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Handover Optimization Scheme for 5G Heterogeneous Network

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Abstract *— The worldwide boom in the use of wireless services has led to previously unheard-of levels of expansion for mobile connections and apps. Data traffic has increased dramatically as a result of this rise in activity, which has led to a research into solutions to meet this need. mm wave bands and very dense deployment are two of main features of fifth-generation (5G) networks. These solutions have resulted in a noticeable increase in the frequency of handovers (HOs), which has raised the incidence of dropped calls and unnecessary handovers. In order to address these problems during user mobility, it becomes imperative to optimize the control parameters associated with handovers. This research contribution provides a self-optimizing handover technique that leverages fuzzy coordination to enable smooth handovers as users move across multi-radio access networks. The suggested technique employs a fuzzy system that takes into account the S/I (signal-to-interference) plus noise ratio, cell load & user equipment speed to effectively balance the opposing requirements of mobility resilience and load balancing. The suggested approach effectively manages and optimizes mobility in a variety of mobile speed circumstances, decreasing ping-pong handovers, radio link failures, and handover delay. This is shown by simulation results. Additionally, the proposed technique greatly minimizes the outage probability when compared to other schemes discovered in the existing literature.*

Keywords*— *Handover Optimization, Self-optimization, Handover, 5G, Heterogeneous Networks

I. BACKGROUND

With the rise and widespread adoption of wireless services globally, mobile connections and applications are experiencing an unprecedented growth, placing significant demands on data traffic. Hence, mm wave bands & ultra-dense have been identified being crucial enabling solutions for 5G networking. Millimeter-wave (mmWave) bands and ultra-dense deployment are important elements and tactics used in 5G networks to improve network performance and capacity.

Between 30 and 300 gigahertz (GHz), a spectrum of radio frequencies is referred to as millimeter waves. These high-frequency bands allow for very fast data transmission rates and large bandwidths. By using mmWave frequencies, 5G networks can achieve substantially better data throughput and lower latency compared to previous generations of wireless networks. However, it's important to keep in mind that mmWave signals have a limited transmission range and are susceptible to signal attenuation due to barriers like grass and buildings. This issue is resolved by employing state-of-the-art beamforming, beam tracking, and antenna technology to guarantee dependable connectivity.

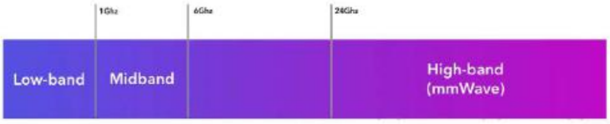


Fig 1.1: mmWave Frequencies

Base stations or small cells are ultra-densely deployed over a certain geographic area. Unlike traditional macrocells, which cover large areas, small cells are compact and may be installed in large numbers to provide targeted coverage and capacity. This technique aims to manage the increasing demand for data traffic by relocating the network closer to users, which reduces signal interference and improves network capacity and performance. A bigger number of concurrent users can be served by numerous tiny cells coexisting nearby thanks to ultra-dense deployment's improved spatial resource usage.

Service providers can take advantage of the benefits of high-frequency spectrum and localised coverage to deliver faster speeds, lower latency, and increased capacity to meet the growing demands of wireless communication and data-intensive applications by incorporating mmWave bands and ultra-dense deployment in 5G networks.

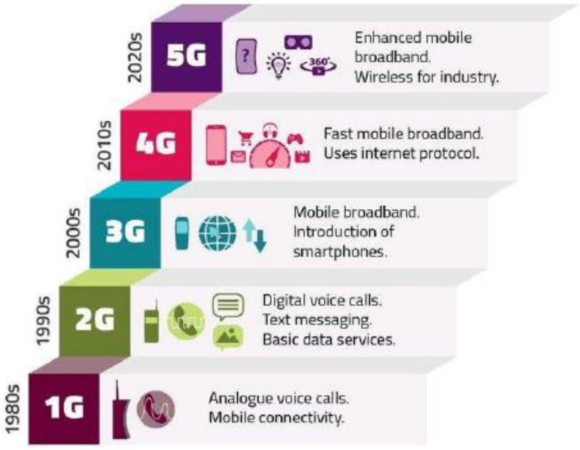
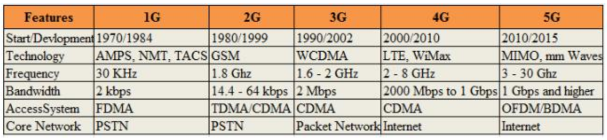


Fig 1.2: Mobile Network Generations

Different generations of mobile networks have developed over time, bringing new technology and capabilities with them. Following are the main mobile network generations:

- 1G stands for the first generation of commercially accessible analogue cellular technology. It had a constrained service area and only supported basic voice communication.
- 2G (Second Generation): 2G introduced digital cellular networks, which provided better call quality, more capacity, and SMS (text message) sending capabilities. GSM (Global System for Mobile Communications) was the most widely used 2G technology.
- Second and a Half Generation, or 2.5G, introduced packet-switched data transfer as a transitional technology between 2G and 3G. It provided faster data transmission rates, allowing for simple web browsing and constrained multimedia capabilities.
- Significant advancements in data transmission, including faster data rates and enhanced multimedia capabilities, were made possible by third-generation (3G) networks. It enabled the usage of mobile internet, video calling, and applications.
- Fourth-generation (4G) networks offer far faster data rates, lower latency, and more efficient networks overall. The introduction of WiMAX and Long Term Evolution (LTE) opened the door for sophisticated mobile applications including smooth multimedia streaming and video conferencing.
- The goal of the fifth generation (5G) of mobile networks is to provide extremely low latency, rapid data rates, and broad coverage. It presents novel technologies such as massive MIMO, mmWave bands, and network slicing. 5G promises to support new technologies such as the Internet of Things (IoT), virtual reality, augmented reality, and driverless vehicles.

Each generation builds on the one that came before it, increasing the capabilities and performance of mobile networks to meet the increasing needs of users for more complex apps and services, faster data rates, and more reliability.



Features	1G	2G	3G	4G	5G
Start/Devlopment	1970/1984	1980/1999	1990/2002	2000/2010	2010/2015
Technology	AMPS, NMT, TACS	GSM	WCDMA	LTE, WiMax	MIMO, mm Waves
Frequency	30 KHz	1.8 Ghz	1.6 - 2 GHz	2 - 8 GHz	3 - 30 Ghz
Bandwidth	2 kbps	14.4 - 64 kbps	2 Mbps	2000 Mbps to 1 Gbps	1 Gbps and higher
AccessSystem	FDMA	TDMA/CDMA	CDMA	CDMA	OFDM/BDMA
Core Network	PSTN	PSTN	Packet Network	Internet	Internet

Fig 1.3: Mobile Networks Features

In case of these generation of networks, many solutions based on various parameters, introduce a considerable increase in the number of handovers (HOs), leading to higher rates of unnecessary HOs and dropped call probabilities. In this context, the appropriate optimization of handover control parameters (HCPs) emerges as the primary factor for effectively addressing HO-related challenges during user mobility.

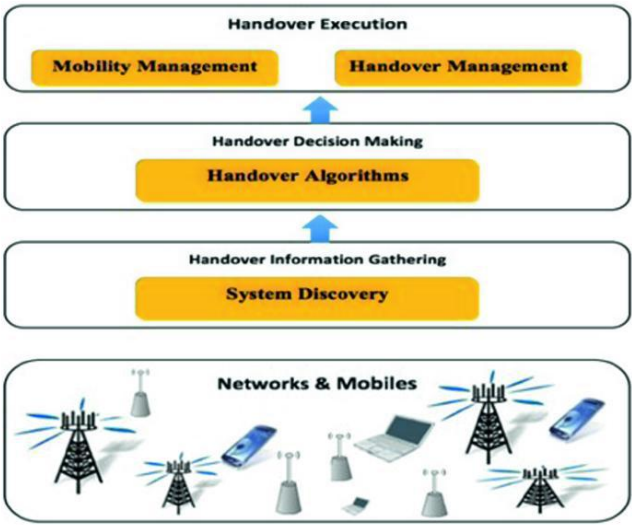


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Fig 1.4: Handover Decision Algorithm for Next Generation

(Source: Sapkale, P., Kolekar, U. 2020)

It is projected that the widespread use of tiny cells in next-generation networks will improve overall network performance. The demand for more capacity and coverage, which is a major challenge for telecommunications carriers, can be addressed by using tiny cells. From a technological perspective, there are a number of difficulties with this new deployment strategy in the context of 5G architectures. The two phases of the 5G rollout are standalone (SA) and non-standalone (NSA), which are standard-based paths for network implementation. Long-term evolution (LTE) and 5G are deployed side by side, with the primary objectives being improved mobile broadband, higher data throughput, and reliable connectivity. Long Term Evolution (LTE) is a standard for high-speed wireless data transport and communication. It is often referred to as 4G technology. With the deployment of this technology, cellular networks can provide mobile data services that are faster and more efficient than those provided by previous wireless technology generations. LTE offers significant improvements in data transfer rates, reduced latency, and increased network capacity over previous technologies such as 3G. It uses advanced modulation techniques, multiple input multiplexing (MIMO) antenna systems, and orthogonal frequency-division multiplexing (OFDM) to boost data throughput and enhance spectral efficiency. Among the many applications and services that LTE makes possible are cloud-based services, video streaming, online gaming, and video conferencing. Voice over LTE (VoLTE) is a technology that enables voice calls over data networks. LTE has been widely adopted globally and forms the backbone of many mobile networks, opening the door for improved mobile internet and the eventual switch to 5G technology.

Fig 1.5: Long Term Evolution (LTE)

After the technology is developed and all 3GPP specifications have been completed, the SA stage is put into practice. Future heterogeneous networks (HetNets) and 5G systems are both greatly impacted by the advent of new radio (NR) bands in terms of communication performance.

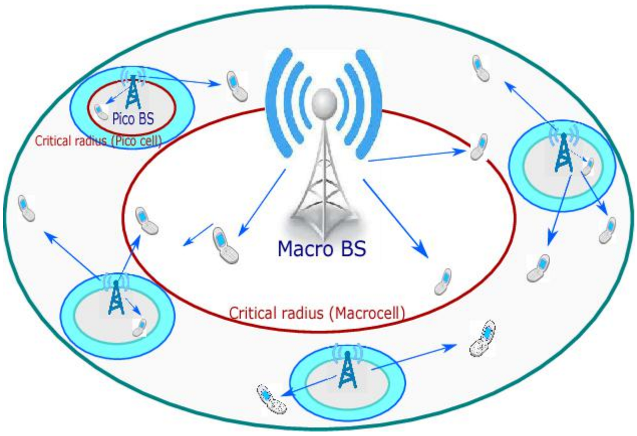


Fig.1.6: 5G Heterogeneous Network
(Source: Munir, H., Hassan, S.A., Pervaiz, H.B., Ni, Q., & Musavian, L. 2017)

A network architecture known as 5G Heterogeneous Networks (HetNets) combines various cell and base station types with various coverage areas and capacities to improve network performance and coverage. HetNets are made to handle the difficulties that come with growing data traffic, fluctuating user densities, and a variety of service demands in 5G networks. Different cell types, including as macrocells (which cover huge coverage areas), tiny cells (which cover localized areas), and relay nodes, are deployed in a 5G HetNet. These cells are arranged with care to optimize coverage and capacity in different areas. Microcells, picocells, and femtocells are further classifications for small cells, each with a distinct function in terms of coverage needs.

Advantages of 5G HetNets are as follows:

- By combining macrocells and small cells, HetNets provide more reliable coverage and increased capacity—especially in high-density areas with substantial data traffic. Small cells provide limited coverage and offload data from congested macrocells to improve network performance.
- Enhanced Data speeds: Because HetNets have more base stations per unit and are situated closer to customers, they offer higher data speeds and reduced latency. Small cells, in particular, offer better user experience and faster data transmission in densely populated areas.
- HetNets effectively distribute traffic across multiple cells, allowing for better usage of available spectrum. Interference is reduced and network efficiency is raised as a result.
- HetNets facilitate seamless transitions between different cells. As customers move from one coverage area to another, the network may dynamically switch the connection to the best cell to ensure continuous service.
- Because HetNets are flexible and scalable, it's easy to build new networks and expand ones that already exist. Tinier cells can be deployed in high-demand areas to meet expanding capacity requirements.

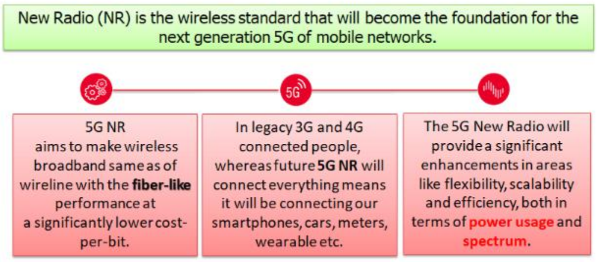
All things considered, 5G HetNets optimize network resources, boost capacity and coverage, and enhance user experience by fusing macrocells and tiny cells. In a range of environments, from rural areas with low population densities to metropolitan areas with high user densities, they are crucial for providing robust and consistent connectivity.

Release 16 marked the beginning of the 5G NR's mass development. The 5G NR uses both high-frequency (millimeter wave or mmWave) and low-frequency (sub-6 GHz) bands, with frequencies ranging from 24.25 - 52.6 GHz & 4.5-6 GHz, respectively. 5G New Radio (NR) is the name of the wireless air interface standard for 5G networks. The specification of 5G technology's device communication and data sharing protocols is an essential component. In contrast to previous wireless technology generations, 5G NR is meant to provide significantly faster data rates, reduced latency, and more network capacity.

- Higher Frequency Bands: Sub-6 GHz frequency bands (mid-band and low-band spectrum) and mmWave frequency bands (high-band spectrum) are both used by 5G NR. The utilization of millimeter-wave (mmWave) bands allows for extraordinarily high data rates and wider bandwidths. Beamforming techniques and advanced antenna technology are necessary for these high-frequency signals because of their limited range and vulnerability to impediments.

- Virtual reality (VR), augmented reality (AR), and other data-intensive apps may be accessed seamlessly with 5G NR's Enhanced Mobile Broadband (eMBB), which provides considerably better internet speeds than its predecessors. Larger MIMO (Multiple-Input Multiple-Output) antenna systems, wider bandwidths, and the use of contemporary modulation techniques all contribute to the higher data speeds.
- 5G NR has exceptionally low latency, making it possible for mission-critical and real-time applications. Ultra-reliable low latency communication (URLLC) is the term for this. Applications like remote robotic surgery, industrial automation, and autonomous cars that demand minimal latency and high reliability depend on this.
- Massive Machine-Type Communication (mMTC): 5G NR, which is designed to support a substantial number of connected devices, is what makes the Internet of Things (IoT) ecosystem viable. This makes it possible to handle a variety of IoT devices effectively, including smart homes and cities and industrial IoT applications.
- Advanced Radio Techniques: In order to improve network capacity, coverage, and spectrum efficiency, 5G NR makes use of advanced radio techniques. Among these techniques are dynamic spectrum sharing, sophisticated interference management, beamforming, and beam tracking. They optimize the use of radio resources, reduce interference, and improve overall network performance.
- One of 5G NR's features is backward compatibility, which aims to ensure it works with older cellular technologies. This makes it possible for 4G and 5G networks to coexist and switch over seamlessly, facilitating a seamless transition from older networks like LTE.

Overall, 5G NR provides increased data rates, low latency, huge connectivity, and support for a variety of use cases and applications, serving as the cornerstone for 5G networks. Significant wireless technology improvements are made as a result, creating new opportunities for consumers, businesses, and sectors of the economy.



New Radio (NR) is the wireless standard that will become the foundation for the next generation 5G of mobile networks.

5G NR aims to make wireless broadband same as of wireline with the **fiber-like** performance at a significantly lower cost-per-bit.

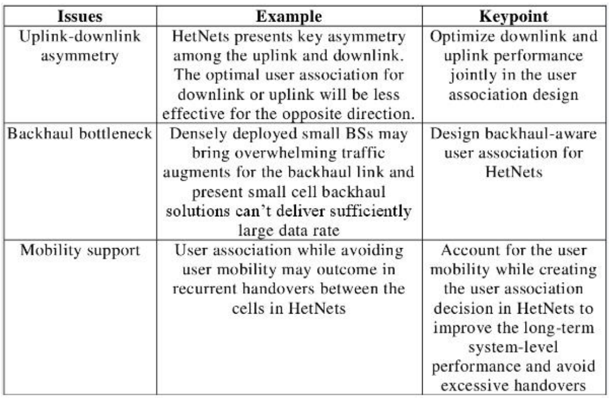
In legacy 3G and 4G connected people, whereas future **5G NR** will connect everything means it will be connecting our smartphones, cars, meters, wearable etc.

The 5G New Radio will provide a significant enhancements in areas like flexibility, scalability and efficiency, both in terms of **power usage** and **spectrum**.

Fig.1.7: 5G New Radio (NR) Characteristics

However, due to the incredibly short wavelengths involved, the high-frequency band only gives a little amount of coverage. User mobility and network installations are critical to communication performance in limited area coverage scenarios because they are directly related to the channel model [4]. Due to the high deployment density and frequent updates of access points required by the mmWave cells' short range, handover, handover failure denoted by HOF, handover ping pong depicted by HOPP and the radio link failure abbreviated as RLF impacts are more likely to occur [5]. Equipment (UE) attributes such as Time to Completion (TTT) and Transition Gap (HOM) and Performance Control Parameters (HCP) determine how an HO state is created based on signal quality and channel status.

Table 1.1: 5G Network Challenges



Issues	Example	Keypoint
Uplink-downlink asymmetry	HetNets presents key asymmetry among the uplink and downlink. The optimal user association for downlink or uplink will be less effective for the opposite direction.	Optimize downlink and uplink performance jointly in the user association design
Backhaul bottleneck	Densely deployed small BSs may bring overwhelming traffic augments for the backhaul link and present small cell backhaul solutions can't deliver sufficiently large data rate	Design backhaul-aware user association for HetNets
Mobility support	User association while avoiding user mobility may outcome in recurrent handovers between the cells in HetNets	Account for the user mobility while creating the user association decision in HetNets to improve the long-term system-level performance and avoid excessive handovers

(Source: Reddy, S.R., & Venkatarama, S. 2023)

MRO & LBO routines compete for attention by independently optimizing handover control parameters (HCPs). The performance of the handover (HO) and the number of radio link failures (RLFs) may both be significantly impacted by this dispute. Existing literature indicates that this conflict's resolution is still an open question, and recent investigations have not yet identified the best answers. The MRO function has been the main focus of recent research, which has suggested ways to optimize the handover margin (HOM), time to trigger (TTT), or both [6-8]. In one study [6], a fuzzy logic control (FLC) method was put forth to modify the HOM in 4G HetNets based on user velocity and radio channel quality. Another study [7] examined several HCP settings under various mobile speed situations to look into the efficiency of HCPs in 5G networks. A compensation between HO performance indicators was evident in simulation. Despite the fact that these suggested remedies improved in terms of lowering RLFs, an ideal solution is still a long way off. Additionally, because of the tiny cell size in ultra-dense HetNets, these solutions are not suitable because the frequency of handovers rises. Coordinating the MRO and LBO operations to adjust HCPs appropriately, it is possible to address this problem and achieve an ideal solution.

Problem Statement

Introduction and popularity of wireless services globally, mobile connections and applications are expanding at a never-before-seen rate, significantly raising demands of data traffic. Due to this, ultra-dense deployment and millimeter-wave bands were taken into account as major enablers for 5G network generations. But these answers dramatically boost no of handovers (HOs), therefore lowering call probabilities and boosting the rate of needless HO. In this sense, the essential element that can effectively manage HO concerns during user mobility is optimizing HO control parameters suitably.

Purpose of the Study

To achieve uninterrupted Handover (HO) as users roam across multi radio networks, this research aims to propose fuzzy coordinated handover scheme which is self-optimizing. The proposed method makes use of fuzzy system that takes into account parameters which include cell load, user equipment (UE) speed, and SINR - signal-to-interference-plus-noise ratio. The aim is to address conflict that exists b/w load balancing & mobility robustness in order to provide seamless HO.

Research Questions

- Are ultra-dense deployment and millimeter-wave bands among the major enablers for fifth-generation (5G) networks?
- Is properly optimizing HO control parameters the key to effectively addressing HO difficulties during user mobility?
- Can users travel freely in multi-radio access networks by adopting fuzzy self-optimizing HO scheme?
- Can a fuzzy system be used in any suggested solution to balance the needs of load balancing functions and mobility robustness, taking into account input parameters of cell load, UE speed, & SINR?

II. SIGNIFICANCE OF RESEARCH

The research findings provide a practical contribution by emphasizing the significance of input parameters and coordination technique while building intelligent handover (HO) systems for densely populated urban HetNets. These results show that when users switch between cells, these characteristics are critical in improving network performance overall.

III. LITERATURE REVIEW

It is projected that the introduction of tiny cells into next-generation networks will improve overall network performance. It is also a workable answer to the problems with capacity and coverage that telecom companies are facing. However, there are a number of technical issues with this new deployment strategy that must be resolved in the context of 5G networks. Non-standalone (NSA) and standalone (SA), which are standardized routes to 5G network implementation, are the two stages of 5G deployment [1]. The main goals of 5G deployment during the NSA stage are to boost data rates, enhance mobile broadband, and guarantee dependable connectivity.

Once the technology is developed and the 3GPP specifications are complete, the SA stage is put into practice. Future heterogeneous networks (HetNets) and 5G systems are both greatly impacted by new radio (NR) bands in terms of communication performance. Release 16 [2] introduces the development of 5G new radio. It operates between 4.5 GHz and 6 GHz and 24.25 to 52.6 GHz and 52.6 GHz, respectively, in the low-frequency (sub 6 GHz) and high-frequency (mmWave) bands [3]. Due to its incredibly tiny wavelengths, the high-frequency band, however, only provides a little amount of coverage. User mobility and network deployments, which are intricately linked to the channel model and have an impact on communication performance in locations with limited coverage, are two such factors [4].

Deploying mmWave cells in dense topologies with limited range necessitates frequent updates to access points, increasing the risk of radio link failure (RLF), HO failure (HOF), HO ping pong (HOPP), & handover (HO). [5]. The frequency of HO occurrences is dependent on a number of factors, including signal intensity, channel conditions, UE behavior, and HO control parameters (HCP) such time-to-trigger (TTT) and HO margin (HOM). In order to enhance user experience, it's important to look consider communication performance during user mobility in HetNets. Because the MRO and LBO processes are independently optimized for HCP, there is a conflict between them.

RLFs may increase and the overall performance of the HO may be compromised. The available study indicates that there is more work to be done in order to resolve this paradox, and the most optimal solutions have not yet been found. Researchers have focused on the MRO function and offered recommendations for enhancing TTT, HOM [6–8]. A fuzzy logic control (FLC) strategy was put forth to modify HOM in 4G HetNets based on user velocity and radio channel quality.

In [8], the authors examined several HCP settings under various mobile speed scenarios to examine the efficacy of HCPs in 5G networks. The outcomes of the simulation showed a trade-off between the HO performance indicators. Although the reduction of RLFs using these suggested techniques was improved, finding the ideal solution still poses difficulties. Additionally, these techniques do not work in ultra-dense HetNets where the tiny cell size leads to an increase in the frequency of HO events. However, by combining the MRO and LBO operations to modify HCPs appropriately, this problem can be addressed and an ideal solution can be reached.

Because the expected HO control parameters produced are not coordinated. Through an increase in the frequency of RLFs and the risk of outages, this paradox ultimately results in substandard system performance [9–12]. Additionally, in extremely crowded networks with high-speed mobile users, this problem could get worse. Therefore, it is necessary to enhance current solutions even further.

Data traffic has increased dramatically as a result of the rapid development of mobile devices and sophisticated apps. By 2025, there are expected to be 8.9 billion mobile customers, with 88 percent of them using mobile broadband connections, according to an Ericsson report released in June 2021 [13]. Over the next five years, the demand for mobile data will expand 1,000-fold as a result of the internet connectivity of billions of additional gadgets and home appliances [14]. The spectrum gap will expand if this trend persists, requiring the activation of more spectrum bands [15, 16].

Heterogeneous Networks (HetNets) have become a viable and efficient response to the growing demand for high data rates and seamless communication. HetNet is the name of a wireless network that incorporates tiny cells of various shapes and sizes beneath the primary macrocell. HetNet's enhanced coverage, increased throughput, energy efficiency, and Quality of Service (QoS) have drawn considerable attention. As a result, the development of HetNet is seen as a key component of the Fifth Generation (5G) wireless mobile communication systems. Small cells can be installed in residences, workplaces, retail establishments, sporting venues, airports, and other densely populated locations [17]. Microcells, Pico cells, relay nodes, and femtocells are a few examples of small cell types. In order to meet the demands for high data rates and coverage, researchers and operators are increasingly motivated to adopt ultra-dense HetNets in 5G wireless communication networks.

In cellular networks, handover (HO) is essential for managing mobility [18]. HO is the process of moving a mobile user's active connections from their serving cell to a destination cell while maintaining QoS. Performance of the network is strongly impacted by the HO process in next-generation wireless HetNets. For instance, the limited coverage area of small cells in 5G HetNets causes an increase in the amount of handovers between these cells. User performance suffers from frequent handovers and increasing signaling overheads. HO schemes' main goals are to reduce frequent handovers, HO failure rates, HO delays, HO interruption times, energy usage throughout the HO process, and ping-pong events while raising HO success rates [42. 43].

In order to improve HO judgements, a lot of study has been done. Xenakis et al. [19] introduced a HO decision algorithm in 2015 that took into account several design principles. Chinnappan et al. (2016) [20] introduced Vertical HO choice methods to guarantee seamless connectivity and uninterrupted service across different Radio Access Technologies (RATs). Zang et al. [21] introduced an efficient HO decision algorithm based on Markov Decision Process (MDP) in 2018 with the goal of enhancing user experience in mmWave HetNets. Using user mobility information, this method effectively handles beamforming misalignments and signal obstructions. Ahmed et al. [22] conducted a comprehensive study on Fifth Generation Vehicular Ad Hoc Networks (5G-VANET) in 2018, focusing on challenges related to mobility, interference, congestion, jamming, and coverage. For high-speed railway networks, Bang et al. [23] presented a machine learning-based HO decision approach in 2019 using a Bayesian regression model to predict cell boundary-crossing time. Handovers can start earlier with this method than with conventional methods. In order to optimize HO in vehicular networks and increase average system resource utilization, Gharsallah et al. [24] presented a novel multi-criteria network selection mechanism in 2019. The mechanism achieved uniform traffic load distribution among available networks by reducing HO failure, HO delay, and packet loss rates.

The telecoms sector works tirelessly to improve its infrastructure in order to handle the increasing traffic demand. Reducing cell size and deploying several Smallcells alongside Macrocells is one novel strategy. The deployment of Smallcells beneath Macrocells was made possible by the LTE-A upgrade and release-12 of the 3GPP, increasing the capacity of cellular networks [25]. However, several research [26, 44] draw attention to potential interference problems linked to such deployments. Deploying more cells is also not cost-effective from the operator's standpoint because it adds to the operator's expenses for power, property leasing, deployment, and maintenance.

The user equipment (UE) in a cellular network receives services from just Macrocells in classic mobile cellular communication systems, which have a homogenous network design. Similar transmit power, antenna designs, Radio Access Technologies (RATs), modulation techniques, Signal-to-Noise Ratios (SNRs), and Evolved Packet Core (EPC) are used by Macrocells in such homogenous networks to service UEs throughout all cells [27]. As a result, these conventional homogenous networks are unable to satisfy the data traffic requirements of 5G networks and fail to provide acceptable coverage, particularly at cell edges.

Cell splitting is an alternative method for solving this issue. However, this method is expensive and unworkable for placing numerous Macrocells in a small area [28]. Because of this, advanced LTE-A systems use a hierarchical cell deployment strategy to implement a more effective and affordable solution. Cells of various sizes can be placed across macrocells in accordance with 3GPP specifications, creating the multi-cell network architecture known as HetNet (Heterogeneous Network) [29].

HetNet architecture deployment is advantageous to subscribers and operators alike. This strategy increases the cellular system's overall throughput while extending the coverage area. The installation of Smallcells is also simple and inexpensive [30]. Handover is a key idea in wireless cellular communication that enables UEs to switch between cells without pausing their sessions. A crucial part of the handover process is efficient UE switching between cells, which maintains strong signals, balances load, lowers costs, and consumes the least amount of energy.

There are two main categories of handovers: Hard Handovers and Soft Handovers. A UE breaks its connection to the current cell via a Hard Handover process, also known as a break-before-connect mechanism, and immediately connects to a new cell. Contrarily, Soft Handover, also known as a connect-before-break strategy, establishes a new connection before severing the current one [45].

Additionally, there are two additional handover types: vertical handovers (VHO) and horizontal handovers (HHO). When a UE changes networks while still connected, HHO happens [31]. VHO, on the other hand, permits seamless UE mobility between various networks [32]. The use of new technologies has enhanced the significance of VHO in 5G and other wireless networks.

Additionally, 5G wireless networks are set to incorporate cutting-edge innovations like HetNet, NR (New Radio), vehicle-to-vehicle (V2V) communication, and intelligent drones. These technologies can be used to satisfy the rising demand for high data rates [33]. HetNet development is complicated by frequent handovers and ping-pong effects, which could harm the performance of wireless networking systems [34]. As a result, managing mobility and effective handoff between different technologies is essential and demands proactive care.

Consequently, effective handover procedures have been discovered through a thorough literature review. In order to reduce power usage during data transmission, a VHO-based technique with a dynamic power control mechanism is proposed in [35]. Similar to this, Fang Wang et al. [36] suggest an effective VHO approach that formulates the method using a Markov Decision Process (MDP). After taking into account the queue length and channel state, this method conducts VHO.

A QoE-Aware Intelligent VHO strategy is described in a different work by Jiamei Chen et al. [37] that is especially made to meet the necessary Quality of Service (QoS) for different applications while providing seamless handover in 5G HetNet. A unique handover choice method is also introduced in [38] to reduce changeover failure and ping-pong effects in the extremely dense 5G HetNet. The authors build a fuzzy logic system that has a hysteresis margin that is dynamically determined, and they show that it performs better than other methods.

Additionally, numerous techniques that try to reduce call dropouts, ping-pong effects, and radio link failures (RLF) are presented in [39-41]. [39] offers a fuzzy multiple-cells selection approach that optimizes the handover process by taking into account UE uplink circumstances, resource block utilization, and selection criterion measurements. The capacity is enhanced while the effects of ping-pong and handover failures are successfully reduced.

IV. RESEARCH METHODOLOGY

The main strategy and methodology revolve around developing a clever coordinated scheme that makes use of fuzzy FLC system to smoothly adjust Handover Control Parameters (HCPs) based on input variables like SINR, cell load & UE speed. To efficiently handle the handover procedure b/w serving and target base stations, a HO decision algorithm will be suggested. Various handover performance measures will be used to thoroughly analyze performance of the proposed scheme to already completed relevant work.

Handovers & Optimization

- This study discusses Hard Handovers (Break-Before-Make) and Soft Handovers (Make-Before-Break).
- Vertical Handovers (VHO) occur when switching between different technologies (e.g.,

LTE to 5G), and Horizontal Handovers (HHO) happen within the same technology.

- In 5G, the handover process is optimized using fuzzy logic to reduce unnecessary handovers, minimize radio link failures (RLFs), and improve mobility robustness.
- Optimized Handover in 5G: The proposed self-optimizing fuzzy logic-based handover optimizes handover control parameters such as Handover Margin (HOM) and Time-to-Trigger (TTT)

The methodology will be centered on achieving the following goals:

- Our strategy entails creating a clever, coordinated system that uses a fuzzy logic controller (FLC) to automatically modify the handover control parameters (HCPs) in response to inputs like SINR, cell load, and UE speed.
- To efficiently handle the handover process b/w serving & target base stations, researcher proposes algorithm for Handover (HO) decisions.
- Using several measures for HO performance and in contrast to previous similar work, researcher evaluated & compared performance of proposed methodology.

Using Signal-to-Interference-Plus-Noise Ratio (SINR) Instead of A-I Ratio

- The A-I Ratio (Antenna-to-Interference Ratio) is not commonly used in cellular networks because SINR provides a better indication of the quality of the received signal by considering both interference and noise.
- SINR is a widely accepted metric in cellular communication because it directly impacts data rates, channel quality, and handover decisions

The analysis and discussion of three crucial aspects—Handover Ping Pong (HOPP), Radio Link Failure (RLF), and Handover (HO) latency—are the main topics of the performance evaluation of the suggested strategy. MATLAB simulations will be run to examine and validate the effectiveness of the suggested approach.

Conceived Model

A total of 62 large hexagonal cells running on 4G and 184 tiny cells running on 5G make up the system configuration, which spans a 7.5 by 7.5 km^2 region. Small cells are consistently positioned in middle of each mega cell sector. It is believed that the coverage of the small cells does not overlap. Our earlier research articles proposed this system concept. The tiny cells have omni-directional antennas, but each sector of the large cells is outfitted with directional antennas. The network model allows UE for connecting single evolved eNodeB at medium access control layer through supporting radio access technology.

Either the small cells or the macro cells in the system provide the User Equipment (UE) with the desired traffic. No presumptions are made in this study about any impediments, including trees, structures, or mountains. As a result, it is expected that all monitored UEs can move freely in all directions during the simulation, allowing for line-of-sight communication linkages. The X2 interface is used for direct cell-to-cell communication during handover (HO) processes. The X2 interface supports the HO process by facilitating the sharing of parameter configurations, operational data, and Radio Link Failure (RLF) status.

Only a small number of jobs are completed on the UE side, with the majority of computing operations taking place at the base station. However, HO assumes some of the required computational tasks when a change in the central management unit is necessary. To optimize the Handover Control Parameters (HCPs), network collects handover information from each cell. A serving cell keeps track of a UE's state when it moves from one cell to another by receiving periodic measurement reports from the UE. The serving cell then decides to choose a target cell using an algorithm that is described. The table below provides the simulation parameters for this study.

Table 3.1: Simulation Parameters Frequencies Used in 4G & 5G

S/No	**Configured Parameters**	**Parameters Values**	
		4G Cell	**5G Cell**
1	Cell radius in meters	490	190
2	No of eNB	63	184
3	Carrier frequency in GHz	2.2	26
4	System bandwidth in MHz	18	490
5	Transmit power (dBm)	45	29
6	Inter-HO preparation time in mili seconds	59	
7	Measurement time in mili seconds	49	
8	Intra-HO preparation time in mili seconds	9	
9	User Equipment height in meters	1.4	
10	SINR threshold (dB)	-9	

- 4G (LTE) Frequencies: Operates in the sub-6 GHz spectrum (2.2 GHz, 3.5 GHz, etc.).
- 5G Frequencies: Uses both sub-6 GHz (4.5 GHz - 6 GHz) and mmWave (24.25 GHz - 52.6 GHz).

The projected Handover Control Parameters (HCP) values optimized by MRO & LBO functions are not coordinated in the existing Handover (HO) solutions. This lack of coordination results in poor system performance, which increases the likelihood of service interruptions and rates of Radio Link Failure (RLF). This issue is especially important for consumers on ultradense networks and high-speed mobile devices. For the purpose of ensuring a smooth transition and maintaining the proper level of service quality, it is therefore necessary to keep developing the current solutions.

To solve this problem, a dynamic coordinated method is proposed that disables the LBO function and uses a different strategy for its input parameter (cell load). UE speed, SINR, cell load, and other input parameters may all be seamlessly modified using a fuzzy logic control system in this intelligent coordinated manner. The structure of the proposed system merges MRO & LBO functions by predicting values for HCPs. It resolves the conflict issue and simplifies the interaction between the functions. In order to optimize handover performance, this well-coordinated plan considers a number of factors and automatically adjusts HCPs using fuzzy logic control.

To sum up, the suggested method offers a workable fix for the current state of the HO solutions' lack of coordination. It seeks to enhance system performance, minimize conflicts, and provide a smooth handover experience for high-speed mobile users and extremely congested networks in order to provide good quality of service.

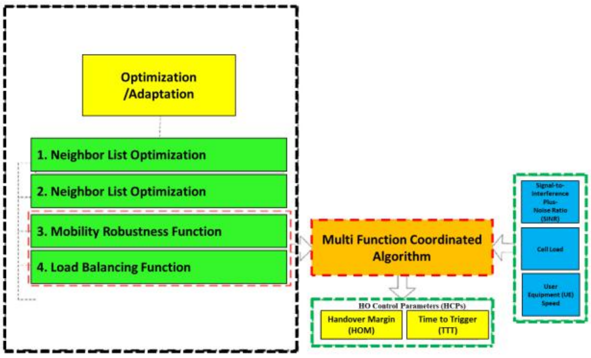


Fig.3.1: Proposed Solution Scheme Framework

The proposed approach includes a dynamic self-optimization mechanism to adjust the Handover Control Parameters (HCPs) based on input parameters from the fuzzy system. The procedure of estimating HCPs also addresses and resolves conflicts between MRO and LBO functions by accounting for cell load factors.

Number of Channels in 4G & 5G Cells & What Happens if no Channel is Available

4G uses OFDMA (Orthogonal Frequency Division Multiple Access) with 18 MHz bandwidth, and 5G uses wider bandwidths up to 490 MHz. If no channel is available, the User Equipment (UE) experiences handover failure, leading to call drops or increased latency, affecting Quality of Service (QoS).

Log Probability (Log P) is not explicitly mentioned or defined in this study, however, logarithmic functions are used in velocity-based handover optimization calculations.

Simulation & Discussion

In respect to Handover Preparation and Execution Time (HOPP), Radio Link Failure (RLF), and Handover (HO) delay, the performance of the suggested scheme is assessed and addressed. Simulations are analyzed using MATLAB in order to validate effectiveness of the suggested method. It is an environment and high-level programming language for numerical calculation, data analysis, and visualization are called MATLAB. Since matrix operations are essential to many scientific and engineering applications, MATLAB, which stands for "MATrix LABoratory," is named after them.

- Operations on matrices: MATLAB has a number of robust built-in operators and functions for working with matrices and arrays. It is effective for processing big data sets because it makes complex mathematical calculations simpler and lets you operate on entire arrays at once.
- Big Library: MATLAB offers a wide range of mathematical, statistical, signal processing, image processing, and machine learning tools. These capabilities let users to do a wide range of tasks, from analyzing and displaying data to solving equations.
- Interactive Environment: For an interactive context, MATLAB provides a command-line interface (CLI) and graphical user interface (GUI). The CLI facilitates experimentation and rapid prototyping by allowing commands and scripts to be executed line by line. The GUI provides a visual interface for performing tasks through interactive menus and tools.
- Data visualization: As visual representations of data, MATLAB offers powerful tools for creating 2D and 3D plots, charts, graphs, and pictures. You may make animations, annotate visualizations, and change their design to effectively exhibit and study data.
- Integration and Interoperability: MATLAB can be integrated with C, C++, Java, Python, and other computer languages. It provides toolboxes and APIs to facilitate data exchange, invoke the functionality of other languages, and leverage pre-existing code libraries.
- Application Development: The Application Compiler in MATLAB makes it possible to create standalone applications. This means that you can package your MATLAB code and distribute it as an executable file, which can be used on computers that aren't running MATLAB.
- A framework for modeling, simulating, and assessing dynamic systems is called Simulink. MATLAB has a graphical interface called Simulink. It's widely used in the design and simulation of control systems, digital signal processing, and other complex engineering systems.

Numerous disciplines, including engineering, physics, mathematics, economics, biology, and data science, use MATLAB. Researchers, engineers, and scientists frequently use it for numerical analysis, data visualization, and algorithm development because of its adaptability, large library, and simple syntax.

Mathematical Modelling

Fuzzy Logic Design Details:

This study describes a fuzzy logic-based handover control scheme that optimizes handover parameters dynamically.

Three fuzzy logic controllers (FLCs) are used:

- SINR-based FLC (for signal quality evaluation)
- Cell Load-based FLC (for network balancing)
- User Speed-based FLC (to adjust handover parameters dynamically)

The fuzzy inference system uses input variables (SINR, Cell Load, UE Speed) to predict Handover Margin (HOM) and Time-to-Trigger (TTT)

SINR $f(\gamma)$, cell load $f(\iota)$, and user velocity $f(v)$, are foundation of suggested self-optimization strategy. The fuzzy system receives these functions as inputs, and the weights given to each constrained function are used to predict the precise values of the Handover Control Parameters (HCPs), more precisely the HOM levels & TTT interval, for individual User Equipment's (UEs). The following formulation can be used to represent the weight function for the HCPs:

$$f(\gamma, \iota, v) = \Omega_{\gamma} \times f(\gamma) + \Omega_{\iota} \times f(\iota) + \Omega_{v} \times f(v)$$

Where $\Omega\gamma$, $\Omega\iota$ and Ωv are normalized weights SINR, cell traffic load (TL) & user velocity and are written as shown below.

$\Omega_{\gamma} = (w_{\gamma} / w_{t})$
$\Omega_{\iota} = (w_{\iota} / w_{t})$
$\Omega_{v} = (w_{v} / w_{t})$

$$w_t = w_\gamma + w_l + w_v$$

SINR, cell load & user velocity weights are indicated as w_γ, w_l and w_v respectively. According to a popular terminology employed in current literature, these weights are regarded as fixed constants within a given range of values. The second function, cell TL f(ι), embodies the Load Balancing Optimization (LBO) aspect, responsible for maintaining balanced cell load by adjusting HOM values & TTT intervals to generate suitable Handover decisions (HOD) towards a target eNB. Expression for second function can be calculated as:

$$f(\iota) = \frac{\iota T - \iota S}{\iota\, max}$$

Here ι_T and ι_S depict cell load of target & serving eNBs. ι_{max} depicts max cell load. Fuzzy Logic Control (FLC) of cell consists of 2 fuzzy sets (ι_T and ι_S) inputs & 1 output set ω_ι, whereas membership function consists of 3 & 4 different levels for input and output sets.

$\iota_T = \iota_S$ = {"low", "medium", "high"},

ω_ι = {"low", "average", "high", "very high"}

In order to modify the Handover Control Parameters (HCPs) based on the velocity of the User Equipment (UE), the third function, UE velocity f(v), is essential. It makes sure that the TTT intervals and HOM values are properly adjusted according to UE speed, avoiding any needless handovers which might occur during UE mobility. The UE velocity can be changed using this function, which is modeled as an unbounded function.

$$f(v) = log_2\ (1 + v_t)$$

This function can be expressed as follows and has been further improved to comply with the proposed method in this study:

$$f(v) = 2\, log_2\left(\frac{v_t + v_{max}}{v_{max}}\right) - 1, -1 \le f(v) \le 1$$

UE speed at "t" & max UE speed 160 km/h) in urban/suburban cars are represented by v_t and v_{max}. Velocity function restricted by lower & upper bounds (−1, 1). Slow vehicle speed results in the minimal lower bound level of f (v), and fast vehicle speed of v_{max} leads to maximum upper bound level of f (v). The inputs of f (v) are supplied as v_t and v_{max}. The velocity FLC is characterized by single input represented as v & output represented as fuzzy set ω_v. Fuzzy membership function comprises four/five levels of input/output sets, respectively.

v = {very slow, slow, moderate, fast, very fast},

ω_v = {"low", "average", "high", "very high"}.

The main goal of developing the suggested system is to choose the output variables that, based on the input functions, correlate to the estimated Handover Margin (HOM) and Time to Trigger (TTT) interval levels. The adapted HOM, indicated by the symbol (HOM), is the first output variable. It is calculated by dividing the $\overline{HOM}$ or HOM_{max} value by weight function f (γ , ι, v). SINR levels of target and serving eNBs in relation to the SINR threshold γth also affect value of HOM. The following is an expression for the estimated value of (HOM):

$$\Delta(HOM) = \begin{cases} \overline{HOM}(f(\gamma, \iota, v)), \text{if } \gamma T, S \le \gamma th \parallel \gamma T, S \ge \gamma th, \\ HOM\ max\,(f(\gamma, \iota, v)), \text{if } \gamma T \le \gamma th \gamma S \ge \gamma th, \\ f(\gamma, \iota, v), \text{if } \gamma S \le \gamma th \gamma T \ge \gamma th, \end{cases}$$

$$\overline{HOM} = \frac{HOM_{max} - HOM_{min}}{2}$$

where HOM_{min} and HOM_{max} depict min & max HOM, that carries values of 0 dB and 12 dB. Second output is TTT that produces tunable value b/w 0 - 650 ms by adding new FLC called TTT-FLC with 3 inputs 1 output of fuzzy sets. The TTT-FLC adjusts TTT interval according to outputs of bounded functions.

Fuzzy membership function of TTT-FLC has 3/4 levels of input and output sets.

$$f(\gamma), f(\iota), f(v) = \{\text{"low"}, \text{"moderate"}, \text{"high"}\},$$

$$\Delta b(TTT) = \{\text{"short"}, \text{"average"}, \text{"long"}, \text{"very long"}\}.$$

After updating Δ (HOM) & Δ (TTT), HOD is taken according to reference signals received power written as RSRP for serving cell RSRPS and target cell RSRPT as per algorithm.

Algorithm HO Triggering and Decision

```
Calculate SINR, cell Traffic Load TL & UE speed
if reference signals received power $RSRP_T > RSRP_S + \Delta(HOM)$ then
    if time to trigger Trigger timer $\geq \Delta(T\ T\ T)$ then
        HO margin HO Decision ←− True
        Send HO Request
    else HO Decision ←− false
        Run Trigger Timer
    end if
else HO Decision ←− false
    Reset Trigger Timer
end if
```

V. PERFORMANCE ANALYSIS

Effectiveness of the suggested approach is examined in respect to HO ping pong (HOPP), Radio Link Failure and HO delay. Simulations in MATLAB are run to investigate and validate the suggested approach. Five alternative mobile speed scenarios are taken into consideration to assess network performance: 10, 40, 80, 120 & 160 km/h. Investigating modified values of TTT and HOM is part of the proposed scheme's evaluation. The simulation's HOM and TTT parameters are initially set at 5 dB and 480 ms, respectively. However, if necessary, these values can be changed during user measurements, especially if the simulation time (t) is greater than 1. Based on the suitable speed scenarios, the suggested technique calculates the correct values of HOM and TTT. Additionally, a comparison is made b/w proposed scheme and existing Souza Scheme, that is based on the FLC (Fuzzy Logic Control) system (D. D. S. Souza. 2020).

At various mobile speeds, the accompanying figure shows the average probability of HO ping pong (HOPP) for both the suggested method and the Souza approach. These findings are based on a review of all users who were being tracked and simulation time. By lowering the HOPP rate in all mobile speed scenarios, suggested strategy clearly out performs Souza scheme. This improvement is made possible by the optimized HCPs and coordinated MRO-LBO functions, which successfully manage the handover process and avoid conflicts between LBO and MRO. As a result, the HOPP rate has been significantly reduced, which reduces the amount of network resources that overhead signaling consumes.

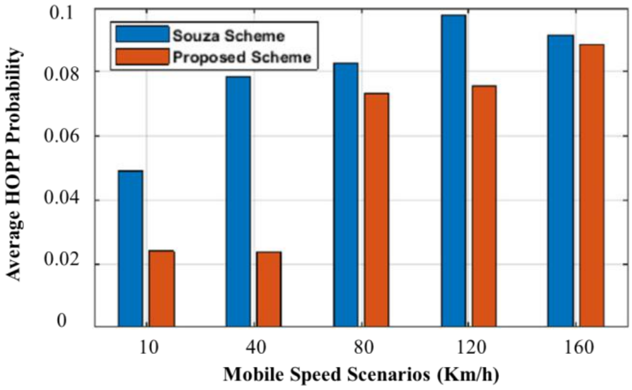


Fig.4.1: Ave HOPP probability (Conceptualized & Souza schemes in relation mobile speeds).

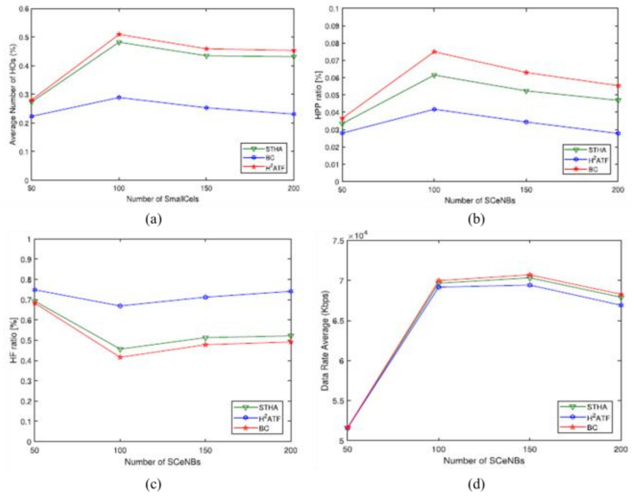


Fig.4.2: Souza approach: Simulation Scenarios (a) Average number of HOs (b) HPP Ratio (c) HOF Ratio (d) Data Rate Average

When three distinct user equipment (UE) speeds are taken into account, Figure 4.3 shows the average chance of Radio Link Failure (RLF) for both the proposed scheme and the Souza scheme over time. As contrast to high-speed cases, the results show a drop in the RLF rate at lower UE speeds. These findings suggest that a low HOPP rate may result in an elevated RLF rate when compared to those in Figure 4.1. A high HOPP rate, on the other hand, leads to overhead signaling, which could lower the RLF rate. Therefore, choosing the right settings for Handover Control Parameters (HCPs) involves making a choice between regulating RLF and reducing HOPP.

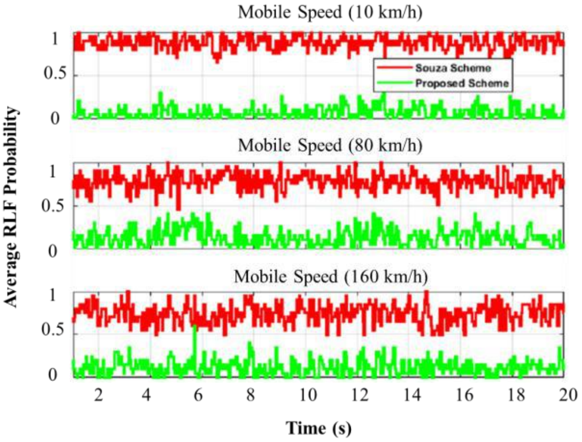


Fig.4.3: Av prob of RLF with respect to mobile speed

A boxplot of the Handover (HO) latency in response to various mobile speed circumstances for all monitored users is shown in Figure 4.4. Notably, when compared to high-speed scenarios, suggested technique significantly reduces HO delay, especially at moderate speeds like 10 & 40 km/h. But in the high speed cases of 120 & 160 km/h, similar median values of HO delay are seen.

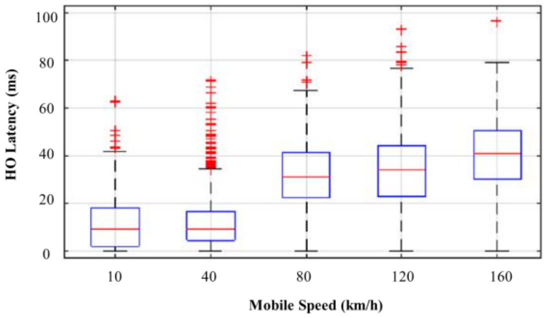


Fig. 4.4: Ave HO latency of proposed scheme with respect to mobile speed

A comparison between the suggested scheme and the Souza method for various mobile speed circumstances is shown in Figure 4.5. At all mobile speeds, proposed scheme consistently outperforms Souza design, resulting in improved connection and increased network service reliability. As shown in Figure 4.1, the suggested technique also successfully lowers HOPP rates, conserving network resources. It is important to note that an increased rate of HO latency during the handover process may cause the transmission of numerous packets to be interrupted, adding to the network's time delays.

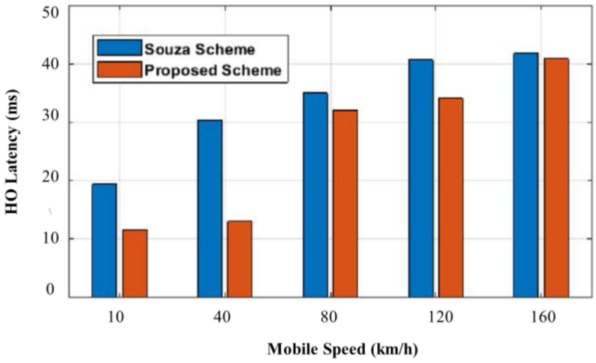


Fig.4.5: Average HO latency of proposed scheme with respect to mobile speed

Figure 4.6 compares the Souza and proposed schemes' overall outage probabilities for all monitored users and mobile speeds. As user equipment (UE) speed increases, the likelihood of an outage tends to rise as well. The outage likelihood, on the other hand, lowers when UE travels at slower speed because the best target evolved NodeB (eNB) is chosen, one with a high SINR and low load. Notably, compared to other techniques, the suggested scheme consistently achieves decreased outage probability over time. Reduction in outage likelihood occurs when serving eNB's signal strength drops below a threshold value is the cause of this improvement. Overall, the proposed plan successfully lowers all handover performance parameters, which significantly lowers the likelihood of an outage.

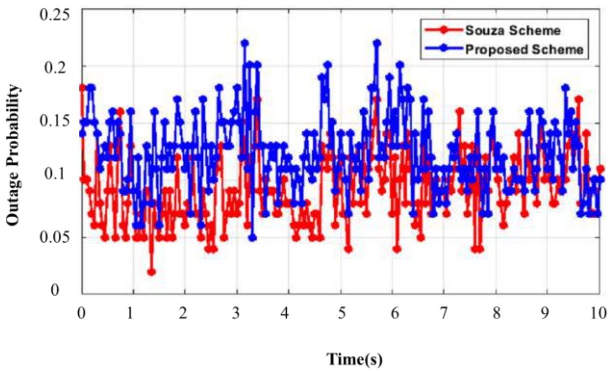


Fig.4.6: Overall outage probability versus time.

This study includes multiple performance evaluation graphs:

- Handover Ping Pong (HOPP) Probability vs. Speed
- Radio Link Failure (RLF) vs. Speed
- Handover Latency vs. Speed

These graphs demonstrate performance improvements of the proposed scheme compared to existing methods. While three graphs provide a strong comparative analysis, additional metrics like outage probability and handover success rates could strengthen for future research.

VI. CONCLUSIONS AND FUTURE WORK

Conclusions

Research presents a dynamic coordinated handover (HO) solution to handle MRO and LBO conflicts in LTE-A/5G HetNets. Weighted fuzzy and bounded functions are used as input to evaluate the weight optimization function of the proposed system. Three fuzzy logic controllers (FLCs) are used in this technique: SINR, user velocity, and cell load. These FLCs enable accurate Handover Decisions (HOD) and improve HO performance by independently predicting each user's Handover Control Parameters (HCPs).

Proposed method performs better in terms of cell edge spectral efficiency, HO latency, and outage probability. Additionally, successfully lessens the intricate interaction that exists between MRO and LBO operations, making faultless handovers possible in networks that use inter-RAT (Radio Access Technology). This finding emphasizes how important the coordination strategy and consideration of input parameters are when building intelligent HO schemes for dense urban HetNets, which contribute to improving network performance in general as users travel between cells.

Handover (HO) concerns during user mobility need fine-tuning the HO control parameters. This paper proposes a self-optimizing fuzzy coordination handover technique (HO) for smooth handovers in multi-radio access networks. The proposed method effectively overcomes the conflict between load balancing functions and mobility robustness by adopting a fuzzy system with three input parameters: signal-to-interference-plus-noise ratio, cell load, and user equipment speed.

Findings demonstrate the effectiveness of the proposed technique in handling ping-pong handovers, radio link failure, and HO delay under a range of mobile speed scenarios. Furthermore, when compared to similar tactics from the corpus of current literature, the suggested strategy significantly reduces the probability of an outage.

VII. FUTURE RESEARCH

While this research has shown encouraging results in optimizing handover performance, there are several areas where future efforts can build upon the current work.

A potential improvement is to explore the use of machine learning techniques. These methods can help in making more adaptive and intelligent handover decisions by learning from network conditions over time.

Future studies can also consider the energy impact of handovers. Reducing energy usage, especially in dense network deployments, is becoming increasingly important and could improve the overall efficiency of the system.

In addition, it may be helpful to study more detailed user movement patterns. Accounting for variations in user behavior, such as sudden stops or irregular speeds, could enhance the precision of handover decisions.

Expanding this work to include other wireless technologies like Wi-Fi or emerging 6G systems would also be a meaningful step forward. This could improve the versatility and broader application of the handover scheme.

Moreover, future research might focus on predicting cell load in advance rather than relying only on current conditions. Anticipating traffic trends could help manage network resources more effectively.

Lastly, strengthening the security aspects of handover processes, especially in highly mobile or sensitive environments, could be another valuable direction. Ensuring secure and smooth transitions between cells will be essential as networks continue to evolve.

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