A comparative Performance Analysis of 4x4 MIMO-OFDM system using Spatial Multiplexing under various Wireless Channels

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***Abstract*— *Multiple Input Multiple Output (MIMO) technology refers to wireless communication systems employing multiple antennas at either the transmitter end or the receiver end or both. In recent times, use of multiple transmit and receive antenna for enhancing spectral efficiency in a wireless system has established much interest in research field. The solution to obtain superior data rates and better range performance at the same time is OFDM integrated with MIMO technique which is based on IEEE 802.11n standard. The main trouble in front of the wireless multipath propagation is the interference between information symbols transmitted through neighbouring channels also called as Inter Symbol Interference (ISI). This could be avoided if we use OFDM technology. Thus MIMO combined with OFDM has got significant importance in future wireless communication system. The major properties of MIMO system involve Spatial Diversity and Spatial Multiplexing which are the main factors to discuss and matter of concern to achieve reliability and high speed data rate. In this paper, we study the performance gain of MIMO-OFDM systems. The main investigation carried out in the following paper is to deal with various Wireless channel models in Spatial Multiplexing (SM) mode. The paper deals with MIMO-OFDM system analysis in various Wireless channel models (Rayleigh, Rician, Nakagami and 3GPP channel Environment) focusing on error rate performance, throughput and Spectral gain in 4x4 MIMO scheme under OFDM system. Evaluation of Bit Error Rate and throughput with respect to varying Eb/No for 4x4 MIMO-OFDM in Spatial Multiplexing mode, employing 16 QAM modulation with N=128 OFDM subcarriers employing MMSE detection, is the baseline of this paper.*

Keywords*— *3GPP, MIMO, MMSE, OFDM, QAM, SM, Eb/No

I. INTRODUCTION

Next generation wireless communication system will demand purely high speed communication links, high quality multimedia and data services with high efficiency and reliability. In order to achieve high bit data rate services such as online gaming, video conferencing or web browsing, the next generation wireless communication systems would have to improve their range, quality of service (QoS), bandwidth, throughput and power efficiency [1]. MIMO has been standardized for 3G, 4G wireless LANs and is now in far flung commercial use. Multiple Input Multiple Output technology has achieved widespread attention in recent years as a promising wireless technology. Such systems offer the dual benefits of wireless channel fading mitigation through diversity reception and link throughput enhancement through Spatial Multiplexing [2]. The SM is typically well suited to users with good channel conditions that is, to users near the cell centre with a high signal-to-noise ratio [3]. One of the most key feature of wireless channels is Multipath propagation. The faster the data rate, the higher the probability that multipath propagation will cause Inter Symbol Interference (ISI) [2]. Due to the multipath propagation, signal suffers rapid and severe fluctuations in amplitude and phase. The solution to obtain noteworthy superior data rates and enhanced range performance at the same time is MIMO-OFDM which is based on 802.11n standard. This increases the link capacity by concurrently transmitting multiple data streams using multiple transmit and receive antennas. OFDM is the technique which is used to mitigate the multipath propagation problem and MIMO is useful for the efficient usage of spectral bandwidth thus combining these techniques results in wireless system that has best spectral coverage, reliable transmission in highly obstructive wireless environment. By multiplying spectral efficiency, MIMO-OFDM opens the door to a range of new applications and enables more cost-effective implementation for existing applications [4].

For our simulation MATLAB simulation tool is utilized which played a significant role to achieve required results. In this paper MATLAB R2015a version is used for simulation of Bit Error Rate and throughput for different channel environment.

II. OVERVIEW OF SPATIAL MULTIPLEXING MODE (SM)

Spatial multiplexing obeys space-time diversity technique whose foundation design is to transmit independent information links from each transmit antenna. Spatial multiplexing can offer an increase in the transmission rate and spectral efficiency, because each spatial channel carries independent data, thereby escalating the data rate of the system. To achieve this goal, we may opt to place different portions of the information on different spatial paths, providing improved data rate of the system. In spatial multiplexing, if the scattering by the environment is well enough, multiple independent spatial links are formed in the same allocated bandwidth. Thus the multiplexing gain, also referred as number of degree of freedom, comes at no extra cost on bandwidth or power. Multiplexing gain or degrees of freedom in a MIMO configuration is equal to min (m,n) where m is the number of transmit antennas and n is the number of receive antennas [5].

Fig. 2 displays a simple spatial multiplexing system using a 2x2 MIMO system. In this study, the first information symbol, s0, is transmitted from the transmit antenna Tx0, and the second information symbol, s1, is transmitted from transmit antenna, Tx1. During the first symbol time the propagation of these two data symbols occurs concurrently. The data symbols s2 and s3 are concurrently transmitted during the next symbol time. In this action, alternate symbols are sent from each antenna and each symbol is only transmitted once, providing doubled data rate. Compared to STC, this technique is entirely different as no information symbols are repeated over two symbol times across the two antennas. Here, it is assumed that antennas are properly placed so that fading coefficients are different. A complex wireless fading coefficient h00 exist between Tx0 to Rx0. A complex wireless fading coefficient h10 exist between Tx0 to Rx1. There is an analogous relationship between Tx1 and the remaining two receive antennas resulting four non-identical complex fading coefficients h00, h01, h10 and h11 [6].

After transmitting all the data symbols through the channel using spatial multiplexing, the receiver receives the signal r0, at antenna Rx0, as an addition of the s_0 and s_1 information symbols, corrupted with complex fading coefficients H00 and H01 respectively. Concurrently, the Rx1 receives s0 and s_1 affected with complex fading coefficients, H10 and H11 respectively. Here, we are neglecting the effect of noise. Therefore received signal at each received antenna can be modeled as

$$r_0 = H_{00}s_0 + H_{01}s_1 \quad \ldots(1)$$

$$r_1 = H_{10}s_0 + H_{11}s_1 \quad \ldots(2)$$

The spatial signatures of the two signals, r0 and r1 are separated under favourable conditions. The receiver section, having knowledge of the channel state, can easily recover symbols s0 and s1by further signal processing. If there are m transmit antenna and n receive antenna then equation can be rewritten in the following matrix form,

$$\begin{bmatrix} r_0 \\ r_1 \\ \vdots \\ r_n \end{bmatrix} = \begin{bmatrix} H_{00} & H_{01} \ldots & H_{0m} \\ H_{10} & H_{11} \ldots & H_{1m} \\ \vdots & \vdots & \vdots \\ H_{n0} & H_{n1} & H_{nm} \end{bmatrix} \begin{bmatrix} s_0 \\ s_1 \\ \vdots \\ s_m \end{bmatrix} + \begin{bmatrix} n_0 \\ n_1 \\ \vdots \\ n_n \end{bmatrix} \quad \ldots(3)$$

In order to recover the information from the received signals, the channel coefficient matrix [H] needs to be inverted. The matrix inversion becomes difficult if the channel coefficients in [H] are highly correlated [6].

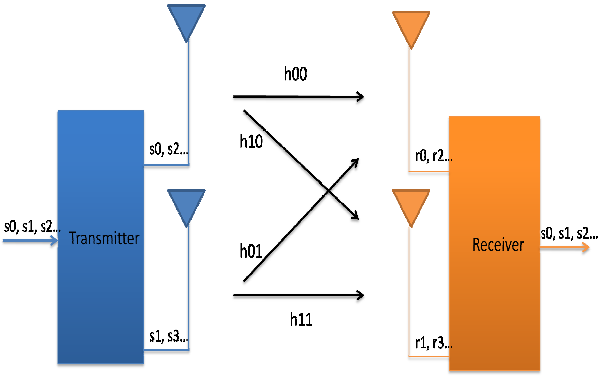

Fig. 1: 2x2 MIMO systems employing Spatial Multiplexing

III. MIMO WITH ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

The motivation behind the MIMO system is to achieve higher throughput and the motivation behind the OFDM system is to convert frequency selective into set of parallel flat fading channels. OFDM compensates for Inter symbol Interference (ISI), while MIMO is employed for its diversity/multiplexing benefits. So we couple the ability of both the system to achieve high throughput as well as simplified processing at the receiver that is converting the frequency selective channel into the set of parallel flat fading channels. Hence, MIMO-OFDM is a combination MIMO communication with OFDM. Similar to OFDM, MIMO-OFDM converts a frequency selective MIMO channel into multiple parallel flat fading channels. From the theory of OFDM, in a MIMO-OFDM system, IDFT and IFFT operation has to be performed at each transmit antenna. Multiple Transmit antennas are used to transmit data modulated by OFDM in a MIMO-OFDM system. At the receiver, after OFDM demodulation, the signal are detected back by decoding every sub-channels from all the transmit antennas [7].

3.1 MIMO-OFDM Operations

3.1.1 Transmitter Section

- S/P Demux for Transmit Antennas: Serial to parallel Demultiplexing of the data bits for the transmit antennas.
- 16-QAM Modulator: It converts the data into a sequence of modulated symbols in complex format.
- S/P Demux: On each transmit antenna, symbols are again demultiplexed for further IFFT operation.
- N pt IFFT: On Each block of symbol, N point IFFT is performed. IFFT operation is used to shift the signal from time domain to frequency domain. It takes N input symbols at one time where N is the number of subcarriers in the system.
- P/S: After N point IFFT, symbols are multiplexed by parallel to serial convertor.
- CP: The symbols are added with cyclic prefix.

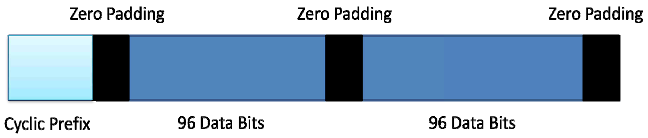

Fig. 2: OFDM signal with cyclic prefix

By this manner, each symbol is processed and transmitted to tth antennas.

3.1.2 Receiver Section

In the similar fashion corresponding receiver operations are performed in MIMO-OFDM.

- CP: Added Cyclic prefix are removed from the symbols.

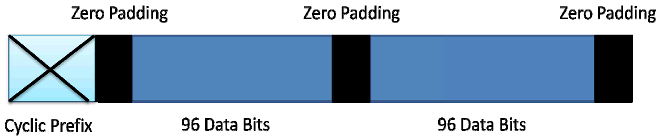

Fig. 3: Removal of cyclic prefix from OFDM signal

- 16-QAM Demodulator: It converts modulated data into a sequence of demodulated symbols.
- S/P Demux: On each receive antenna, symbols are demultiplexed for further FFT operation.
- N pt FFT: On Each block of symbol, N point FFT is performed. FFT block is employed to shift the received time-domain signal into frequency-domain.
- MIMO Detection: On each OFDM sub-channel MIMO detection is performed. Appropriate detection technique is employed on each OFDM subcarriers.
- P/S Mux: After MIMO detection, symbols are multiplexed by parallel to serial convertor. Corresponding symbol blocks are decoded at P/S Demultiplexer.

IV. FLOW CHART OF THE PROPOSED WORK

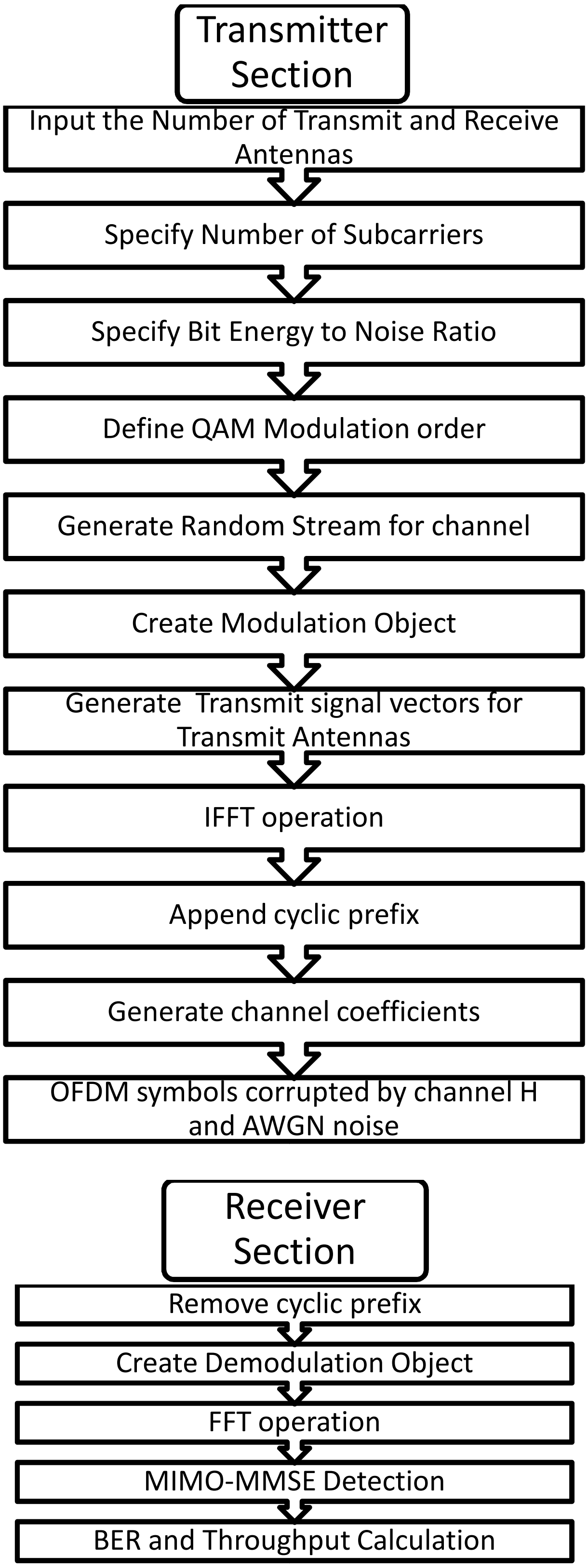

Fig. 4: Algorithm flowchart

V. SIMULATION PARAMETERS AND RESULTS

In the following analysis, a 4x4 configuration for MIMO-OFDM is incorporated i.e. m=4 transmit antennas and n=4 receive antennas. This simulation analysis integrates baseband transmission with MIMO-OFDM using 40MHz bandwidth. The Eb/No assessments are divided into three categories i.e. low Eb/No (1-5) dB, medium Eb/No (5-10) dB and high Eb/No (>10) dB. Table 1 enlists the simulation parameters and their corresponding specifications.

Table 1: Simulation parameters

Parameters	**Specifications**
Model	MIMO-OFDM
Transmission Mode	Spatial Multiplexing (SM)
Number of Transmit Antennas (m)	4
Number of Receive Antennas (n)	4
Number of Subcarriers (N)	128
Modulation	16 QAM
Detection Scheme	MMSE
Bandwidth	40 MHz
Channel type	Rayleigh, Rician, Nakagami, 3GPP channel Models

5.1 Comparative analysis of BER vs Eb/No under various Wireless channels in a MIMO-OFDM system with m=n=4 in SM Mode with N=128 Subcarriers

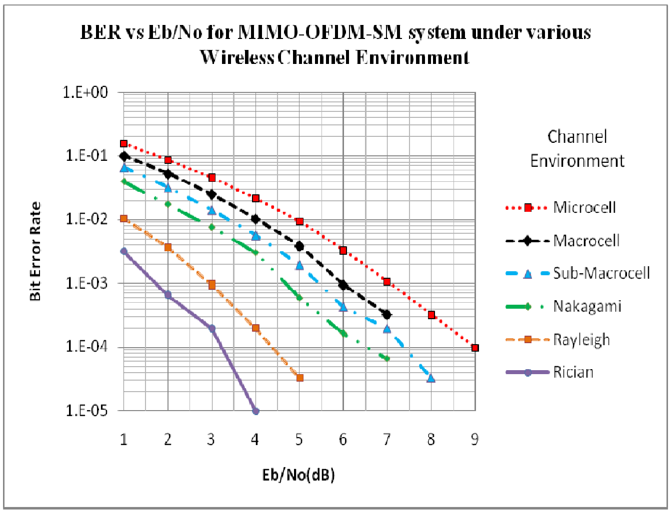

Fig. 5: Comparative analysis of BER vs Eb/No for MIMO-OFDM-SM system under various Wireless channel Environment

In the following observation, the comparative analysis of BER vs Eb/No for various Wireless channels for a MIMO-OFDM system with m=n=4 in SM Mode is carried out with N=128 subcarriers.

- An alluring observation in this fig. 5 is that simulation result with respect to BER in Rician fading channel is better than Rayleigh, Nakagami, Sub-Urban Macrocell, Urban Macrocell and Urban Microcell channel Environment respectively.
- A very significant amount of performance improvement in terms of BER is observed in Rayleigh and Rician fading channels, when the system embedded with N=128 subcarriers is utilized in low Eb/No region (1-5) dB where channel conditions deteriorates or in a scenario where the signal component is bound to experience distortion and deep fading.
- It is noteworthy to observe that in Nakagami, Sub-Urban Macrocell, Urban Macrocell and Urban Microcell channel Environment, system enabled with N=128 subcarriers provides significant reduction in BER in medium Eb/No region (5-10) dB.
- It is observed that Rician fading Environment achieved BER of 10^{-4} at nearly 3.3 dB whereas Rayleigh fading Environment achieved BER of 10^{-4} at 4.5 dB. For Nakagami, Sub-Urban Macrocell, Urban Macrocell and Urban Microcell channel Environment BER of 10^{-4} is achieved at 6.5 dB, 7 dB, 7.2 dB and 9 dB respectively.
- Another appealing observation in this fig. 5 is that in Rician fading channel BER of 10^{-4} is achieved at 3.3 dB which provides best result. In Nakagami fading channel BER of 10^{-4} is achieved at 6.5 dB which provides moderate result and Urban Microcell channel Environment achieved BER of 10^{-4} at 9 dB which provides poorest result among all channel environments. Table 2 enlists the required Eb/No to reach a target BER of 10^{-4} among all channels.

Table 2: Comparative analysis of required Eb/No to reach a target BER of 10^{-4} under different Wireless channel

Channel Environment	**EB/No (dB)**	**Performance**
Rician	3.3	Best
Nakagami	6.5	Moderate
Urban Microcell	9	Worst

5.2 Comparative analysis of Throughput vs Eb/No under various Wireless channels in a MIMO-OFDM system with m=n=4 in SM mode with N=128 Subcarriers

The following observation illustrates the comparative analysis of Throughput vs Eb/No for various Wireless channels in a MIMO-OFDM system with m=n=4 in SM mode with N=128 subcarriers.

- It can be clearly seen from the fig. 6 that the simulation result of throughput in Rician fading channel is better than Rayleigh, Nakagami, Sub-Urban Macrocell, Urban Macrocell and Urban Microcell channel Environment respectively.
- As it can be observed that in Rician fading channel, maximum throughput is achieved at 4 dB whereas in Rayleigh fading channel maximum throughput is achieved at 6 dB. For Nakagami, Sub-Urban Macrocell, Urban Macrocell and Urban Microcell channel Environment maximum throughput is achieved at 8 dB, 8 dB, 9 dB and 10 dB respectively.

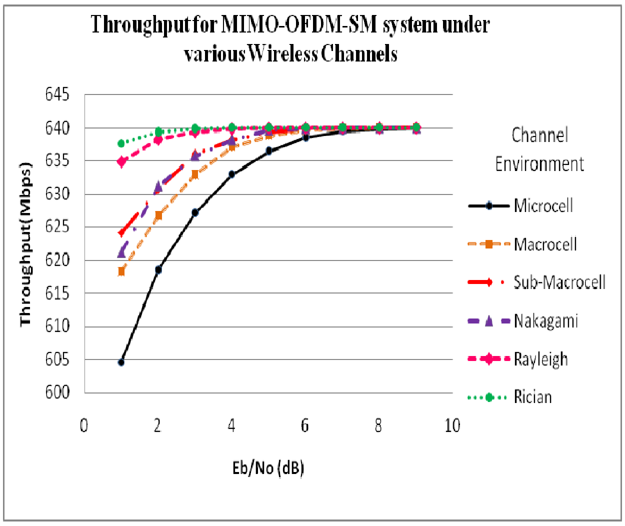

Fig. 6: Comparative analysis of Throughput vs Eb/No for MIMO-OFDM-SM system under various Wireless channel

- An enthralling observation in this fig. 6 is that Rician fading channel achieves maximum throughput at lowest Eb/No of 4 dB, providing best result. In Nakagami and Sub-Urban Macrocell Environment, maximum throughput is achieved at 8 dB. Urban Microcell channel Environment achieves maximum throughput at Eb/No of 10 dB which is greatest from all channels, providing worst result.

Table 3: Comparative analysis of variation of minimum throughput among different channel Environment

Channel Environment	**Throughput (Mbps)**	**Performance**
Rician	637	Best
Nakagami	621	Moderate
Urban Microcell	604	Worst

VI. CONCLUSION

In this paper, the Performance analysis in terms of BER and Throughput in MIMO Spatial Multiplexing integrated with OFDM system for various Wireless channel models has been addressed. In SM mode, when number of subcarriers (N=128) was employed then Rician fading Environment achieved BER of 10^{-4} at 3.3 dB which provides best result. In Nakagami fading Environment BER of 10^{-4} is achieved at 6.5 dB which provides moderate result and Urban Microcell channel Environment achieved BER of 10^{-4} at 9 dB which provides poorest result among all channel environments.

A very significant amount of performance improvement in terms of BER is observed in Rayleigh and Rician fading channels, when the system embedded with N=128 subcarriers is utilized in low Eb/No region (1-5) dB where channel conditions deteriorates or in a scenario where the signal component is bound to experience distortion and deep fading. In Nakagami, Sub-Urban Macrocell, Urban Macrocell and Urban Microcell channel Environment, system enabled with N=128 subcarriers provides significant reduction in BER in medium Eb/No region (5-10) dB. It was also found that the minimum throughput offered by the system changes with variation in the channel environment in SM mode. It was observed that by increasing the number of subcarriers (N), Eb/No decreases at the same Bit Error Rate.

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