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DIVERSITY COMPARISON OF VARIOUS COMBINING SCHEMES IN IDMA FOR RAYLEIGH AND RICIAN FADING CHANNEL

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ABSTRACT

Recent advancements and demand of wireless communication technique have gained huge attraction in cellular communication standards. Several standards have been developed such as 1G, 2G, 3G, 4G and 5G communication. However, these techniques suffer from Multiple Access Interference (MAI) and Inter Symbol Interference (ISI). Several multiple access schemes have been introduced such as FDMA, TDMA and CDMA but achieving higher efficiency still remains a challenging task. Currently, Interleave-Division Multiple Access (IDMA) is considered as a promising technique to combat with these issues. However, fading is a challenging scenario in IDMA systems. To overcome this issue, several diversity schemes have been developed. These diversities require a combiner module to mitigate the fading effect. In this work, we focus on combining schemes such as selective combining, equal gain combining and maximal ratio combining for IDMA systems. With the help of these combining schemes we measured the performance of IDMA for Rayleigh and Rician fading. The experimental study shows that maximal ratio combining scheme achieves better performance in both fading schemes.

Keywords: *IDMA, Combining Schemes, Diversity Comparison, Rayleigh Fading, Rician Fading*

1. INTRODUCTION

Recently, the demand for wireless communication has augmented perpetually. This increased demand for wireless communication consume high bandwidth in the communication. This excess consumption of bandwidth has started to surpass the available bandwidth in wireless networks. In the current generation, cellular wireless communication is an important paradigm to communicate with each other. In the early stages, first generation (1G), second-generation (2G) and third generation (3G) communication standards have been developed [1]. Now, the current advancement in technology has led to the fourth generation (4G) and fifth generation (5G) communication standards because of their substantial use in multimedia communication such as video conferencing, mobile TV and multimedia data transmission.

The excessive use of these cellular communication standards lead towards the enormous data traffic, where ensuring the connectivity while maintaining the efficient QoS is a challenging task. Several techniques have been developed to mitigate the connectivity related issues for multiple users [2]. Recently, multiple access schemes are considered as revolutionary techniques which have gained enormous attraction in cellular communication to provide efficient data communication for multiple users [3-4]. These techniques include frequency division multiple access (FDMA) [5], time division multiple access (TDMA) [6] and code division multiple access (CDMA) [7] schemes which are adopted in 1G, 2G and 3G communication technologies. The performance of CDMA based communication techniques is restricted due to multiple access interference (MAI) [8] and inter symbol interference (ISI) [9] which require multiuser detection (MUD). Moreover, it urge to use of interleavers for user separation. Recently, interleave-division multiple access (IDMA) is considered as a promising technique in this field of cellular communication.

The IDMA scheme is considered as a special case of CDMA which uses lo-rate coding in spreading and separating the users from interleavers. IDMA treats the interleaving index sequence of CDMA as multiple access codes [10]. IDMA gets benefits from the characteristics of CDMA such as it deals with fading by using diversity scheme, mitigates the interference problem. Moreover, chip- by-chip iterative multiuser detection strategy also can be applied to improve the performance. In [11] authors combined orthogonal frequency-division multiplexing (OFDM)-IDMA to improve performance for large number of devices to access simultaneously.

1.1 IDMA over CDMA

The existing CDMA scheme achieve the high data rates by reducing the spreading factor and adopting the multi-code CDMA. The spreading gain of CDMA is reduced against the fading and interferences. Whereas, IDMA systems achieve higher data rate by combining Forward Error Correcting (FEC) codes with high coding rates. Similarly, multiple access interference is a challenging task for both IDMA and CDMA techniques [12]. CDMA mitigates the MAI caused due to multi-user detection but higher computational complexity limits the number of users in practical systems. In contrast to this, the IDMA systems use iterative chip-by-chip (CBC) detection methods to combat the intra-cell interferences.

The computational complexity of CBC for each user doesn't depend on the number of user involved. Due to this reason, for same sum rate, more user in the system will consume less average transmitted sum-power. The IDMA systems consist dynamic power control mechanism which helps to improve the link capacity and QoS for all users. These advantages of IDMA over CDMA improve the overall performance for all users. The other orthogonal multiple access techniques such as TDMA, FDMA and OFDMA require frame synchronization to maintain the orthogonality whereas IDMA doesn't require any synchronization. Moreover, it can perform asynchronous transmission.

1.2 Diversity Schemes and Combining Techniques

In cellular communications, diversity techniques are known as a method to improve the message reliability by using two or more communication channel with diverse channel characteristics. This technique is used in radio communication and main aim of this approach is to combat the fading, mitigating co-channel interference and minimizing the errors. Generally, the diversity schemes are classified into 6 different categories which are as follows time diversity where signals are transmitted at different time instants [13], frequency diversity where signals are transmitted using several frequency channels [14], space diversity where signals are transmitted over different propagation path [15], polarized diversity where signals are transmitted via antennas with different polarization [16], multi user diversity which uses opportunistic user scheduling at either receiver or transmitter antenna [17] and cooperative diversity which uses cooperation distribution of antenna to achieve the diversity gain [18]. In order to employ the diversity schemes "combiner" techniques are used which can process signals redundantly. Generally, the combiner techniques are classified as selective, equal gain and maximal ratio combining techniques which are widely used in various cellular systems.

In this work, our aim is to study these combining techniques and analyze their impact on the IDMA systems. For evaluation, we consider different fading schemes and measured the bit error rate for varied branches of combining.

1.3 Paper Organization

Rest of the article is organized as follows: in section 2 we present a brief discussion about current diversity combining techniques for IDMA systems, section 3 presents the modeling of different combing techniques, section 4 presents the experimental analysis and finally, we present the concluding remarks in section 5.

2. RELATED WORKS

This section presents a brief discussion about diversity techniques and their impact on IDMA systems. The performance of IDMA systems is restricted due to MAI and inter-symbol interference. Mahmood et al. [8] also reported that MAI degrades the system performance. However, there exists several methods such as successive interference cancellation, parallel interference calculation and suboptimal approaches. In radio based communication systems, the knowledge of noise and MAI can help in various stages on the system such as designing an optimal receiver based on maximum likelihood, evaluation of probability of bit error, system capacity computation, outage probability analysis channel impulse response estimation, maximum likelihood modeling and maximum a posteriori probability (MAP) criterion. However, the existing schemes don't consider MAI and noise together. Based on this problem, authors introduced a probability density function (PDF) for Rayleigh fading and AWGN noise to mitigate the multiple access interference. Karimi et al. [13] discussed that detection on number of transmitter antenna is an important phase to design the multi antenna wireless communication system. The existing schemes require a priori information about the received signal such as modulation type, coding scheme, and pilot patterns but this approach uses second-and fourth-order statics of received signal and time-varying nature of wireless channel. Thanh et al. [14] presented Repeated Index Modulation for OFDM (ReIM-OFDM). This technique provides better performance for same spectral efficiency by providing additional space and frequency diversity. This scheme uses total K subcarriers out of N subcarriers to deliver the data bits using active sub-carriers and their indices.

Özyurt et al. [15] applied coordinate interleaving scheme to an OFDM system to achieve the signal space diversity with BPSK modulation. In this approach, two different CI schemes are introduced by taking the correlation coefficients of subcarrier channel gains. A close form expression is presented for Rayleigh fading to derive the closed-form expression for bit error probability. Zhao et al. [19] exploited secrecy outage performance of maximal ratio combining in MIMO cognitive radio networks over Rayleigh fading channels. According to this architecture, the secondary user equipped with N_A antennas which utilize transmit antenna selection (TAS) and transmit the secret message to another secondary user which are equipped with N_B antennas. These antennas use MRC scheme to process the different signals. Meanwhile, an eavesdropped is also incorporated with N_E antennas and adopts MRC scheme for message overhearing. Tiwari et al. [20] introduced a closed-form expression of channel capacity with different combing schemes such as maximal ratio combining, equal gain combining and selection combining. These combining schemes are realized with different transmission policies such as optimal power, optimal rate adaption, channel inversion with fixed rate and truncated CIFR.

Han et al. [21] reported that Non-Orthogonal Multiple Access (NOMA) is a promising solution to achieve the better spectral efficiency for 5th generation multiple access. Along with this, the information and power transfer mechanisms also focus on improving the energy efficiency. In this work authors presented NOMA model for energy harvesting in downlink for multiple antenna relaying network. The communication phase is divided into two slots. In first slot, relay node performs energy harvesting from the received signals and in second slot, relay node uses harvested energy to broadcast the received signal to the mobile users. For base station, antenna selection mechanism is used and mobile users use maximal-ratio combining. Islam et al. [16] presented an investigative model for non-Hermitian coherent-optical OFDM FSO system. This OFDM system uses space frequency block code and polarization diversity. This setup helps to evaluate the effect of cross polarization in the condition where channel impairment exists. Bilim et al. [22] focused on cooperative communication and reported that cooperative communication can help to improve the performance by mitigating the signal attenuation caused due to fading. Hence, authors presented a cooperative IDMA network with relays over Weibull fading channels. In this work, authors present moment-generating function (MGF) with the help of Pade approximation for IDMA. Moreover, a closed-form asymptotic expression is also derived for error analysis.

3. ANALYSIS OF COMBINING SCHEMES FOR IDMA SYSTEMS

In this section, we investigate the different combining schemes and compare their performance for IDMA systems over IDMA systems. First of all, we present the IDMA system and later derive the expression of combining schemes.

3.1 IDMA System

We consider a general transmitter and receiver model of IDMA system model for K users which are using single path channel as depicted in figure 1.

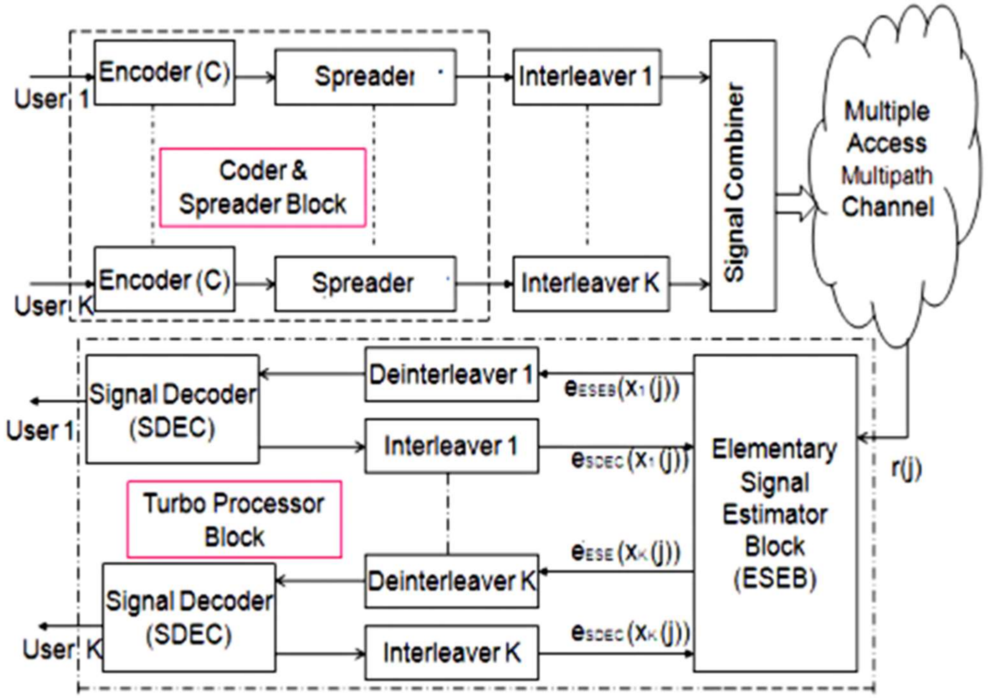

Figure 1: IDMA System with K Users

Let us consider that the transmitter antenna transmits the N length data sequence as $d_k = [d_k(1), \ldots d_k(i), \ldots d_k(N)]^T$ for k^{th} user. This data is encoded into chips as $c_k = [c_k(1), \ldots . c_k(j), \ldots c_k(J)]$ using low rate of coding C with the chip length J. These chips are interleaved using chip level interleavers as $\prod_k$ which produces a transmitted chip sequence as $x_k = [x_k(1), \ldots x_k(j), \ldots x_k(J)]^T$. These bits are transmitted over the considered channel where different fading scenarios are considered. The received sequence is denoted as $r = [r_k(1), \ldots . r_k(j), \ldots r_k(J)]^T$. Here, we adopt AWGN channel for data transmission.

In receiver side, after processing through all the phases, the received signal from K^{th} user can be expressed as:

$$r(j) = \sum_{k=1}^{K} h_k\, x_k(j) + n(j), j = 1,2, \ldots J \qquad (1)$$

Where, h_k represents the channel coefficients for k^{th} user and $n(j)$ denotes the noise samples of AWGN channel with zero mean and variance $\sigma^2 = \frac{N_0}{2}$. The receiver side of IDMA consists of an Elementary Signal Estimator Block (ESEB) and *A Posteriori* Probability (APP) decoders (SDECs) for K user. The ESEB, APP and SDECs operate in an iterative manner. Several modulation schemes are present, the suitable scheme can be selected according to the requirement. The outputs of ESEB and SDECs are obtained as extrinsic Log-Likelihood Ratios (LLRs) which can be given as:

$$e(x_k(j)) = \log\left(\frac{p\left(\frac{y}{x_k(j)} = +1\right)}{p\left(\frac{y}{x_k(j)} = -1\right)}\right), \forall_{k,j} \qquad (2)$$

Further, these LLRs are represented as $e_{ESEB}(x_k(j))$ and $e_{SDEC}(x_k(j))$ which are generated by ESEB and SDEC, respectively.

Here, we use random interleaver thus the ESEB task can be accomplished in a chip-by-chip manner with one sample at time t. This can be expressed as:

$$r(j) = h_k x_k(j) + \zeta_k(j) \qquad (3)$$

Where $\zeta_k(j)$ denotes the distortion in received signal with respect to user k. This is given as $\zeta_k(j) = r(j) - h_k x_k(j) = \sum_{k' \neq k} h_{k'} x_{k'}(j) + n(j)$.

The LLR output of ESEB is obtained as

$$e_{ESEB}\left(x_k(j)\right) = 2h_k \frac{r(j) - E\left(r(j)\right) + h_k E\left(x_k(j)\right)}{Var\left(r_j\right) - |h_k|^2 Var\left(x_k(j)\right)} \qquad (4)$$

Similarly, the LLR output of SDEC can be obtained as

$$e_{SDEC}\left(x_k\left(\pi(j)\right)\right) = \sum_{j=1}^{S} e_{ESEB}\left(x_k\left(\pi(j)\right)\right), j = 1, \dots, S \qquad (5)$$

With respect to power, we denote the received signal for i^{th} as

$$r_i(t) = g_i S(t) + n_i, i = 1,2, \dots, J \qquad (6)$$

Where $S(t)$ denotes the unit power, g_i is the complex channel gain. Hence, thee instantaneous SNR of i^{th} path is given as:

$$\gamma_i = \frac{|g_i|^2}{\sigma_n^2} \qquad (7)$$

3.2. Signal Combiners

In this section, we present a brief modeling of selective, equal gain and maximal ratio combining scheme for IDMA systems.

3.2.1. Selective combining scheme

In selective combining, the antenna which has highest SNR for the received signal, is considered for processing at receiver. The weights of selection combiner are selected as follows:

$$w_k^{SC} = \begin{cases} 1, & \gamma_k = \arg\max_i \gamma_i \\ 0, & otherwise \end{cases} \qquad (8)$$

If it is assumed that the channel noise is same across all branches, then the SNRs of each branch are dominated by gains of each fading channel. In this scenario, the weight of path is measured based on the highest fading gain. This is expressed as:

$$w_k = 1, k = \arg\max_i \left|\hat{h}_i\right| \qquad (9)$$

The output after selecting the best suitable path is expressed as:

$$y = \sum_{k=1}^{k=N} w_k^* r_k \qquad (10)$$

Average output SNR for the selected path is defined as:

$$\gamma_T = \Gamma \sum_{i=1}^{M} \frac{1}{i} \cong \Gamma\left(C - \ln J + \frac{1}{2J}\right) \qquad (11)$$

Where C represents the Euler's constant and $\Gamma = \frac{\mathrm{P}_0}{\sigma_n^2}$ and P_0 is a statistical average of $|g_i|^2$. The total BER if computed as:

$$BER_T = \int_0^\infty erfc\left(\sqrt{2\gamma_T}\right) \frac{M}{\Gamma} e^{\frac{\gamma_T}{\Gamma}} \left[1 - e^{\frac{\gamma_T}{\Gamma}}\right]^{M-1} d\gamma_T \qquad (12)$$

With the help of this model, we perform the combining in signal combiner module as depicted in figure 1 and measure the performance for different branches.

3.2.2. Equal Gain Combining (EGC)

According to equal gain combining scheme, each signal branch is weighted with the same factor without considering signal amplitude. In this process, all signal are summed up coherently. The main aim of EGC is to increase the average SNR. According to this process:

$$\omega_i = e^{j\angle g_i} \Rightarrow \omega_i * g_i = |g_i| \Rightarrow \vec{\omega}\vec{G}^T = \sum_{i=0}^{J-1} |g_i|, \vec{G} = \left[g_1, g_2, \dots g_J\right] \qquad (13)$$

The SNR for i^{th} branch can be given as:

$$\gamma_i = \frac{\left[\sum_{i=0}^{J-1} |g_i|\right]^2}{J\sigma_n^2} \qquad (14)$$

Based on this, the average SNR of entire system can be obtained as:

$$\gamma_T = \frac{E\left\{\left[\sum_{i=0}^{J-1} |g_i|\right]\right\}^2}{J\sigma_n^2} = \left[1 + \frac{(J-1)\pi}{4}\right]\Gamma \qquad (15)$$

3.2.3. Maximal Ratio Combining (MRC)

Generally, the MRC scheme is employed in large phased array systems. Unlike EGC, in this approach, the signals are weighted with respect to their corresponding SNR and then summed up. Moreover, the gain of each channel is arranged as proportional to the RMS signal level and inversely proportional to the mean square noise level in channel. Each channel uses different constant for proportionality. The received signal $r_i(t)$ is a linear combination of signal with weighting factor ω_i of i^{th} branch. The received signal using MRC is obtained as:

$$r(t) = \sum_{i=1}^{J} w_i r_i(t)$$

$$= S(t) \sum_{i=1}^{J} \omega_i g_i \qquad (16)$$

$$+ \sum_{i=1}^{J} \omega_i n_i$$

It is assumed that $S(t)$ has the unit power, thus, the SNR at the output can be given as:

$$\gamma_T(\vec{\omega}) = \frac{1}{\sigma_n^2} \frac{\left|\sum_{i=1}^{J} \omega_i g_i\right|^2}{\sum_{i=1}^{J} |\omega_i|^2} = \frac{\left|\vec{\omega}\vec{G}^T\right|}{E\{\left|\vec{\omega}\vec{N}^T\right|\}} \qquad (17)$$

We apply these combining techniques for IDMA system for varied fading such as Rayleigh and Rician fading and measure the performance for different paths.

4. RESULTS AND ANALYSIS

In this section we present the complete experimental analysis of different combining schemes for varied fading. The complete experiment is performed using MATLAB simulation tool running on windows platform with Intel i5 processor. Below given table 1 shows the simulation parameters used in this work.

Table 1 Simulation Parameters

Simulation Parameter	Considered Value
Total number of users	8
Modulation Type	QPSK
Number of bits per user	2560
Spreading factor	64
Interleaver	Tree
Receiver Iteration	15
Carrier frequency	1.8 GHz

We consider 8 user scenario of IDMA system. Each user assigned 2560 bits for transmission. The spreading factor is fixed as 64 with a tree interleaver. The data is transmitted over Rayleigh and Rician fading channels by applying QPSK modulation where the carrier frequency is assigned as 1.8GHz. Generally, the performance of these types of communication setups is measured in terms of Bit Error Rate (BER) for varied SNRs. In this work also, we measure the performance in terms of bit error rate for varied SNR by considering several combination of simulations such as Rayleigh Fading and Rician Fading for various combining schemes. In the first experiment, we measure the BER performance for Rayleigh fading for selective combining scheme for 4 branches.

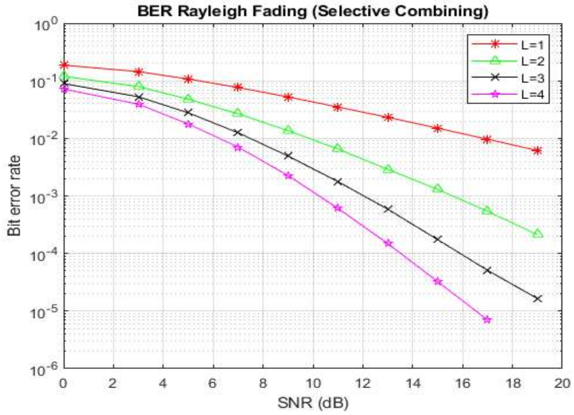

Figure 2: BER Analysis for Rayleigh Fading using Selective Combining

Above given figure 2 shows a comparative analysis of BER for different branches from 1 to 4. The average BER is obtained as 0.0658, 0.0299, 0.019, and 0.0139 for branch L=1, L=2, L=3 and L=4, respectively.

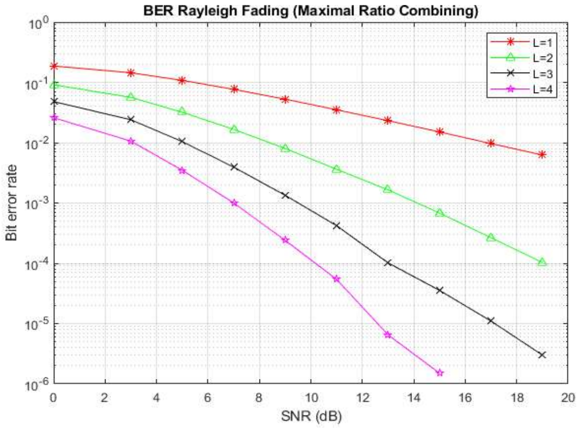

Figure 3: BER Analysis for Rayleigh Fading using Maximal Ratio combining

Similarly, we measure the BER performance for maximal ratio combining scheme as depicted in figure 3. The average performance is obtained as 0.0658, 0.0211, 0.0088, and 0.0041 for branch L=1, L=2, L=3 and L=4, respectively. With same experiment setup, we measure the performance using equal gain combining. Figure 4 shows the comparative analysis of BER using EGC over Rayleigh fading.

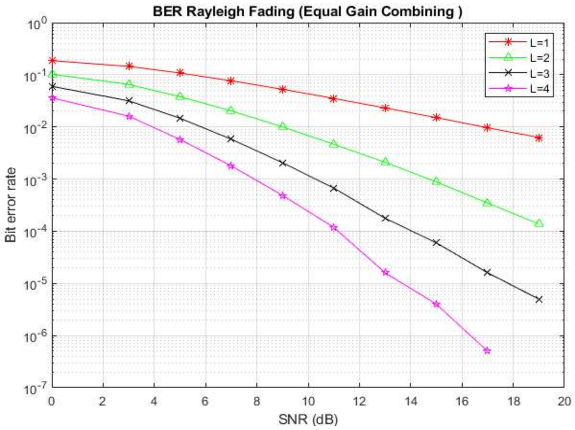

Figure 4: BER Analysis for Rayleigh Fading using Equal Gain Combining

In this experiment, we obtained the average BER performance as 0.0658, 0.0244, 0.0115, and 0.006 for branch L=1, L=2, L=3 and L=4, respectively. The complete analysis shows that maximal ratio combining scheme performs better when compared with selective combining and equal gain combining. However, the equal gain combining outperforms the selective combining scheme. For branch L=1, all combining schemes achieve same average BER hence more number of branches need to be assigned during signal combining.

Further, we measure the performance of these combining schemes for Rician fading channel in the IDMA system. The outcome of selective combining scheme is depicted in figure 5.

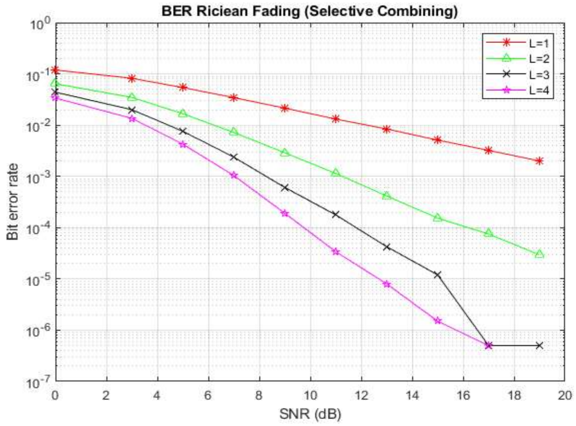

Figure 5: BER Analysis for Rician Fading using Equal Gain Combining

With the help of selective combining, we obtained the average BER as 0.0342, 0.0128, 0.0075, and 0.0053 for branch L=1, L=2, L=3 and L=4, respectively. Similarly, we consider Rician fading and applied maximal ratio combining scheme as depicted in figure 6.

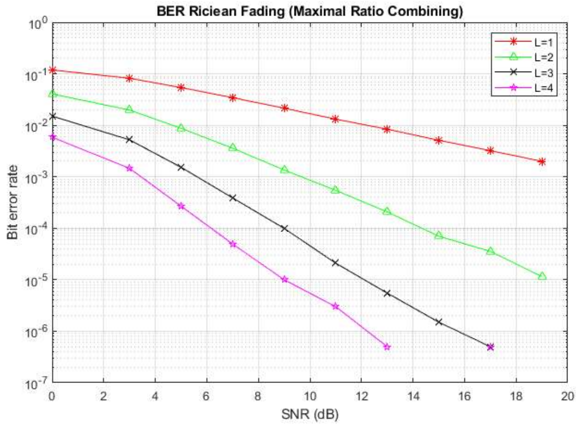

Figure 6: BER Analysis for Rician Fading using Maximal Ratio Combining

In this experiment, we achieve the average performance as 0.0342, 0.0075, 0.0022, and 0.0007662 corresponding to each branch. The equal gain combining scheme is also evaluated for Rician fading channel. The obtained performance is shown in figure 7.

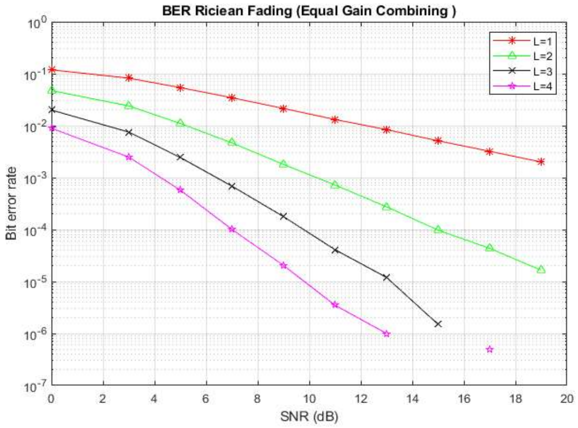

Figure 7: BER Analysis for Rician Fading using Equal Gain Combining

For equal gain combining scheme, we achieved the average performance as 0.0342, 0.009, 0.0031, and 0.0012 for each branch. For both scenarios of Rayleigh and Rician fading, the outcome shows that maximal ratio combining scheme achieves better performance. Further, we evaluate the combined BER performance for selective, maximal ratio and equal gain combining in Rayleigh fading. The comparative analysis is depicted in figure 8.

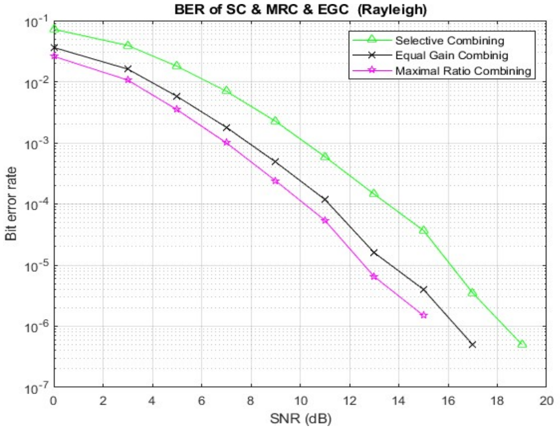

Figure 8: Comparative BER Analysis for Rayleigh Fading

According to figure 8, we obtain the average BER performance as 0.0139, 0.0060, and 0.0041 using Selective Combining, Equal Gain Combining, and Maximal Ratio Combining, respectively.

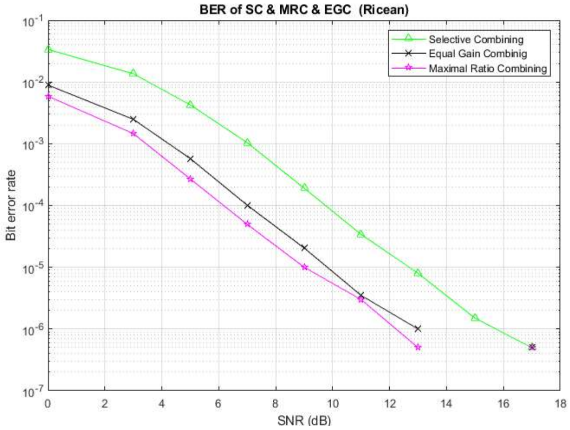

Figure 9: Comparative BER Analysis for Rician Fading

Further, we applied Rician fading on the same experiment and measured the combined BER performance for different combining schemes as depicted in figure 9. The average performance of SC, EGC and MRC is 0.0053, 0.0012 and 0.0007662 for Rician fading. In order to show the robustness of fading schemes, we measured the BER performance using Rayleigh and Rician fading as depicted in figure 10.

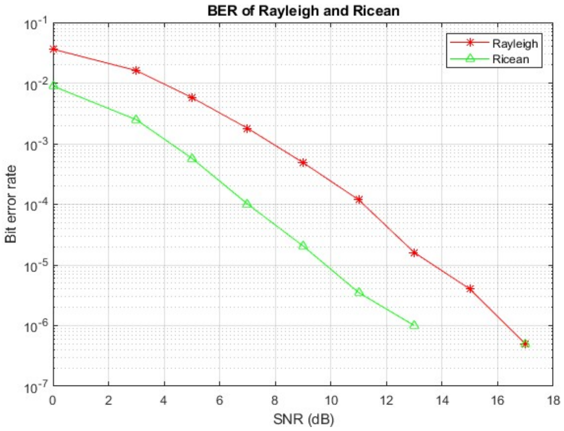

Figure 10: BER Analysis of Rayleigh and Rician Fading Channels

The experimental results shows that average BER is obtained as 0.0060 and 0.0012 using Rayleigh and Rician fading channels. Finally, we present a comparative performance analysis in terms of average BER for each branch using aforementioned combining methods. The comparative analysis is presented in below given figure 11.

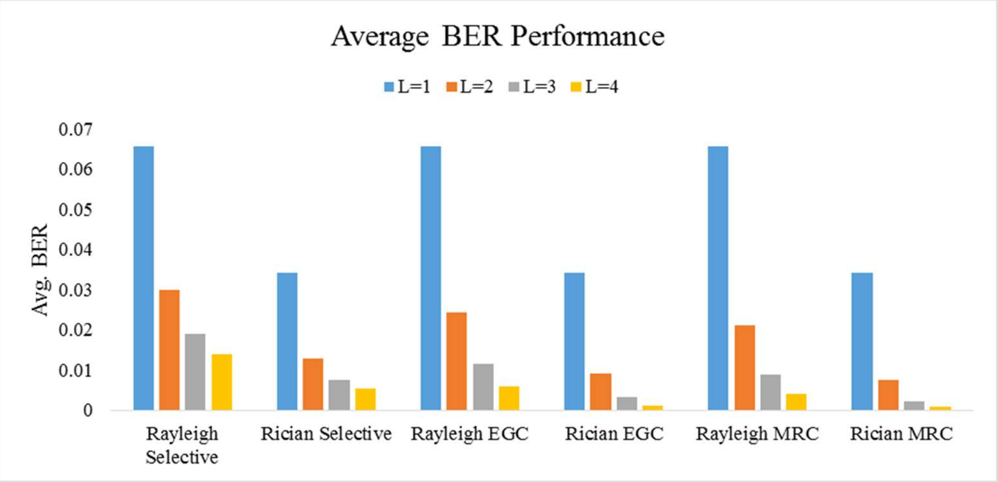

Figure 11: Average BER analysis

The complete experimental study shows that maximal ratio combining scheme achieves the better performance when compared with selective and equal gain combining scheme in both fading schemes. However, the overall better performance is achieved in Rician fading. Furthermore, we evaluate the performance for varied path by considering multipath fading for 1, 3,5 and 7 number of paths.

Table 2 BER performance for multipath fading channel

SNR	Multipath fading channel			
	1 path	3 path	5 path	7path
0	0.05114	0.0765	0.0985	0.1132
2	0.01245	0.0168	0.0368	0.0558
4	0.0008	0.0025	0.0075	0.0121
6	0.0	0.0001	0.0011	0.0018
8	0.0	0.0	0.0001	0.0001
10	0.0	0.0	0.0	0.0

5. CONCLUSION

The cellular communication systems have grown drastically due to their enormous use in daily life scenario. The communication technologies have grown from 1G to 5G. These communication systems demand for higher throughput to maintain the QoS which is affected due to inter symbol interference and multiple access interference. The conventional interference schemes such as FDMA, TDMA and CDMA fail to achieve the promising performance for current communication standards hence, interleave-division multiple access (IDMA) scheme is widely adopted in these systems to combat the fading effect. In this work, we consider the IDMA system and applied different diversity combining schemes such as selective combining, equal gain combining, and maximal ratio combining for Rayleigh and Rician fading schemes. We present a comparative experimental analysis which shows that maximal ratio combining scheme achieves better performance and Rician fading helps to achieve the less bit error rate. In future research, the IDMA channel estimation, IDMA multiuser detection, interference cancellation and error correcting codes can be applied to improve the performance of IDMA systems.

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