reliability)	Retain

The item-analysis for respondents' assessment on perceived emotional impact reveals that all items demonstrate "Good" to "Very Good" reliability, with corrected item-total correlations mostly ranging from

.319 to .651. These values indicate acceptable reliability for the various constructs related to the purchasing decision process, such as need recognition, information search, evaluation of alternatives, purchase decisions, and post-purchase behavior. While some items like [EVA3] and [EVA4] show slightly lower correlations, they still remain within an acceptable range for retaining them.

This suggests that the respondents consistently perceive the factors influencing their decision-making as important, while providing insights into what aspects may require further exploration or refinement in future studies. The Cronbach's alpha values also support the robustness of the instrument, reflecting a reliable scale for assessing consumer perceptions regarding Hero MotoCorp.

Hypothesis Testing

	NULL HYPOTHESIS	TEST	SIG.	DECISION
1	The distribution of Brand Awareness is the same across categories of Factors Influencing Purchase.	Independent Samples Kruskal Wallis Test	.002	Reject the null hypothesis.
2	The distribution of Brand Associations is the same across categories of Factors Influencing Purchase.	Independent Samples Kruskal Wallis Test	.002	Reject the null hypothesis.
3	The distribution of Perceived Quality is the same across categories of Factors Influencing Purchase.	Independent Samples Kruskal Wallis Test	.000	Reject the null hypothesis.
4	The distribution of Brand Loyalty is the same across categories of Factors Influencing Purchase.	Independent Samples Kruskal Wallis Test	.001	Reject the null hypothesis.

The Kruskal-Wallis test results indicate a statistically significant relationship between brand perceptions (awareness, associations, perceived quality, and loyalty) and the factors influencing motorcycle purchase decisions in the Philippines. With p-values less than 0.05 for each brand perception category, the null hypothesis (that the distribution of each brand perception is the same across different purchasing factor categories) is rejected. This suggests that consumer brand perceptions of Hero MotoCorp vary significantly depending on the factors they consider important when buying a motorcycle, highlighting the need for Hero MotoCorp to tailor their marketing strategies to specific consumer segments based on their purchasing drivers.

	NULL HYPOTHESIS	TEST	SIG.	DECISION
1	The distribution of Need Recognition is the same across categories of Brand Perception.	Independent Samples Kruskal Wallis Test	.012	Reject the null hypothesis.
2	The distribution of Information Search is the same across categories of Brand Perception.	Independent Samples Kruskal Wallis Test	.058	Retain the null hypothesis.
3	The distribution of Evaluation of Alternatives is the same across categories of Brand Perception.	Independent Samples Kruskal Wallis Test	.018	Reject the null hypothesis.

4	The distribution of Purchase Decisions is the same across categories of Brand Perception.	Independent Samples Kruskal Wallis Test	.000	Reject the null hypothesis.
5	The distribution of Post-Purchase Behavior is the same across categories of Brand Perception.	Independent Samples Kruskal Wallis Test	.000	Reject the null hypothesis.

This Hypothesis Test Summary table reveals the relationship between consumer purchasing decision stages and brand perception for Hero MotoCorp in the Philippines. Using the Kruskal-Wallis test, the analysis found statistically significant differences in the distribution of Need Recognition, Evaluation of Alternatives, Purchase Decisions, and Post-Purchase Behavior across varying levels of Brand Perception ($p < 0.05$). However, Information Search showed no significant difference ($p = 0.058$).

This indicates that brand perception plays a substantial role in how consumers recognize their needs, evaluate alternatives, make purchase decisions, and exhibit post-purchase behavior related to Hero MotoCorp motorcycles. The lack of significance for Information Search suggests that, for this particular aspect of the purchasing process, brand perception may not be a differentiating factor.

V. CONCLUSIONS

The study highlights that these findings suggest that Hero MotoCorp's brand perception significantly influences several key stages of the consumer motorcycle purchasing journey in the Philippines. Specifically, how consumers perceive the brand affects their initial need recognition, their evaluation of alternative motorcycle options, their ultimate purchase decisions, and their post-purchase behavior. The notable exception is the information search stage, where brand perception doesn't appear to play a significant differentiating role. This implies that while consumers may gather information regardless of their brand perception, their established perception of Hero MotoCorp significantly shapes how they interpret their needs, compare options, decide to buy, and feel about their purchase afterward. Hero MotoCorp should focus on cultivating a positive brand image to positively impact these crucial stages, while recognizing that information search may be driven by other factors beyond brand perception.

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Economic Suitability of Electronic Fare Meters for Tricycle Drivers in Cabanatuan City

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Abstract *— This descriptive study investigated the economic suitability of electronic fare meters for tricycle drivers in Cabanatuan City, Philippines, using a stratified random sampling technique and a self-made survey questionnaire. The research found that tricycle drivers in Cabanatuan City generally operate under a distance-based fare structure with varying passenger ridership and daily income levels. While most drivers were aware of electronic fare meters, their perceptions regarding potential benefits and concerns were mixed. Some expressed concerns about upfront costs and fare reductions, while others acknowledged the potential for fairer fares, improved passenger trust, and easier fare collection. Overall, the findings suggest that electronic fare meters could offer economic benefits for tricycle drivers in Cabanatuan City, particularly through increased efficiency and potentially higher income. However, successful implementation requires careful consideration of driver concerns and the development of strategies to address issues like affordability and potential income fluctuations.*

Keywords *— **Economic suitability; Electronic fare meters; Sustainable transportation; Technology adoption; Tricycle transportation***

I. INTRODUCTION

The tricycle is a form of public transportation in the Philippines, particularly significant for short-distance travel and last-mile connections within cities. In Cabanatuan City, Nueva Ecija, tricycles play a vital role in daily commutes, providing an affordable and accessible transportation option for many residents. Cabanatuan City has earned the moniker "Tricycle Capital of the Philippines" due to the sheer number of tricycles operating within its borders. Studies estimate that there are over 30,000 registered tricycles in the city (Balaria, 2016), highlighting their crucial role in the city's transportation network.

In Cabanatuan City, a fare matrix was established in 2019 and displayed on stickers for tricycles with franchises. Table 1 outlined fares for the first three kilometers.

For distances exceeding three kilometers, an additional five pesos was charged per passenger per kilometer.

However, this fare matrix is currently outdated and not strictly enforced. The lack of a new fare matrix from the local government unit (LGU) has resulted in a system based on negotiation or a fixed rate, leading to inconsistencies and potential disputes between drivers and passengers. This lack of a standardized fare system can create uncertainty for both parties.

Passengers may be unsure of the appropriate fare, and drivers may struggle to ensure they receive fair compensation for their journeys. Furthermore, the absence of a clear and reliable fare structure may limit transparency and accountability within the tricycle transport sector (Philippine Daily Inquirer, 2019).

Table 1 Current Tricycle Fare Matrix in Cabanatuan City

	Regular Passenger	Student / Senior Citizen / Person with Disability
Single passenger	Php 20.00	Php 15.00
Two or more passenger	Php 15.00	Php 10.00

Electronic fare meters have emerged as a potential solution to address inefficiencies and inconsistencies within the Philippine transportation system. While traditionally used in buses and taxis, the technology holds promise for the tricycle sector, a dominant mode of public transport, particularly in cities. Electronic fare meters can be programmed with a predetermined fare structure based on distance travelled or other factors (Sacromento, 2019). This eliminates the need for negotiation, ensuring passengers are charged a consistent and fair fare regardless of their bargaining skills or the driver they encounter (Philippine Daily Inquirer, 2019). The lack of standardization on the current fare collection, as highlighted in a report by the Philippine Department of Transportation (DOTr) (2023), can lead to confusion and disagreements between passengers and drivers. Another study emphasizes the need for a more sustainable tricycle transport system, including a fare system that ensures both economic viability and environmental responsibility (Balaria, et al., 2017) Electronic fare meters offer a compelling solution to these challenges.

By implementing a standardized fare structure based on distance travelled or other factors, meters can ensure fairness and transparency; passengers are charged a consistent and predetermined fare, eliminating negotiation and potential disputes (Sacromento, 2019). Moreover, a clear fare structure can guarantee drivers receive fair compensation for their services, potentially leading to increased and stable income. Research by Ong et al. (2021) highlights the importance of understanding passenger satisfaction with tricycle service quality, which can inform efforts to improve the industry. Electronic meters can also streamline the fare collection process, reducing waiting times and friction between passengers and drivers.

Limited implementations of electronic fare meters in tricycles exist within the Philippines. A pilot program in Davao City in 2019 implemented meters in 1,000 tricycles (Philippine Daily Inquirer, 2019). The program yielded positive results in terms of passenger satisfaction and streamlined fare collection. However, challenges remain, including upfront costs. The cost of acquiring and installing electronic meters can be a barrier for some tricycle drivers. Some drivers also fear lower fares due to government regulation of meter rates (Philippine Daily Inquirer, 2019). Ensuring proper maintenance and technical support for the meters is also crucial for long-term success (Sacromento, 2019).

Further research is crucial to assess the economic viability of electronic fare meters for tricycles across the Philippines. Studies like this one, focusing on Cabanatuan City, can be replicated in other tricycle-dominant areas to understand the broader economic impact. Public perception is another critical factor. Understanding driver concerns and passenger preferences through surveys can help tailor meter implementation strategies to address potential anxieties and ensure a smooth transition.

II. METHODOLOGY

This study employed a descriptive research method using a self-made survey questionnaire to gather data from tricycle drivers in Cabanatuan City. A survey approach is well-suited for this study as it allows for efficient data collection from a large and geographically dispersed population of tricycle drivers (Creswell & Creswell, 2018). A stratified random sampling technique was used to ensure a representative sample of tricycle drivers across different areas of the city. This involved dividing the

city into distinct areas based on its location, calculating the appropriate sample size within each stratum and randomly selecting participants within each stratum to ensure unbiased representation. As a result, 327 tricycle drivers were chosen as respondents to this study.

The self-made survey questionnaire was distributed among the tricycle drivers and covered the current economic landscape such as socio-demographic profile, current fare structure and operational costs, as well as the drivers' awareness of electronic fare meter technology and their perception of the potential benefits and concerns regarding implementation and willingness to adapt electronic fare meter systems.

Descriptive statistics was used to analyze the collected data. This involved frequency distributions for categorical variables to understand the prevalence of different characteristics within the sample and measures of central tendency to provide an overview of typical values.

III. RESULTS AND DISCUSSIONS

Current Economic Landscape of Tricycle Drivers in Cabanatuan City

Understanding the current economic landscape of tricycle drivers in Cabanatuan City is crucial for assessing the potential impact of electronic fare meters on their livelihoods. This section includes the demographics, experience, and ownership patterns of tricycle drivers in the city, providing a snapshot of their economic situation.

Socio-Demographic Profile of Tricycle Drivers

The average age of the drivers was 42 years old, with a range of 21 to 65 years. The most common age group was 31-40 years old, with 193 respondents, accounting for nearly 60% of respondents.

The majority of respondents (94.80%) were male, with only 17 females out of the 327 respondents. This confirms the male-dominated nature of the tricycle driver profession (World Bank, 2023) and aligns with the broader social context in the Philippines, where physically demanding occupations like driving are often seen as more suitable for men. The study also showed that the average driver had been working in the sector for more than five years, indicating a relatively experienced workforce. The majority of drivers (55.35%) had 4-6 years of experience, while 15.90% had 1-3 years and 9.79% had 10 or more years of experience.

A noteworthy finding is that nearly 87% of drivers own their tricycles. This indicates a level of financial investment in the business, suggesting a potential economic stake in the success of their livelihood. This ownership could also influence their attitudes towards EFM adoption, as any additional costs associated with the technology may directly impact their financial situation.

Current Fare Structure

The survey data in this section reveals insights into the current fare structure used by tricycle drivers in Cabanatuan City.

The most common fare system is based on distance, with 74% of drivers relying on this method. A significant portion of drivers (26%) use a combination of distance-based fares and negotiation with each passenger. A smaller percentage (4.6%) relies solely on negotiation for fare collection. Furthermore, the majority of drivers (71.25%) serve 10-20 passengers per day. A notable portion (22.94%) serves less than 10 passengers daily, while a smaller group (5.81%) serves 20-30 passengers daily. This data suggests that a significant number of tricycle drivers may have limited ridership, potentially impacting their daily income. This, combined with the income distribution, suggests that many drivers may operate within a modest income range. The small number of riderships could be because of the number of tricycles operating within the city. Tricycle drivers spend a significant amount of time in line at their terminal, along with other drivers.

The most prevalent income range is ₱301-₱500, accounting for nearly 69% of drivers. A significant percentage (18.96%) earn between ₱501-₱1000 daily. A smaller group (12.54%) earns less than ₱300 daily. This highlights the economic vulnerability of a segment of the tricycle driver population, who may struggle with financial fluctuations and unexpected expenses.

The findings also reveal that a significant majority of tricycle drivers spend between ₱100 and ₱200 on fuel daily, accounting for over 53% of respondents. This suggests that fuel is a major operational cost for most tricycle drivers. A noteworthy finding is the

substantial percentage (42.51%) who spend less than ₱100 on daily fuel. This could be due to several factors, such as ridership, as the number of passengers carried throughout the day can influence fuel consumption. Fewer passengers may translate to lower fuel use. A smaller segment (4.28%) spends between ₱201 and ₱300 daily on fuel. The dependence on fuel and its fluctuating costs can be a source of economic vulnerability for tricycle drivers. Even a slight increase in fuel prices can significantly impact their daily profits, especially for those with lower ridership or already tight profit margins.

The findings also reveal that a significant majority (67.89%) of tricycle drivers incur monthly maintenance costs of less than ₱500. This suggests that many drivers can maintain their tricycles at a relatively low cost. However, it is important to consider the potential limitations of this finding. Older tricycles or those in poorer condition may require more frequent and expensive maintenance. Different tricycle models may have varying maintenance requirements and costs as well. Moreover, drivers who navigate rough roads or operate in a way that puts more stress on the tricycle may experience higher maintenance needs. As EFM implementation could influence driver income and potentially introduce new maintenance considerations, a comprehensive analysis of its potential impact on overall operational costs is crucial (Sadrani, Najafi, Mirqasemi & Antoniou, 2023).

Perception of Electronic Fare Meters

Table 2. Tricycle Driver's Awareness of Electronic Fare Meters

Statement	WM	VI	VD
I am aware of electronic meters being used for tricycles	3.42	Strongly Agree	The respondent is very much aware of the statement
I would be willing to adopt electronic meters for my tricycle if the economic benefits were clear	3.35	Strongly Agree	The respondent is very much aware of the statement
I am confident that I can learn to use electronic meters if there is a training program	3.47	Strongly Agree	The respondent is very much aware of the statement

Table 2 provides valuable insights into the awareness and receptiveness of tricycle drivers in Cabanatuan City towards electronic fare meters. The data reveals a strong level of awareness regarding fare meters among tricycle drivers. A significant portion of respondents (over 3.4 on a 4-point scale for all statements) strongly agreed with being aware of electronic meters being used for tricycles. This suggests that tricycle drivers are not unfamiliar with the concept of fare meters. While drivers demonstrate awareness, their willingness to adopt fare meters appears to be contingent on economic benefits. Their strong agreement (over 3.3) with adopting meters if economic benefits are clear suggests a pragmatic approach. Drivers are likely open to electronic fare meters if they perceive a tangible financial advantage. The strong agreement (over 3.4) with the statement regarding confidence in learning to use fare meters with proper training programs indicates a positive attitude towards adapting to the technology. Drivers seem receptive to acquiring the necessary skills if adequate support is provided.

Table 3 offers valuable insights into how tricycle drivers in Cabanatuan City perceive the potential benefits of electronic fare meters. Drivers strongly agree (over 3.3 on a 4-point scale) that electronic fare meters could ensure fairer fares for both themselves and passengers. This suggests a recognition of potential issues with the current fare structure, possibly including fare negotiation disputes or a lack of transparency. Fare meters, with their standardized fare displays and clear billing systems, are seen as a solution to promote fairness in fare collection. A significant agreement (over 3.4) exists regarding the potential of fare meters to improve passenger trust in tricycle drivers, leading to higher ridership. Drivers strongly agree (over 3.4) that fare meters could make fare collection easier and faster. This suggests a

potential benefit in terms of operational efficiency, allowing them to spend less time on transactions and more time serving passengers. While drivers acknowledge the potential benefits of fare meters, their strong agreement (over 3.3) with the need for a government subsidy suggests a concern regarding the initial cost of acquiring and installing the technology. Financial incentives appear to be a crucial factor for wider driver adoption. These findings align with technology acceptance models that emphasize perceived usefulness and ease of use as key drivers of adoption (Venkatesh et al., 2003)

Table 3. Tricycle Drivers' Perceived Benefits of Electronic Fare Meters

Statement	WM	VI	VD
I believe electronic meters could help ensure fairer fares for both drivers and passengers.	3.37	Strongly Agree	The respondent viewed the statement as highly agreeable
Electronic meters could improve passenger trust in tricycle drivers, leading to potentially higher ridership.	3.42	Strongly Agree	The respondent viewed the statement as highly agreeable
Electronic meters would likely make it easier and faster for me to collect fares from passengers.	3.43	Strongly Agree	The respondent viewed the statement as highly agreeable
Data from electronic meters could help me optimize my routes and potentially save on fuel costs.	3.40	Strongly Agree	The respondent viewed the statement as highly agreeable.
I will be more willing to adopt electronic meters if there is a government subsidy.	3.35	Strongly Agree	The respondent viewed the statement as highly agreeable.

Table 4. Tricycle Drivers' Concerns on Electronic Fare Meters

Statement	WM	VI	VD
I am concerned about the upfront cost of acquiring and installing electronic meters.	3.47	Strongly Agree	The respondent viewed the statement as highly concerning
I am worried that electronic meters might lead to lower fares due to the regulation	3.32	Strongly Agree	The respondent viewed the statement as highly concerning
I am concerned that some passengers might resist using electronic meters and prefer negotiated fares.	3.34	Strongly Agree	The respondent viewed the statement as highly concerning
I am concerned that installing electronic meters would incur additional maintenance costs.	3.38	Strongly Agree	The respondent viewed the statement as highly concerning
I believe the government or tricycle driver associations should provide financial assistance to offset the cost of electronic meters.	3.51	Strongly Agree	The respondent viewed the statement as highly concerning.

Table 4 shows the key concerns tricycle drivers in Cabanatuan City hold regarding the implementation of electronic fare meters. Drivers strongly agree with concerns about the upfront cost of acquiring and

installing electronic fare meters. This highlights a potential financial barrier to driver adoption, especially for those with limited resources. The strong agreement with the need for financial assistance from the government or tricycle driver associations further emphasizes the financial burden associated with electronic fare meter adoption. Drivers seem to seek support in mitigating these upfront costs. While some drivers perceive potential benefits in fare fairness, a significant portion (over 3.3) also express concern that meters might lead to lower fares due to regulation. This suggests a fear of potential income reduction under a standardized fare system. Drivers show concern regarding potential additional maintenance costs associated with installing fare meters. This suggests a fear of unforeseen expenses related to maintaining the new technology. Studies on technological change in transportation sectors highlight the importance of mitigating driver concerns and ensuring a just transition (Shaheen et al, 2012)

IV. CONCLUSION AND RECOMMENDATIONS

Conclusion

1. The driver population is predominantly male with an average age of 42, and relatively experienced with the most common age group being 31 – 40 years old. Notably, 87% of the respondents owned their tricycles, indicating a financial stake in their vehicles. The majority of the drivers rely on a distance-based fare system with a significant portion using a combination of distance and negotiation for fares. Passenger ridership varies, with most drivers serving 10-20 passengers daily. The data on the survey revealed a modest income range for a significant portion of tricycle drivers, with many relying on daily earnings between ₱301-₱500. Fuel costs represent a major operational expense, with most drivers spending between ₱ 100 and ₱200 daily. Monthly maintenance costs vary depending on factors like tricycle age and condition, but a substantial portion maintain their tricycles for less than ₱500 monthly.

2. The survey results indicate a high level of awareness regarding fare meters among tricycle drivers in Cabanatuan City. However, their willingness to adopt the technology appears conditional. Drivers seem open to electronic fare meters if clear economic benefits, such as increased efficiency and fairer fares, are demonstrated. Strong agreement exists with the need for training programs to ensure a smooth transition and build confidence in using fare meters. Overall, driver perceptions suggest a pragmatic approach – they are open to technological change if it translates to a positive impact on their livelihoods.

3. Drivers recognize the potential of fare meters to promote fairness in fare collection for both themselves and passengers by eliminating negotiation and implementing standardized fares. The transparency and legitimacy associated with fare meters could incentivize passengers to choose tricycles more frequently leading to potentially higher ridership and improved driver income. However, the initial cost of acquiring and installing fare meters is a major concern for drivers, particularly those with limited resources. Financial assistance from the government or tricycle associations is seen as crucial for wider adoption. While some drivers perceive potential benefits in fare fairness, a concern exists that fare meters might lead to lower fares due to regulation.

4. Based on the analysis of the landscape and driver perceptions, the overall economic suitability of fare meter implementation for tricycle drivers in Cabanatuan City is low. While the technology offers potential economic benefits like increased efficiency, fairer fares and potentially higher ridership, significant challenges can hinder adoption. Upfront costs of acquiring and installing electronic fare meters create a financial barrier for many drivers. Concerns also exist regarding lower fares due to regulation, potentially impacting driver income negatively.

Recommendations

For Policymakers and Stakeholders. Establish a clear and transparent fare-setting process that considers operational costs, driver income sustainability, and passenger affordability. Communicate the rationale behind fare regulations effectively to both drivers and passengers. Organize workshops and consultations with tricycle driver associations to gather detailed feedback on their concerns and preferences when it comes to their livelihood. Explore alternative fare structures that balance passenger affordability with driver income sustainability.

For Future Researchers. Conduct a comprehensive cost-benefit analysis that considers not only the upfront costs of electronic fare meters but also the potential long-term economic benefits for drivers, passengers, and the government.

By addressing these areas for further exploration, policymakers and stakeholders can make informed decisions about electronic fare meter implementation. This research approach will ensure a more comprehensive understanding of the potential economic and social implications, paving the way for a more sustainable and equitable tricycle transportation system in Cabanatuan City in the future.

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Enhancing Data Security and Transparency: The Role of Blockchain in Decentralized Systems

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Abstract *— Blockchain technology has become a game-changer in strengthening data security and transparency within decentralized systems. This study examines its role in tackling major challenges related to data integrity, access control, and auditability, with a focus on industries like finance, decentralized finance (DeFi), and supply chain management. Using data analysis, case studies, and expert opinions, the research highlights how blockchain provides a secure, transparent, and efficient framework for digital transactions. The findings reveal that blockchain enhances security by eliminating weaknesses found in traditional centralized systems. With features like immutable record-keeping, cryptographic encryption, and decentralized control, blockchain ensures transactions remain secure, tamper-proof, and resilient against fraud and cyber threats. Additionally, its ability to maintain a shared, verifiable ledger fosters transparency and builds trust among stakeholders. Smart contracts further improve efficiency by automating processes and ensuring compliance with predefined rules. However, despite its many benefits, blockchain adoption faces hurdles such as scalability challenges, regulatory uncertainties, and integration difficulties. To overcome these barriers, the study suggests developing clear regulatory guidelines, implementing advanced scalability solutions, increasing awareness and technical training, promoting cross-industry collaboration, and adopting hybrid blockchain models that balance security with privacy. In conclusion, this research emphasizes blockchain's potential to reshape data security and transparency across various sectors. By addressing existing challenges, blockchain can drive innovation, streamline operations, and enhance trust in digital ecosystems.*

Keywords *— **Blockchain, Data Security, Transparency, Smart Contracts, Decentralization***

I. INTRODUCTION

Blockchain technology has emerged as one of the most significant advancements in recent years, offering a secure and transparent approach to data storage and sharing. It enhances security, efficiency, and transparency in various industries, transforming business operations. This technology enables decentralized record-keeping, reducing the risk of data manipulation while improving trust among stakeholders. Its applications span multiple sectors, including healthcare, finance, and manufacturing, where it helps streamline processes and improve decision-making. However, the implementation of blockchain also presents challenges, such as security risks, privacy concerns, ethical considerations, and governance issues. Addressing these concerns is essential for maximizing its benefits. [1] Additionally, advancements in data processing techniques have contributed to improved automation and pattern recognition, allowing for more effective decision-making processes. These developments rely on statistical methods to analyze large datasets, making predictions or decisions without requiring predefined programming

instructions. More sophisticated approaches involve complex network models, which enhance the ability to identify intricate patterns in data, further advancing efficiency and problem-solving capabilities. [2]. Blockchain technology offers a reliable and transparent method for storing and sharing data, making it a valuable tool for enhancing security and efficiency in various industries. At the same time, advanced data-driven systems are transforming decision-making processes by learning from information patterns. However, there is limited research on whether blockchain can help meet legal cybersecurity requirements for emerging technologies.[3].

As digital technology continues to advance, the demand for secure, transparent, and efficient data management has become more critical than ever. Traditional centralized systems often face significant challenges, including security vulnerabilities, data manipulation risks, and single points of failure, making them prone to cyberattacks and operational inefficiencies. Blockchain technology offers a solution to these issues by introducing a decentralized framework for data storage and transactions, enhancing security, transparency, and reliability (Nakamoto, 2008). While originally designed for cryptocurrency transactions, blockchain has since evolved to serve various industries such as finance, healthcare, supply chain management, and governance, where maintaining trust and security is essential. [4]. At the heart of blockchain technology lies its decentralized ledger system, which records transactions across multiple nodes, reducing reliance on central authorities and lowering the risk of fraud and unauthorized access. The use of cryptographic security ensures that once data is verified and added to the blockchain, it becomes immutable, strengthening trust among participants. Furthermore, smart contracts—self-executing agreements programmed with predefined conditions—streamline processes and enhance operational efficiency by automating transactions. [5].

As digital advancements continue to reshape industries, ensuring the security of sensitive data has become more critical than ever. Traditional centralized data storage systems often face significant security threats, including data breaches, unauthorized access, and cyberattacks, due to their reliance on a single authority. Blockchain technology presents a powerful alternative by offering a decentralized and tamper-proof system for managing and exchanging data. Through its cryptographic security mechanisms and distributed ledger structure, blockchain enhances data integrity, transparency, and fraud prevention. One of the defining features of blockchain is its decentralized ledger, which records transactions across multiple nodes in a network, reducing dependence on a central authority and minimizing the risk of data manipulation [6]. Once added to the blockchain, information cannot be altered or erased without the consensus of the entire network, ensuring a high level of security and trust. This makes blockchain particularly beneficial in sectors such as finance, healthcare, and supply chain management, where protecting data and maintaining transparency are essential. Furthermore, smart contracts—self-executing programs that enforce agreements automatically—enhance security and efficiency by eliminating the need for intermediaries. Despite its advantages, blockchain technology faces certain challenges, including scalability limitations, regulatory uncertainty, and high energy consumption. Addressing these challenges is crucial for unlocking the full potential of blockchain in strengthening data security. This paper examines how blockchain technology enhances data protection, explores its advantages and obstacles, and discusses its future role in securing digital assets across various industries. [7].

Ensuring transparency is crucial in today's digital landscape, particularly in industries where trust, accountability, and data integrity play a vital role. Traditional centralized systems often struggle with transparency issues due to restricted access, the risk of data manipulation, and reliance on intermediaries, which can result in inefficiencies and security threats. Blockchain technology offers a solution to these challenges by providing a decentralized and tamper-proof ledger system, enhancing transparency across multiple sectors. By maintaining an immutable and publicly verifiable record of transactions, blockchain fosters greater trust and accountability among stakeholders. A key advantage of blockchain lies in its decentralized structure, where transactions are distributed across multiple nodes rather than being controlled by a

single authority. This ensures that once data is recorded on the blockchain, it cannot be altered or removed without the consensus of the entire network, significantly reducing the risk of fraud and unauthorized modifications. [8] Furthermore, smart contracts—self-executing agreements programmed with predefined conditions—facilitate automated transactions while promoting transparency by removing the need for intermediaries. The transparency offered by blockchain has significant applications across various industries, including finance, supply chain management, and governance. In financial services, blockchain improves auditability and helps combat fraud. In supply chains, it enables real-time tracking of goods, reducing the chances of counterfeiting and improving operational efficiency. Additionally, governments and organizations can utilize blockchain for transparent public records, which can minimize corruption and enhance accountability in decision-making processes. [9].

The increasing volume and complexity of interbank transactions have heightened the need for secure and reliable mechanisms to maintain data integrity and prevent fraud. Interbank transactions serve as the foundation of global financial systems, facilitating cross-border payments, clearing, and settlements. However, traditional transaction systems often suffer from vulnerabilities such as fraudulent data access, delays in reconciliation, and inefficiencies resulting from centralized infrastructure. Research indicates that financial institutions collectively lose billions, or even trillions, each year due to fraudulent activities and operational shortcomings, underscoring the urgency for innovative solutions. [10]. To address these challenges, blockchain technology has emerged as a transformative solution. It provides a secure method for recording transactions on a decentralized ledger, eliminating the need for centralized intermediaries. Each transaction is recorded within a block that is cryptographically linked to the previous one, forming a tamper-proof and immutable chain. Unlike traditional centralized systems, blockchain eliminates single points of failure, enhancing security and resilience against cyber threats. [11]. While blockchain holds significant promise for interbank transactions, certain obstacles must be overcome to achieve its full potential. Key issues include scalability, regulatory compliance, and integration with existing banking infrastructure. Scalability remains a pressing concern, as current blockchain networks struggle to process transactions at the high speeds required by interbank systems. Additionally, regulatory uncertainties and ambiguities often hinder adoption, leaving financial institutions hesitant to implement blockchain-based solutions. Furthermore, integrating blockchain with existing enterprise systems presents a significant challenge, requiring substantial financial investment in both technology and expertise. Successfully addressing these barriers is essential for unlocking the full benefits of blockchain in the financial sector. [12]

II. REVIEW OF LITERATURE

2.1 Relvent Research

Blockchain technology has gained widespread recognition for its ability to enhance transparency, efficiency, and data security across various sectors. By utilizing decentralized ledgers and smart contracts, blockchain offers a reliable framework for real-time tracking, data integrity, and automated compliance, effectively addressing persistent challenges in these fields. In Cold Chain Management, blockchain ensures product traceability, mitigates data tampering, and improves visibility throughout the supply chain, particularly for temperature-sensitive goods. This examines current blockchain-based applications and frameworks, highlights existing challenges, and explores future opportunities for improving critical systems through blockchain technology. The findings underscore blockchain's transformative impact in optimizing operations, enhancing security, and ensuring data transparency across various industries, providing a strategic pathway for organizations to fully leverage its potential. [13].

The convergence of big data and blockchain technology is transforming decision-making processes across various industries by enabling decentralized, secure, and transparent operations. This explores how these technologies, in combination with distributed systems, enhance data security, improve transparency, and facilitate real-time processing, leading to more efficient and informed decision-making. Their integration ensures secure, immutable records, strengthens traceability, and

enables real-time data analysis. While obstacles remain, ongoing advancements and innovative solutions in these technologies demonstrate substantial potential. Their continued development is expected to accelerate the adoption of decentralized decision-making, ultimately enhancing efficiency and driving better outcomes across multiple sectors. [14].

The integration of Blockchain and Artificial Intelligence (AI) has the potential to transform business operations by enhancing security, efficiency, and transparency. This r explores the synergy between these two technologies, examining how their convergence can drive innovation across various industries. AI's advanced data analysis and decision-making capabilities, combined with Blockchain's secure and transparent data-sharing framework, create opportunities for groundbreaking solutions in multiple sectors. This aims to assess the benefits and challenges of this integration, emphasizing the need for further exploration and development. Through a systematic literature review, the research will evaluate existing findings to provide a comprehensive understanding of how Blockchain and AI can complement each other in optimizing business processes. AI can enhance Blockchain by enabling smart contract automation, improving data analysis, and strengthening decision-making, while Blockchain ensures a secure and transparent operational framework for AI-driven applications. [15].

Blockchain offers several advantages, including decentralization, persistence, anonymity, and auditability. Its applications span a wide range of industries, from cryptocurrency and financial services to risk management, the Internet of Things (IoT), and public and social services. While numerous studies explore the use of blockchain in different domains, there is a lack of a comprehensive review that examines both its technological and application aspects. To address this gap, this paper provides an in-depth survey of blockchain technology. It categorizes blockchain systems, introduces common consensus algorithms, reviews various blockchain applications, and discusses technical challenges alongside recent advancements aimed at overcoming these obstacles. Additionally, the paper highlights potential future directions for blockchain development, offering insights into its evolving landscape. [16].

2.2 Enhancing security

The integration of blockchain technology significantly enhances the security and privacy of data generated by Internet of Things (IoT) healthcare devices. It ensures that sensitive health information remains protected while allowing authorized parties to access relevant data when necessary. This secure and transparent approach to data management aligns with legal frameworks such as HIPAA, which safeguard patient privacy and data protection. As large-scale data collection for COVID-19 research continues, strict adherence to international laws and regulations is essential to maintain data security and confidentiality. Regulatory frameworks like HIPAA play a crucial role in governing the release of medical records, while innovative data-sharing models, as discussed by Jerbi et al., further strengthen secure information exchange. Additionally, the growing reliance on IoT medical devices highlights the need for enhanced data security, which can be effectively addressed through blockchain integration. [17]

The combination of blockchain technology with the Internet of Medical Things (IoMT) offers significant potential for improving patient privacy and optimizing device functionality. This integration leverages blockchain's decentralized and secure nature to provide multiple benefits. A key advantage is the enhancement of patient privacy, as blockchain's distributed architecture ensures that sensitive health data remains protected and tamper-proof. Storing patient records on the blockchain guarantees that only authorized individuals or entities can access them, reinforcing both confidentiality and compliance with regulatory standards. Furthermore, blockchain eliminates the reliance on centralized intermediaries, which are commonly involved in traditional healthcare systems for data management. By removing these intermediaries, blockchain streamlines the transmission of patient information across global healthcare networks, ensuring a more efficient, secure, and transparent system. [18]

2.3 Blockchain benefits and challenges

Blockchain technology has the potential to transform multiple industries by improving security, transparency, and efficiency while reducing costs. One of its most significant advantages is decentralization, meaning no single entity or organization has control over the system. By utilizing cryptographic algorithms, blockchain ensures the

security of transactions and data, making it nearly impossible to alter or tamper with recorded information [19]. Additionally, blockchain offers transparency by allowing users to view all transactions and recorded data, thereby fostering accountability and trust across various industries. In supply chain management, blockchain enhances traceability by enabling the tracking of products and transactions, making it easier to detect and prevent fraud and other illicit activities [20].

Despite its benefits, blockchain technology also presents several challenges. Iranmanesh et al. discuss blockchain's advantages as a distributed ledger technology, particularly its role in enhancing transparency and minimizing transactional fraud. However, they also highlight concerns regarding implementation costs, especially in the context of AI integration. One of the major issues is energy consumption, as blockchain networks—particularly those based on proof-of-work, like Bitcoin—require substantial computing power. When combined with resource-intensive AI models, operational costs can escalate significantly. Additionally, scalability remains a crucial challenge, as increasing blockchain capacity often results in trade-offs between security, decentralization, and efficiency, commonly referred to as the scalability trilemma. Addressing these trade-offs is essential to maintaining cost-effectiveness while ensuring system reliability. Furthermore, interoperability—the ability of different blockchain networks to communicate and operate seamlessly—remains a key technical hurdle that must be overcome for widespread adoption. [21]

III. METHODOLOGY

The initial phase of this research adopts a mixed-method approach to examine how blockchain technology can enhance the integrity and security of interbank transactions. This methodology encompasses data collection, system design, experimental analysis, and a qualitative evaluation of the system. By integrating both qualitative and quantitative data, this approach provides a well-rounded assessment of blockchain's potential impact on interbank transactions, offering a comprehensive understanding of its effectiveness and feasibility.

3.1 Research Design

This study employs an exploratory sequential research design, where insights from qualitative interviews and evaluations of blockchain applications guide both qualitative and quantitative assessments of a simulated blockchain-based interbank system (Creswell & Clark, 2017). This iterative approach ensures that findings are continuously refined and validated through multiple research methods.

3.2 Data Collection

A systematic review was conducted, analyzing peer-reviewed articles, industry reports, and white papers to identify the key features, benefits, and challenges of integrating blockchain into financial systems. To ensure the inclusion of high-quality and relevant literature, reputable sources such as Scopus, IEEE Xplore, and industry journals like Deloitte Insights were utilized.

IV. RESULT

This chapter presents the findings of the study on the role of blockchain in enhancing data security and transparency within decentralized systems. The results are categorized based on key parameters, including security improvements, transparency enhancement, and system efficiency. The findings are drawn from data analysis, case studies, and expert interviews, providing insights into the effectiveness of blockchain in addressing challenges related to data integrity, access control, and auditability.

4.1 Blockchain in finance

Blockchain technology is redefining industries, with its most significant impact observed in the financial sector. This innovative system operates as a decentralized and distributed ledger, ensuring secure, transparent, and tamper-proof record-keeping. By addressing long-standing issues related to security, transparency, and operational efficiency, blockchain has the potential to revolutionize financial transactions. At its foundation, blockchain consists of a series of interconnected blocks, each containing a record of verified transactions. These blocks are linked together chronologically, forming an immutable ledger. What makes blockchain unique is its decentralized nature—rather than relying on a central authority or intermediary, the system is maintained collectively by a network of participants, known as nodes. Each node holds a complete copy of the

blockchain, eliminating single points of failure and ensuring data integrity. Moreover, because blockchain operates as a distributed ledger, information is stored across multiple nodes rather than a single centralized database. This decentralized architecture significantly enhances security, making it highly resistant to tampering or unauthorized modifications. As a result, blockchain technology offers a reliable framework for industries that prioritize secure and transparent transactions. [22]

4.2 Enhancing Security in the Financial Sector

Security is a top priority in the financial sector, where vast amounts of money and confidential data are constantly at risk. Traditional financial systems, which rely on centralized databases, are highly susceptible to cyber threats, fraud, and unauthorized access. Blockchain technology, with its decentralized framework and cryptographic security, offers a powerful solution to these vulnerabilities.

A. Immutable Record-Keeping: One of blockchain's most significant security advantages is its immutability. Once a block is added to the chain, it cannot be altered or removed. This tamper-proof system ensures that transaction records remain secure, minimizing the chances of fraud or manipulation. In the financial industry, this feature helps prevent unauthorized modifications to financial data, reducing fraudulent activities.

B. Cryptographic Security for Transactions: Blockchain secures transactions through advanced cryptographic techniques. Each participant in the network has a unique cryptographic key, consisting of a publicly visible key and a private key known only to the owner. This encryption mechanism maintains transaction integrity and confidentiality, adding a crucial layer of protection to financial exchanges.

C. Decentralized Control: Traditional financial systems often depend on a central authority or server, creating a single point of failure that, if compromised, could lead to severe consequences. Blockchain eliminates this risk through its decentralized structure. Even if a single node in the network is attacked, the overall system remains secure, significantly lowering the chances of widespread security breaches.

4.3 Enhancing Transparency in Finance

Transparency plays a crucial role not only in the financial sector but also across various industries. A lack of transparency can create distrust among stakeholders and disrupt the smooth operation of financial markets. Blockchain technology offers a groundbreaking approach to transparency by maintaining a shared, real-time, and verifiable transaction record.

A. Instant Settlement of Transactions: Traditional financial transactions, especially international ones, often require multiple intermediaries and extended processing times. Blockchain streamlines this process by enabling almost instant settlements, reducing risks associated with third parties while maintaining a clear and traceable record of transactions.

B. Open and Distributed Ledger: The decentralized nature of blockchain ensures that all participants in the network have access to a shared ledger. While individual transaction details remain pseudonymous, the visibility of the overall ledger allows for consistent and verifiable data across the network. This level of openness fosters trust among stakeholders by providing an independent verification mechanism for transactions and balances.

C. Tamper-Proof Transaction History: Every transaction recorded on the blockchain is time-stamped and permanently linked to previous transactions, creating an immutable and fully traceable history. This feature is particularly beneficial for financial audits, as it provides a transparent and verifiable record of transactions. Regulators and auditors can rely on blockchain's integrity to validate financial statements with greater confidence.

4.4 Importance of Transparency, efficiency, and Data Security in Critical Systems

Ensuring transparency, efficiency, and data security is essential for maintaining operational trust and reliability across various industries. As shown in Table 1, sectors such as Agile Project Management, Decentralized Finance (DeFi), and Cold Chain Management benefit significantly from enhanced transparency. Real-time access to data allows stakeholders to track processes seamlessly, promoting accountability while reducing risks associated with fraud and miscommunication. By addressing information gaps, transparency fosters more accurate decision-making and strengthens user confidence,

which is particularly crucial in financial services and supply chain operations where accuracy and credibility are paramount.

Efficiency also plays a vital role in optimizing operations by minimizing delays, improving resource allocation, and ensuring a swift response to changing conditions. In industries that demand rapid execution, well-structured systems help streamline workflows, lower operational costs, and improve overall service delivery. Blockchain's decentralized structure aligns with these needs by enabling secure and automated data transactions, ensuring agility and reliability across different platforms. [23]

Equally important is data security, which acts as a safeguard against unauthorized access and tampering—key concerns in financial and supply chain management. Blockchain employs advanced cryptographic techniques to protect sensitive data, ensuring its integrity throughout the system. The combination of transparency, efficiency, and data security underscores blockchain's transformative potential in strengthening and modernizing critical systems. [24]

Table 1: Importance of Transparency, Efficiency, and Data Security in Critical Systems

Aspect	Transparency	Efficiency	Data Security
Agile Project Management	Enables clear accountability across teams, reducing ambiguity in tasks and progress.	Streamlines project tracking, reducing delays and improving resource use.	Ensures sensitive project data is secure, minimizing unauthorized access risks.
Decentralized Finance (DeFi)	Facilitates open transaction visibility, ensuring trustworthy interactions.	Optimizes transaction processes, reducing costs and processing times.	Protects user identity and assets, securing transactions in real-time.
Cold Chain Management	Allows real-time tracking of goods, fostering consumer trust and regulatory compliance.	Increases operational efficiency by automating monitoring and reporting.	Safeguards data on temperature and handling, ensuring product quality.
Overall Importance	Boosts accountability and compliance across sectors.	Promotes streamlined workflows and resource management.	Protects critical system integrity, enhancing trust across industries.

4.5 Overview of Blockchain Technology and its Core Functionalities

Blockchain technology functions as a decentralized ledger, enabling secure, transparent, and tamper-resistant data exchanges across networks , as illustrated in Figure 1. Initially developed to support Bitcoin, blockchain has since expanded far beyond cryptocurrency, becoming a fundamental technology for secure data transactions across various industries. Its key components—a decentralized ledger system and smart contracts—help address major challenges by ensuring data integrity, operational transparency, and security. The decentralized ledger, which serves as the foundation of blockchain, records transactions across multiple nodes in a distributed network. This reduces reliance on centralized authorities and minimizes the risk of data breaches.[25]. Additionally, smart contracts—self-executing agreements with embedded terms—automate processes by triggering specific actions when predefined conditions are met . This feature is particularly beneficial in industries that require real-time data processing and automated regulatory compliance, such as finance and supply chain management, where accuracy and accountability are crucial. These functionalities of blockchain are integral to its potential in critical domains like Agile Project Management, DeFi, and Cold Chain Management,

where they not only strengthen security but also foster efficiency through reliable, autonomous data handling. Thus, blockchain technology emerges as a pivotal tool in optimizing data-driven processes across industries. [26] .

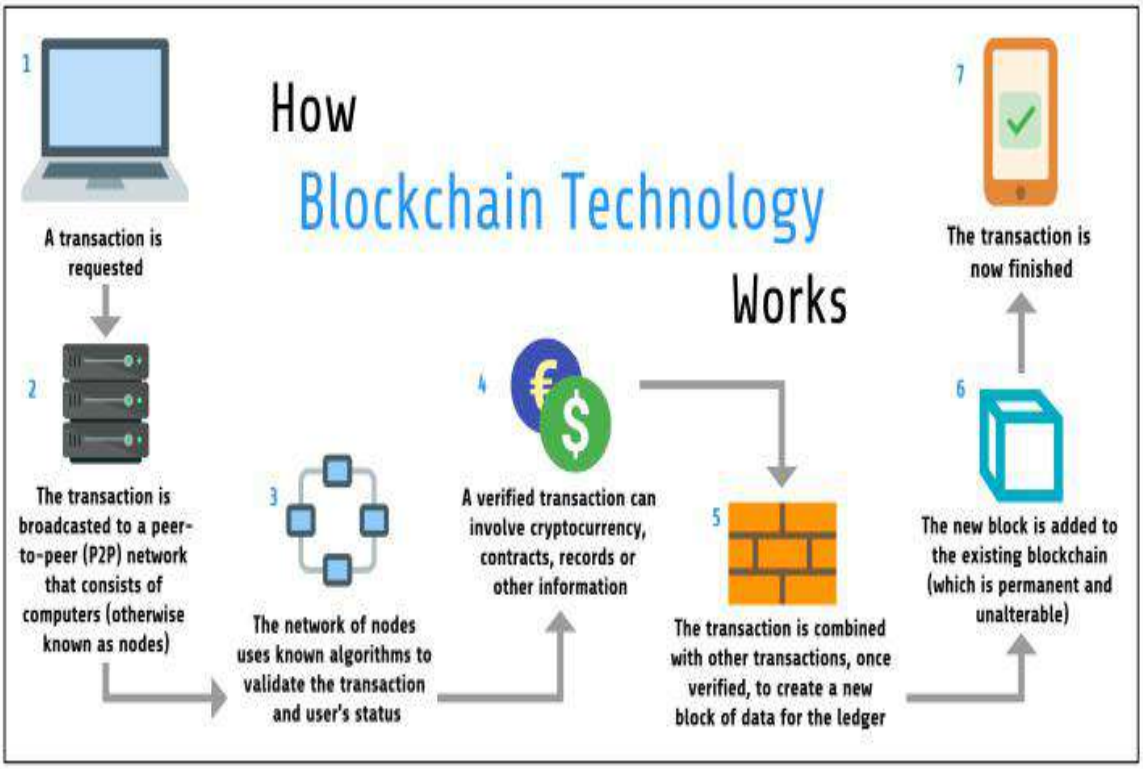

Fig 1: Picture Showing the Overview of Blockchain Technology and its Core Functionalities. [27] .

Figure 1 illustrates the blockchain transaction process, highlighting its core functionalities. The process starts when a user initiates a transaction request, which is then broadcast to a decentralized peer-to-peer (P2P) network made up of multiple nodes. These nodes employ algorithms to validate the transaction and authenticate the user. Once verified, the transaction—whether involving cryptocurrency, digital contracts, or records—is recorded and grouped with other validated transactions to form a new data block. This block is then securely added to the existing blockchain, making it permanent and resistant to tampering. At this point, the transaction is officially completed. Blockchain's decentralized ledger system ensures secure and transparent data sharing without the need for a central authority, making it a key feature of this technology. Additionally, smart contracts enhance blockchain's functionality by automatically executing transaction terms when predefined conditions are met, enabling self-enforcing agreements. This capability is particularly beneficial in fields such as decentralized finance (DeFi), Agile project management, and Cold Chain Management, where transparency, security, and operational efficiency are critical. Through cryptographic security and distributed validation, blockchain guarantees that every transaction remains immutable, fostering trust and reliability across various applications.

V. CONCLUSION AND RECOMMENDATIONS

Conclusion

This study has explored how blockchain technology enhances data security and transparency in decentralized systems. The findings highlight blockchain's effectiveness in tackling major challenges in industries such as finance, supply chain management, and decentralized finance (DeFi). By securing transactions, improving transparency, and increasing operational efficiency, blockchain has the potential to revolutionize the way businesses operate. In the financial sector, blockchain strengthens security by eliminating vulnerabilities common in traditional centralized systems. Features like immutable records,

cryptographic security, and decentralized control ensure transactions remain secure, tamper-proof, and resistant to fraud. The ability to facilitate real-time settlements while cutting out intermediaries reduces costs and minimizes delays, making financial processes more efficient. Transparency is another key advantage of blockchain. It provides stakeholders with access to a shared and verifiable transaction history, fostering trust and accountability. With smart contracts automating agreements and ensuring compliance, blockchain simplifies complex processes, reducing the risk of human error or manipulation.

Additionally, blockchain's decentralized structure enhances data security by eliminating single points of failure. Advanced cryptographic techniques protect sensitive information from unauthorized access, making blockchain a reliable tool for safeguarding digital transactions and assets. While blockchain presents transformative possibilities, its widespread adoption is still hindered by challenges such as scalability, regulatory uncertainty, and integration difficulties. Addressing these obstacles will be essential for maximizing its potential and ensuring its seamless adoption across industries.

RECOMMENDATIONS

To fully leverage the benefits of blockchain, the following steps are recommended:

1. Establishing Clear Regulatory Frameworks

Governments and regulatory bodies need to create well-defined policies that support blockchain adoption. Consistent regulations will provide clarity for businesses, reduce compliance risks, and encourage broader implementation of blockchain-based solutions.

2. Improving Scalability

Developers should focus on scalability solutions such as sharding, sidechains, and layer-2 protocols to improve transaction speeds without compromising security. Advancements in these areas will help blockchain networks handle higher transaction volumes efficiently.

3. Increasing Awareness and Skill Development

Organizations should invest in training programs and workshops to enhance knowledge and technical expertise in blockchain technology. Educating professionals about its applications will drive adoption and innovation across industries.

4. Encouraging Cross-Industry Collaboration

Stronger partnerships between financial institutions, tech firms, and government agencies can accelerate blockchain adoption. By working together, stakeholders can develop tailored solutions and promote innovation in various sectors.

5. Exploring Hybrid Blockchain Models

Businesses should consider hybrid blockchain solutions that blend public and private blockchain benefits. This approach allows for greater data control while maintaining the transparency and security of decentralized networks.

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Optimization of Growth Process and Structural Characterization of Nanoscale Compound Semiconductor Heterostructures

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Abstract *— This study focuses on optimizing the process sequence for fabricating a double quantum well structure composed of the compound materials AlAsSb/InGaAs/GaAsSb. The selection of optimized sequence parameters is guided by an extensive literature review on material properties, nanoscale engineering considerations, and molecular beam epitaxy (MBE) growth conditions. A key advantage of using heterostructures is the precise control over the thickness of individual material layers, which is crucial for device fabrication. To ensure uniform epitaxial growth of the ternary compounds AlAsSb, InGaAs, and GaAsSb, a slow deposition rate of 0.5 micrometers per hour is maintained during the MBE process.*

Keywords *— **MBE, Quantum well, Heterostructure, Compound Semiconductor.***

INTRODUCTION

Optoelectronic devices like light-emitting diodes (LEDs), laser diodes (LDs), Photodetectors (PDs) and optical waveguides are widely utilized in the field of optical fiber communication, medical science, automobile industries and spectroscopy for pollution monitoring and food control. This growth of the semiconductor optoelectronic components industry is mainly expected by the increased use of visible range and infrared components due to the long life, cheap and low power consumption demand. Nanoscale heterostructures, new materials and improved fabrication techniques have led to improvement in the performance of optoelectronic devices [1-4]. The heterostructure is the interface of two dissimilar materials with different bandgap energy. Nanoscale heterostructures involve quantum confinement so that it gives diverse electronic and optical properties which are useful for device development. The simulation work of the structure $AlAsSb/In_{0.59}Ga_{0.41}As/GaAs_{0.53}Sb_{0.47}$ is already simulated and discussed by the authors of this paper [5]. Heterostructure manufacturing generally requires the use of molecular beam epitaxy (MBE) and chemical vapor deposition (CVD) technology for the deposition of compound material layers. But at the nanoscale and for mass production, MBE provides more precise control over the thickness during the deposition process and creates a cleanly lattice match abrupt interface [6-9]. MBE is the process in which thin crystal layers are deposited on a substrate using an atomic or molecular beam in a high vacuum chamber. The major benefit of quantum well structure from the perspective of device fabrication is that we can regulate the thickness of the material layer during the film deposition. In this process optimization, the MBE process is proposed for the thin film deposition of nanoscale thickness because it precisely controls the thickness due to low deposition rate.

Structural Information and Process Sequence Optimization:

A schematic cross-section of the structure is shown in fig 1, where an AlAsSb (10 nm thick) confinement layer is proposed to grow on the GaAs substrate. Then P-doped InGaAs (mole fraction x=0.59) of 2 nm thick followed by the 4 nm GaAsSb (mole fraction x =0.53) material layer. After it again InGaAs and AsAsSb (10 nm) is proposed for deposition.

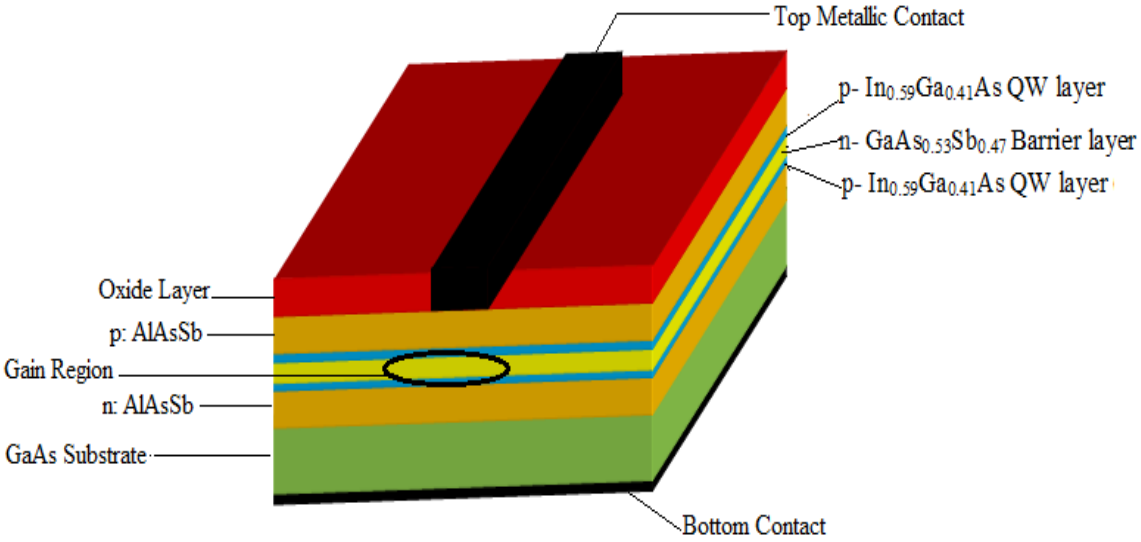

Fig.1. A schematic cross-section of the proposed structure for process sequence optimization

For epitaxial growth of these III-V compound semiconductor layers, GaAs substrate is usually utilized. So first we will take the standard p-type GaAs substrate and cleaned it with the standard process before going to molecular beam epitaxy. Pre-cleaning of the substrate is important because it removes the hydrocarbons, water molecules and other particles from a substrate. For effective results, the GaAs wafer cleaning includes the acid cleaning step in acetone solution for approximately 45 seconds, deionized water cleaning to remove the deposited cleaning solutions and a rotary drying process to dry the GaAs wafer. Rotary dryers work by tumbling material in a rotating drum in the presence of drying air. The substrate cleaning using these three steps provides the cleaned GaAs wafer without precipitate particles. After the substrate cleaning, the GaAs wafer is fixed on the MBE substrate heating holder for the epitaxial growth of the material layers. The optimized parameters of the sequences are selected based on the literature study of the materials properties, nanoscale engineering and MBE growth parameters [10-18].

Table 1: Quantum well structure with fabrication techniques

QW structure (Substrate- GaAs) with parameters	Design/ Fabrication technique	Emission wavelength (μm)
GaSb/ AlGaSb	Molecular beam epitaxy (MBE)	1.65
GaInAs/GaAsSb	Metalorganic vapour-phase epitaxy (MOVPE)	1.2 - 1.47
GaInAs/GaAsSb	Metalorganic vapour-phase epitaxy (MOVPE)	1.2
GaAsSb/lnGaAs	Molecular beam epitaxy (MBE)	1.38, 1.43
GaAsSb/lnGaAs	Metalorganic chemical vapor deposition (MOCVD)	1.022, 1.075

For the deposition process, the materials (Al, Ga As, In, Sb and dopants) put in the MBE effusion cell. These cells provide highly efficient and controllable vapor deposition. The close-coupled thermocouple in the radiatively heated crucible ensures stability and reproducibility, not found in conventional evaporation sources. All the cells are heated using the heating coil and maintained temperature for vaporization. All the effusion cells have the shutter, so once the deposition is done for the required time, we close the shutter and no excess amount of material will be deposited that is why it is a very precise kind of method. For the designed heterostructure, Boron can be utilized for the p-type dopant and phosphor for the n-type dopant. The doping concentrations and the mole fractions are selected based on the atomic weight percentage and atomic mass of the materials. To find the mass percent of any element in the compound semiconductor, we divide the mass of the element in 1 mole of the compound by the compound's molar mass and multiply the result by 100. In general, the mole fraction and chemical composition can be determined using Augur spectroscopy. The substrate GaAs is fixed on the heating substrate holder and it is rotated, so that uniformity can be obtained in the deposition. The substrate temperature can be chosen at 200 °C. This high temperature of the substrate facilitates mobility and lesser defects. During the deposition process, we should be assured that atoms will not collide with any ambient atmosphere that is left in the chamber. For this purpose, the MBE base chamber pressure can be taken of the order of 10^{-9} Torr. The deposition pressure is of the order of 10^{-5} torr. This low pressure of the chamber is required so that the atoms can travel to the substrate without colliding with each other and a mean free path of around 10 meters with the ambient atmosphere. To attain this low pressure for the MBE chamber, we can use a rotary pump (up to 10^{-3} torr), diffusion pump (up to 10^{-6} torr) and turbomolecular pump (up to 10^{-9} torr). After making the high vacuum or low pressure inside the chamber the deposition process takes place. In order for uniform epitaxial growth of ternary material AlAsSb, InGaAs and GaAsSb, the deposition time is chosen very slow i.e. 0.5 micrometers per hour during the process in the MBE and layers are deposited as per the required thickness of the layer i.e. for the thickness of layer 10 nm the deposition time is taken 72 seconds for optimum growth. The deposition thickness can be determined by the use of a reflection high-energy electron diffraction (RHEED) gun, where the electrons are incident on the film, so we can control the thickness of the film more precisely. The top and bottom contacts for the characterization can be formed with the use of the thermal evaporation method.

CONCLUSION

In this research work, the process sequence optimization for the nanoscale heterostructures based on the ternary compounds is investigated for the NIR and visible range applications. The applications of the heterostructure depend on the emission wavelength. The choice of the materials and thickness of the material's layers are the critical parameters for the design of the heterostructures for an application. In the heterostructure, the thickness of the well layer or active layer is in our control. This is an important advantage of the heterostructures for device fabrication. So this research gives the choice of alternate materials for the development of optical sources for the NIR and visible range applications. The heterostructure designed in this work is of nanoscale and can be fabricated for device development. After the device fabrication, we can apply pn junction engineering to study the electro-photoluminescence (PL) spectra under the forward voltage, reverse voltage conditions and in open circuit conditions in order to know the internal quantum efficiency or emission property. It is expected that the heterostructures will give emission as proposed in the simulation work and these can be utilized for optoelectronic devices development.

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