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BER Analysis of BPSK Modulation Scheme for Multiple Combining Schemes over Flat Fading Channel

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Abstract: Focus of the study was to provide error-free communication in mobile communication with higher data rates, spectral efficiency, and energy efficient. Basically, work was done to investigate the performance of the Binary Phase Shift Keying (BPSK) modulation technique for multiple combining schemes and the behavior of signal in wireless communication where multipath propagation and uncertainty in the system. We use the Multiple-input Multiple-output (MIMO) and antenna diversity to get many copies of the same signal; some of them were faded but some had sufficient information. Then the next step was to combine or select the best signal to achieve the optimum results from them. Moreover, the Bit Error Rate (BER) of multiple combining schemes for 2*1 and 2*2 were found and the results of each combining scheme were compared. Later on, the comparison of these combining schemes was collectively represented; it is very important because getting the required data from the received copies of the same signal is not easy.

Keywords: BER Analysis; BPSK; Modulation Scheme; MIMO; Antenna Diversity.

1. Introduction

As new technologies are invented the users grow faster; because of the limitations of physical connections in wireless networks it generates a challenging task for researchers [1]. The main challenge is meeting the demand for high-quality wireless services while taking into account the frequency spectrum that is limited and expensive, it is required that it should be operating as efficiently as possible [2]. Due to the multipath propagation in wireless communication, the transmitted data experience fading, co-channel interference, and uncertainty because of outsiders accessing your network and the most credible situation is that the reception is affected by large distances, obstacles, and interference [3]. Now a day's, everyone demands fast data rates, which has boosted demand for technologies that supply bigger capacities and reliable links which should be targeted by given current systems [4]. Multipath signal propagation in wireless communication is a basic source of fading; the abrupt and random change in the received signal is known as fading [5]. The signal experiences diffraction, reflection, and refraction as it travels across a radio channel and the communication environment changes rapidly and adds more complexity to the channel response, especially in suburban and metropolitan areas where cell phones are mostly used [6]. Antenna diversity is a good scheme to reduce the effects of fading [7], hence increasing the system routine performance, reliability, and expanding the capacity of the channel [8]. While several antennas are employed at the receiver in receiver diversity, many antennas are a main component of the transmitter portion in transmitter diversity; communication benefits from the technique of modulation, which transmits data through varying low-powered signals [9]. The main goal of utilizing the modulation technique is to increase data rate with better quality while using the least amount of bandwidth and signal power when there are channel imperfections possible [10]. The majority of first-generation systems, which use an analog transmission technique, have been introduced in the middle of the 1980s; the disadvantages of this technology are the relatively low data rate and very poor noise, these are the drawbacks of this scheme[11]. In the early 1990s, the second-generation system that uses digital communication was introduced and it has a lot of advantages over analog technology, which enhances communication system performance [12]. The adoption of the digital modulation method depends on factors including power efficiency, spectrum efficiency, and bit error rate performance [13]; while designing a modulation scheme, power, and spectral efficiency are always trade-offs. Furthermore, more bandwidth and strong signal strength can also be assigned to achieve improved Bit Error Rate (BER) performance [14]. Mobile communication has been evolving since 1990; the goal of the next generation is to achieve a wider bandwidth, a high data rate, and a seamless handoff [15].

The main work for researchers is on offering flawless services across a large wireless network and the next generation of mobile communication systems will be able to offer a comprehensive solution, delivering voice, data, and streamed multimedia to consumers when needed at high data rates [15]. It will mark a significant development toward ubiquitous communications networks and seamless, high-quality communication services [16]. Additionally, Multiple-input Multiple-output (MIMO) communication systems can accomplish the majority of our goals [17]. These concepts of a wireless communication link create a new avenue for reliable communication and significantly increase system performance and dependability [18]. The idea behind MIMO is to get multiple copies of the same signal by designing the transmit antennas at one end and the receive antennas at the other[19]; after combining these signals the BER and SER for each user are enhanced [20]. Such technologies gained a lot of interest in mobile communication as a result of this tremendous capacity growth and it makes use of the particular diversity obtained in a dense multipath scattering environment by specially spaced antennas [21]. Theoretical investigations have shown that the number of transmit antennas utilized causes a sudden shift in the capabilities of MIMO systems if we add more antennas, BER and SER will also be modified [22].

This research work presents the performance analysis of a system for multiple combining schemes and the present communication system receives multiple copies of the same signal at the receiving end. In this scenario, for Binary Phase Shift Keying (BPSK) modulation scheme in a flat fading channel, using a space-time block coding scheme and multiple diversities in the presence of channel-estimation error is studied for different combining schemes. BER analysis of wireless communication over fading channels is an important performance metric to measure the quality and full end-to-end system performance including transmitter, receiver, and transmission medium between them.

2. System Model and Performance Analysis

In this article, we discussed the performance analysis and mathematical modeling of multiple diversity techniques with space time coding scheme in Rayleigh channel. We presented transmit diversity and also discussed linear combination schemes which are less complex with the assumptions that the channel state information at receiver, two relays and a destination node over Rayleigh fading channel. Due to multipath propagation and fading changes with time in wireless communication introduce uncertainty and the communication will be non-comparable with the fiber cable, coaxial cable and in satellite communication [23]. There are multiple ways to reduce the fading effect but here we used antenna diversity. In MRRC scheme for 1*2, it mean one antenna at transmitter and two at receiver are used but we get same results by using 2*1, two antennas as transmitter and one receiver. After this same result it can be made general for two antenna diversity at transmission and for any M number of antennas at receiver.

2.1 BER and its Probability (P_B) for BPSK

It is an important measure of performance used for comparing digital modulation schemes [24]; the total number of bit errors per unit at a time time is known as bit error rate. It is determined by dividing the bit errors by the total bits transmitted during the course of the time period under consideration and the expected value of the bit error ratio is the probability of bit error [25].On the other hand, bit error rate can be considered as approximate estimation of probability of bit error rate; this estimation is accurate for long time interval and high bit errors. Suppose that the transmitted signals are W_1 and W_2. Then the probability of BER of transmitted signals will be

$$p_B = -\int_{(a_1-a_2)/2\sigma_0}^{\infty} \frac{1}{\sqrt{2\pi}} exp\left(-\frac{u^2}{2}\right) du = Q\left(\frac{(a_1-a_2))}{2\sigma_0}\right) \quad (1)$$

2.2 Selective Combining Diversity

This approach provides the best criteria to trade off of receiver complexity and performance of any system as the receiver will pick the signal with highest SNR value [26]. To explain this technique, consider the single transmit antenna and multiple receiving antennas. There are N multiple copies of transmitted symbols. By using the SC we combine these copies of data and extract the optimal solution [27] and we already know that the BER with BPSK modulation scheme in AWGN channel is

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{Eb}{N_o}}\right) \quad (2)$$

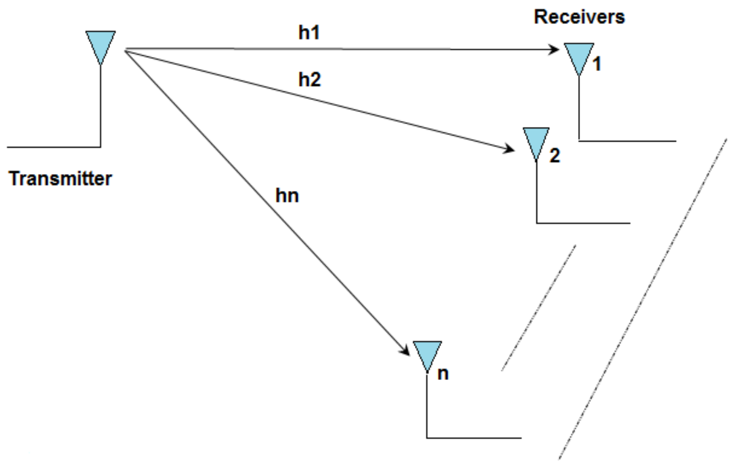

Figure 1. Receiving diversity in a wireless link.

The Figure 1 represents receiving diversity in a wireless link, suppose that r is the effective bit energy to noise ratio by this scheme, then the total BER will be integration of all possible BER values of r.

$$P_b = \int_0^{\infty} \frac{1}{2} erfc(\sqrt{r}) P(r) dr \quad (3)$$

$$= \int_0^{\infty} \frac{1}{2} erfc(\sqrt{r}) \frac{N}{Eb/N_o} e^{-\frac{r}{Eb/N_o}} \left[1 - e^{-\frac{r}{Eb/N_o}}\right]^{N-1} dr \quad (4)$$

After solving this equation will become

$$P_e = \frac{1}{2} \Sigma_{k=0}^{N} (-1)^k \binom{N}{K} \left(1 + \frac{k}{Eb/N_o}\right)^{-1/2} \quad (5)$$

2.3 Maximal ratio combining diversity scheme (MRC)

In this technique, each copy of received signal is multiplied by the branch factor which directly proportional to the amplitude of signal [28]. It further boosts up the strong signal and attenuated the weak signal. In this approach, all branch signals are taking and the gain of all branches will be proportional to the RMS value of signal, moreover it is inversely proportional to mean square of given channel. The signals from all branches will be weighted as compared to their SNR's and added them and all signals will be considered for phase alignment before adding them. At receiver the signal will be,

$$r_1=h_1s_0+n_1 \quad (6)$$

$$r_2=h_2s_0+n_2 \quad (7)$$

After combining signals,

$$s_0=h_1^*r_1+h_2^*n_2 \quad (8)$$

The BER for BPSK is

$$P_b=\frac{1}{2}erfc\left(\sqrt{\frac{Eb}{N_o}}\right) \quad (9)$$

The effective BER to noise ratio with MRC is r, the total BER will integral over all possible values of

r,

$$P_e=\int_0^\infty \frac{1}{2}erfc(\sqrt{r})P(r)dr \quad (10)$$

$$=\int_0^\infty \frac{1}{2}erfc(\sqrt{r})\frac{1}{(N-1)!(\frac{Eb}{N_o})^N}\ r^{N-1}\left[e^{\frac{-r}{Eb/N_o}}\right]\ dr \quad (11)$$

This will be reduces into

$$P_e=P^N\ \Sigma_{k=0}^{N-1}\left(\binom{N-1+k}{K}(1-p)^k\right) \quad (12)$$

Where

$$P=\frac{1}{2}-\frac{1}{2}\left(1+\frac{1}{Eb/N_o}\right)^{-1/2} \quad (13)$$

2.4 Equal Gain Combining Diversity

According to MRC technique, there should be exact estimate of channel amplitude gain, which increases the complexity of receiver[29] but in this approach, it considers all the signals equally after coherent detection. This is very simple diversity method, because it simply added all coherent detected signals and given to the decision device. The exact estimation of fading will not be required for any receiver, so that why its complexity automatically decrease. The BER by using this diversity with two receiving antennas are,

$$P_e=\frac{1}{2}\left[1-\frac{\sqrt{Eb/N_o(\frac{Eb}{N_o}+2)}}{Eb/N_{o+1}}\right] \quad (14)$$

3. Performance Analysis of Various Combining Schemes over Rayleigh Fading Channel

Radio spectrum is becoming more significant for service providers as a result of the examination of new mobile communication technologies [30]. Therefore, there is a constant search for digital modulation techniques that will be efficient with bandwidth and have very low BER [31]. Due to the benefits of analog modulation systems, researchers are now focusing their study on digital modulation techniques. On the other hand, different modulation techniques are chosen depending on the application, cost, power efficiency, bandwidth efficiency, error rate, and other performance characteristics of digital modulation techniques are in conflict with one another. We simultaneously cannot optimize everything.

The best usage strategy is one that offers these requirements the best trade-off. Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), Phase Shift Keying (PSK), and Quadrature Amplitude Modulation (QAM) will be the major modulation methods. The carrier in digital modulation is analog in nature, while the signal is digital in nature. There are multiple parameters, including amplitude, frequency, and phase of analog carrier signal are changing based on the base band digital signal [32]. As a result of its poor quality, ASK are utilized in slow-moving communication processes like telemetry circuits. FSK has very low error performance when there is channel noise. Phase Shift Keying (PSK), one of several digital modulation schemes, performs better in terms of errors and band width efficiency. While the carrier's peak amplitude and fundamental frequency will not change, the carrier's phase will change in response to the baseband digital signal in PSK to represent multiple signals[33]. Modulation schemes are studied because of their numerous performances of valuable characteristics. As the number of M rises, the error performance of 8-PSK and 16-QAM over AWGN channel improves [34]. It has been determined through performance analysis of various M-ary PSK modulation schemes, including BPSK, QPSK, and 8-PSK, that error rate lowers as the value of M rises.

3.1 BPSK modulation scheme with Maximum likelihood (ML) combining scheme

The results as seen in the graph with 2*2 ML equalization helped us to get the good performance which is comparable with other schemes. These results are very closely related with the 1*2 MRC scheme. If we want to compute the results for higher constellation, then ML combining scheme will become very complex. For example, in case of 64 QAM we have to find the minimum from = 4096 combinations. So that's why it might be difficult to compute for higher order constellation. Figure 2 represents BER for BPSK modulation with 2x1, 2x2 MIMO and ML equalizer by using Rayleigh fading channel.

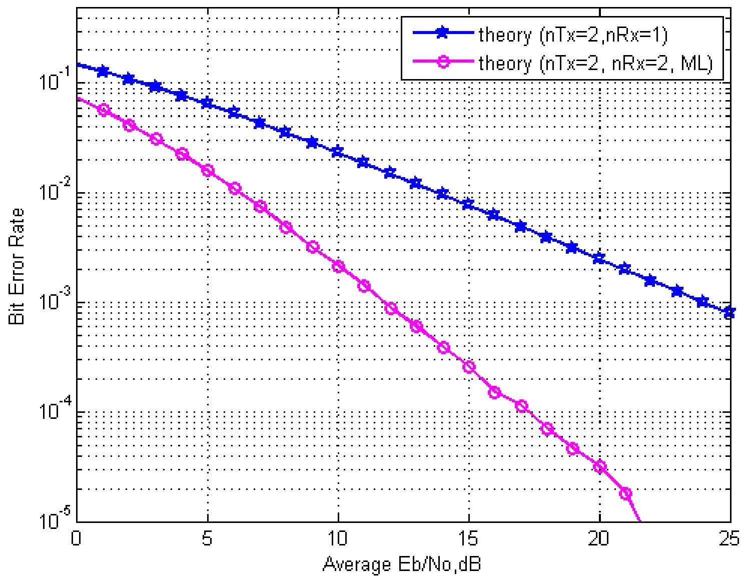

Figure 2. BER for BPSK modulation with 2x1, 2x2 MIMO and ML equalizer by using Rayleigh fading channel.

3.2 BPSK modulation scheme with Equal Gain Combining (EGC) scheme

The results as seen in the Figure 3 are much correlated with theoretical results. It is also same with the MRC scheme but the gain of all the branches are set to equal and cannot changed. If we use multiple antennas the branch signals are multiplied with the same branch gain. We see that for calculation the bit error rate with respect to E_b/N_o, have lessor value for 2*2 EGC as compared with 2*1 combining scheme. So by the analysis of this it can be conclude that the performance of the EGC receiver is better than selection combining scheme and marginally close to the MRC. This scheme is practically better to use because of its complexity is less as compared with the optimum MRC. In this technique there is no knowledge about the amplitude of each branch signal.

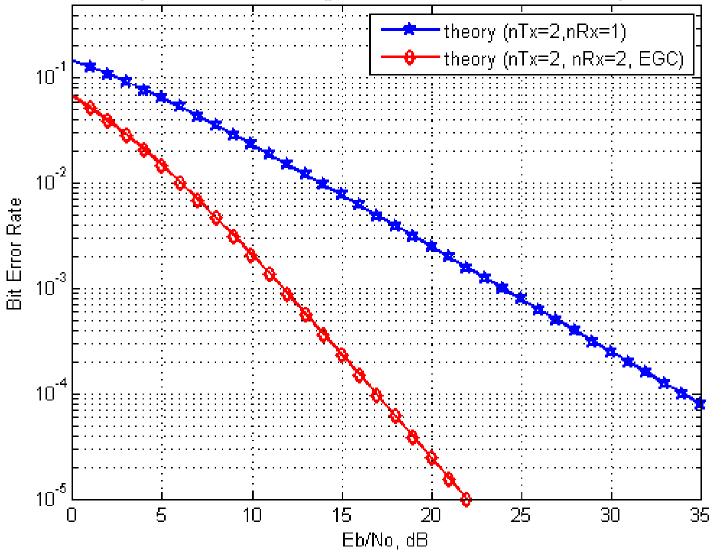

Figure 3. BER for BPSK modulation with 2*1, 2*2 MIMO using Equal Gain Combining in Rayleigh channel.

3.3 BPSK modulation scheme with Maximum Ratio Combining (MRC) scheme

In this technique each branch signals are considered and weighted according to their instantaneous energy to noise ratios. The branch signals are co-phased before summation to insure that the signals which have to be considered will be in- phase. The resultant signal consider as received signal and forward to the demodulator. As we seen that the performance of 2*2 MRC is better as compared with the 2*1 scheme. It is very complicated and correct estimates of signal level and average noise power will be required to get better performance. By this scheme the improvement can be made if both branches are completely correlated.

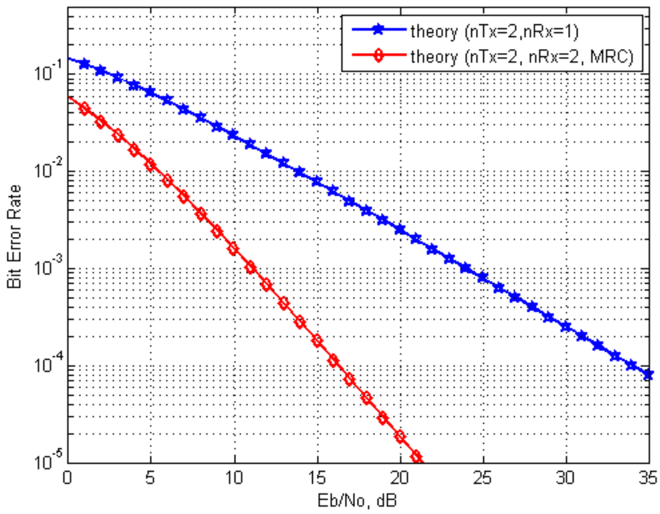

Figure 4. BER for BPSK modulation with 2*1, 2*2 MIMO using Maximum Ratio Combining in Rayleigh channel.

3.4 BPSK modulation scheme with Selection Combining (SC) scheme

The branch signal with higher signal to noise ratio is selected from the receiving signals by the SC scheme. The selected signal then forward to the demodulator. We see that there is large difference of BER between 2*1 and 2*2 selection combining scheme. Generally for larger the number of receiving branches, there is more probability that having greater SNR at the output. This technique is comparable with other combining schemes and easy to implement.

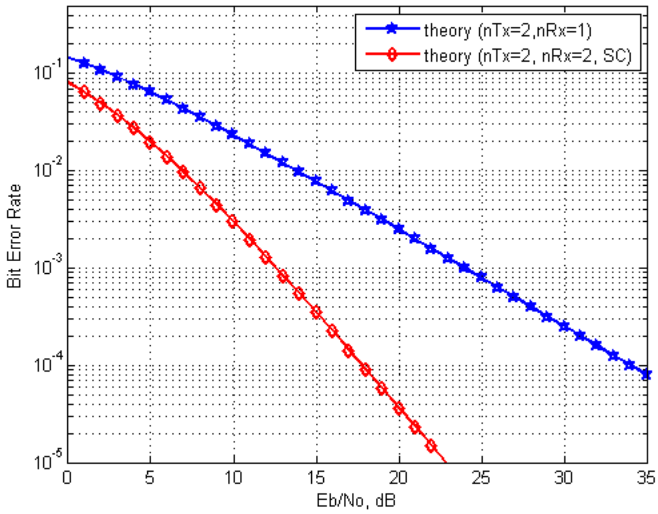

Figure 5. BER for BPSK modulation with 2*1, 2*2 MIMO using Selection Combining in Rayleigh channel.

3.5 BPSK modulation scheme with Zero Forcing Combining (ZF) scheme

In the scheme, it tries to nullify the received signals which are interfered. So the diagonal terms which are not zero tries to be zero due to ZF equalizers. Moreover to solve the $w_1$the interference due to w_2 is tries to be cancelled out and vice versa. Due to this technique there can be noise amplification. On the other hand, however it is easy and simple to implement. Moreover, it is clear that the signal from spatial dimension is a like 1*1 diversity. So that's why the BER analysis for 2*2 and 2*1 ZF combining scheme with Rayleigh fading channel is same.

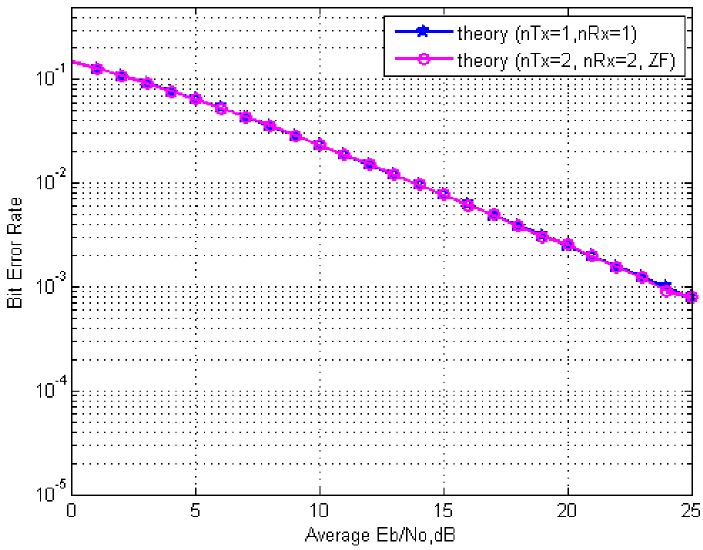

Figure 6. BER for BPSK modulation with 2*1, 2*2 MIMO using Selection Combining in Rayleigh channel.

4. BER Comparison of Multiple Combining Techniques

In previous section each combining scheme was compare with different receiving antenna diversity but now we will compare the performance of the multiple techniques in terms of efficiency in BER and complexity. As expected the best improvement is for MRC, while the worst is for ZF combining scheme. Here we determine the code by which multiple combining schemes can be compared. In terms of the required processing, the selection combining scheme should be easiest, because it required only the value of SNR of each signal, not the phase and amplitude, this combiner also needs not be coherent. On the other hand, MRC and EG combiner required the phase information. The MRC also require the accurate information of the gain too. So that's why this is difficult to implement, because the range of Rayleigh fading signal is very large.

4.1 BPSK modulation scheme with Maximum Mean Square Error (MMSE) scheme and zero forcing

In the MMSE, it tries to minimize the interference between symbols and recover the signal having good SNR. This equalizer also proves the BER properties of the recovered signal. Moreover it should be clear that it is an equalizer which minimizes the mean square error. As seen in the graph, it is very comparable with the zero forcing equalil2zer, actually if noise term is zero the MMSE equalizer reduces to ZFE. However this scheme is simple but not practically good as other combining schemes. Moreover, it is observed that if the number of transmitter kept constant and increases of receivers the BER will be decreases.

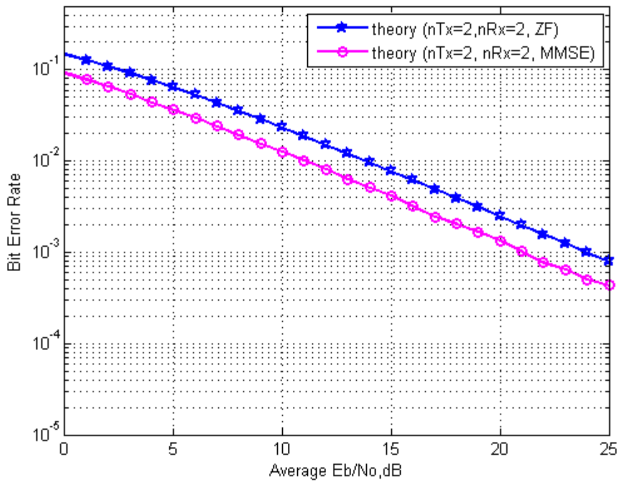

Figure 7. BER for BPSK modulation with MIMO using ZF and MMSE Combining scheme in Rayleigh channel.

4.2 EGC, MRC and ML combining scheme

We will compare here three combining schemes on the bases of BER and complexity. As seen in the diagram that BER improvement is a function of number of elements. Moreover the best improvement is only for MRC and worst for ML for 2*2 MIMO. There is much improvement in EGC scheme which is comparable with MRC and other combining schemes. But there is a problem with these two combining schemes is that because of complexity and therefore not good for abruptly changing environment. That's why these two combining schemes are not uses for ultra-high frequency and mobile communication because the channel is not properly co-phased and tracked. On the other, hand ML combining is very simple that the combiner compares the received signals with the pre-defined reference signal value in terms of BER. It selects the signals with which is very close to the reference signal. This technique is very easy to use as compared to above mentioned schemes.

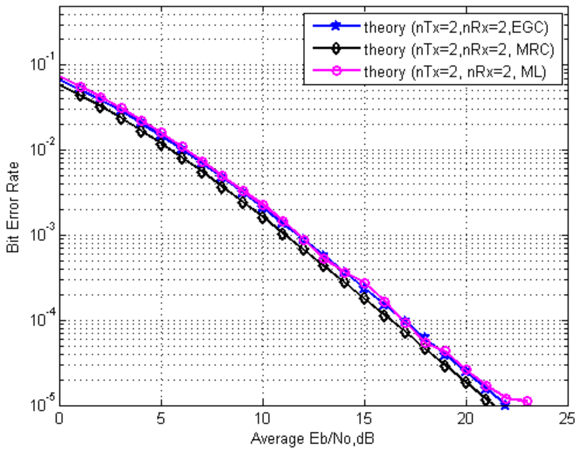

Figure 8. BER comparisons for BPSK modulation with MIMO using EGC, MRC and MMSE combining scheme in Rayleigh channel.

The similarity between EGC and MRC is that all the branches should be co-phased, but because we know that in MRC all branches are consider and weighted on the basis of their amplitude's. On the other hand, in EGC it not likes that of MRC and only channel vector will be required.

4.3 ZF, MRC, MMSE and EGC scheme

As seen in Figure, it is clear that which technique is better to use and which one is not. There is too much difference of BER between these four schemes. It is clear for designers of the network that which technique is better and which one not. For 2*2 MIMO the ZE and MMSE combining scheme having BER is very high as compared with the MRC and EGC schemes. But the BER of MMSE and ZF are close to each. If the noise is minimized by MMSE then it will show the results very close to the ZF. We observed that the BER for BPSK is same in MRC and EGC scheme for 2*2 antenna's but is not same with higher of receiving antenna's. Then result will be different. This situation is same with other combining schemes.

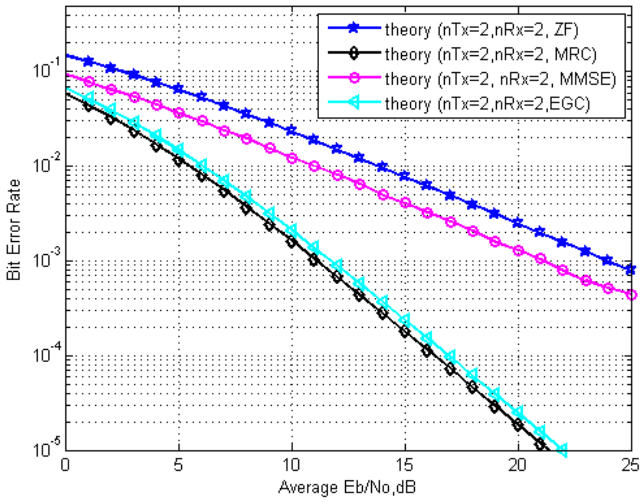

Figure 9. BER comparisons for BPSK modulation with MIMO using EGC, MRC MMSE and ZF Combining scheme in Rayleigh channel.

4.4 *EGC, MRC, ML and SC technique*

There is an interesting result which we observe in the above Figure is that the results of SC and EGC scheme are exactly same but complexity is different. In the selection combining scheme it selects the signal with higher BER and does not require the amplitude and phase of the received signals. But on the other hand, in MRC and EGC it requires the phase and amplitude. It is clear that MRC show good BER performance but it also requires accurate measurement of gain. So it difficult to implement because there is wide range of Rayleigh fading signal. For this additional cost in MRC it improves only 0.6db over the EGC scheme at a BER of 1%.

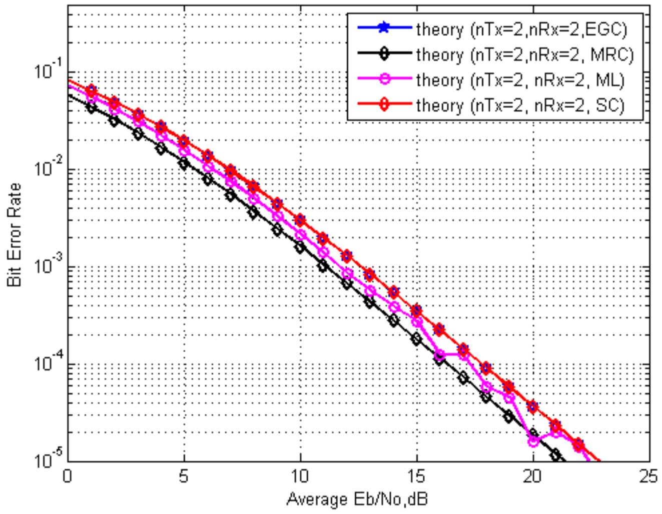

Figure 10. BER comparisons for BPSK modulation with MIMO using EGC, MRC, SC and ML Combining scheme in Rayleigh channel.

5. Conclusions

The focus of the study was on the mathematical analysis of different combining techniques in wireless fading environments. More important and specifically discussed in this study was the BER analysis of the BPSK modulation technique with MIMO by using multiple diversity combining schemes in the environment where the signal strength is constantly changing due to wireless communication. One of the important contributions of this work was the development of a generalized mathematical framework to compute the BER of multiple combining schemes by using MIMO. To complete this study, a space-time block coding scheme is applied for 2*1 and 2*2 MIMO, and the results of these schemes are presented mathematically and graphically. On the other hand, the result shows that the SC and EGC schemes are also good for use because the results are very close to the optimum MRC and are easy to use. Moreover, from the obtained results it is shown that the diversity combiner using EGC for multipath diversity gives satisfactory throughput results with much lesser implementation complexity than the MRC approach.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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