Evaluation of Selection Combining, Equal Gain Combining and Maximum Ratio Techniques in Orthogonal Frequency Division Multiplexing System

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ABSTRACT

Mobile communication systems employing orthogonal frequency division multiplexing technique are mainly the fourth and fifth generation. This technique serves as a multi-access scheme which supports information splitting in sub-channel frequencies during data transmission. This technique is sensitive to multipath fading and signal strength can be lost due to shadowing in different radio frequency propagation terrains during practical applications. One of the waysin mitigating this multipath fading problem is by utilizing antenna diversity combining techniques. In this paper, Simulink software is employed to analytically simulate three antenna diversity techniques, selection combining, equal gain combining and maximum ratio combining. Symbol error rate and bit error rate are used as performance indicators, the result indicates that the maximum ratio combining performs optimally. The results indicate that the performance of the three diversity techniques increases as the antenna grows in quantity.

KEYWORDS: **Bit error rate, symbol error rate, selection combining, equal gain combining, maximum ratio combining,**

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1. Introduction

Radio wave transmission over free space is beset by a significant signal strength loss. Waves interact with layers of the atmosphere in their propagating environment as they travel through space, producing several copies of the sent signal that arrive at the receiver antenna input with varying attenuations, phase shifts, and delays [1]. Fading is the process whereby the motion of transmitters and receivers causes the amplitude of the signal received to vary over time as these replicas superpose at the user's end [2]. Because fading affects radio communications, a number of scientific approaches, including modulation schemes and channel models, have been used to lessen fading's impacts and enhance the performance of transmitted signals. If the needed signal has multiple wave types or multipath, there may also be some fading of the signals' overall amplitude. By establishing multipath, or multiple independent routes, for the received signal and optimizing the combination of these paths, an effective diversity combining technique is utilized to counteract this type of fading. The Transit Antenna Diversity Technique has been employed in wireless transmission recently. There are various forms of diversity; space diversity is the state in which multiple antennas are spaced apart. There is frequency diversity, which refers to the transmission of different signals at various frequencies. Time diversity occurs when different signals are delivered several times throughout different time slots. Additionally, there is polarization variety, in which different signals have distinct polarization fields. The Rayleigh, Rician, Nakagami, and Additive White Gaussian Noise (AWGN) channels are a few distribution channels that are used to reduce fading in radio propagation [1][3]. Depending on the particulars of the surroundings, these channels are modeled and utilized. When there is no direct line-of-sight (LOS) between the transmitting and receiving antennas, for example, the Rayleigh channel model is used. The Rayleigh channel model works well in city settings. When there is LOS, the Rician model is used in suburban and intercity settings [3]. The fluctuations in signal strength received in an urban context are described by the Nakagami model [4]. These channels are modeled, and the average signal power fluctuations level represents the broadband frequency propagation characteristics throughout a sizable multiuser communication system. The Additive White Gaussian Noise (AWGN) channel is typically used to illustrate the variations [2]. There are other ways to enhance or improve system performance with respect to fading, however diversity strategies are the most widely used method [3][6]. Several statistically independent copies of the transmitted signals are used in this technique. Following the deployment of diversity approaches, combining signals techniques like Selection Combining (SC), Maximum Ratio Combining (MRC), Equal Gain Combining (EGC), and Switch and Stay Combining (SSC) are frequently used [1]. In order to build an endless future, the telecommunications industries must fight fading. Higher data speeds and spectrum efficiency are projected to be useful as the need for wireless communication grows. More bandwidth-efficient schemes are required. Choosing wisely from the various multicarrier modulation techniques available is necessary to achieve large data rates. The multi-carrier transmission approach that is most needed to increase signal transmission is called orthogonal frequency division multiplexing, or OFDM. One could consider OFDM to be a modulation technique that enhances spectral efficiency by sending data at greater speeds [7]. With the use of this approach, the available spectrum is divided into multiple subcarriers, each of which transmits data in a single stream and is modulated at a very low symbol rate, producing a signal with a high resistance to interference. There are times during signal transmission when signals weaken to a certain degree, which could be related to certain noise. The end user will undoubtedly encounter some kind of signal interruption during these times of attenuation or signal loss.

The study carried out by [8] have shown that antenna diversity has the tendency to improve received signal strength and also help in reducing signal fluctuation level in a system that is experiencing fading. These advantages stem or result directly from the fact that antennas positioned appropriately experience roughly independent fading channels. Both the transmitter and the receiver can make use of antenna diversity. In order to provide a higher average receive signal-to-noise ratio (SNR), receive antenna diversity systems intelligently combine the multiple of signal received [9]. Since it necessitates either channel independent space-time coding or channel dependent beam forming, transmit antenna diversity is more challenging to achieve [10]. The case where antenna diversity was used only at the transmitter or receiver was the focus of classical wireless research. Beam forming techniques are utilized when there are only multiple antennas available at the transmitting end. In order to take advantage of the diversity offered by the multiple-input single-output (MISO) wireless channel when multiple antennas are only available at the transmitter, beam forming techniques like selection diversity transmission (SDT), equal gain transmission (EGT), and maximum ratio transmission (MRT) have been applied. Alternatively, combining schemes like maximum ratio combining (MRC), equal gain combining (EGC), and selection diversity combining (SDC) have been used to obtain diversity advantage from the corresponding single-input multiple-output (SIMO) wireless channel when multiple antennas are only available at the receiver.

The multiple-input multiple-output (MIMO) channel encountered in the memoryless case is a matrix when antenna diversity is used at both the transmitter and the receiver. In MIMO communication channels, beam forming and combining are still appropriate; however, in order to optimise the receive signal strength (SNR), the beam forming vector and the receiver combining vector need to be combined. Full diversity order was demonstrated by MIMO maximum ratio transmission and maximum ratio combining, as discussed in [11]. In [12], systems with selection diversity transmission and maximum ratio combining were examined and demonstrated to offer complete diversity order. The process of designing these vectors is tend to be more difficult and frequently involves an optimisation issue that is difficult to resolve in real-time systems. Because it doesn't require the antenna amplifiers to change the transmitted signals' amplitudes, equal gain transmission has less demanding transmit amplifier requirements than maximum ratio transmission. This characteristic makes it possible to use low-cost amplifiers at each antenna, provided that the gains are properly matched. For instance, low complexity substitutes for MRC and MRT, respectively, have already been proposed for SIMO EGC and MISO EGT [13]. MIMO communication systems are important, but the application of EGT to these systems has not yet been discussed. It is possible to determine the optimal combining vector for the cases under consideration as a function of the beam forming vector; typically, this necessitates a nonlinear optimisation. The requirement for complete channel knowledge at the transmitter in order to design ideal beam forming vectors is one issue that arises during the deployment of MISO and MIMO beam forming systems. It is impossible to obtain all of the channel information at the transmitter in many systems, including those that use frequency division duplexing. A potential resolution to this issue involves allowing the receiver to create the beam forming vector, which would then be transmitted to the transmitter [14]. In comparison to MISO systems, MIMO quantized beam forming represents a far more challenging problem because it is hard to find the optimal beam forming vector in beam forming and combining systems.

The type of fading situation that may likely be experienced in communication multipath environment is either the large-scale fading or small scale fading. Large-scale fading is when the power the signal receives varies steadily due to signal attenuation caused by the path profile geometry. On the other hand, small scale fading causes rapid or fast fluctuations of the phase and amplitude of the received signal. The case where the bandwidth of the received signal channel is larger than the bandwidth of the transmitted channel and having a varied frequency of the received signal in the same proportion at the same time is known as flat fading. In this research, a non-Line of Sight (LOS) distribution channel, the Rayleigh fading model is employed [15].

Selection Combining (SC) is more in use for combination of signals when considering signal diversity system. It is the processed signal received by a receiver from the antenna possessing the strongest signal to noise ratio (SNR). In selection combining technique, for an end user who experiences an outage of signal, SNR received from all branches must be below the signal threshold. SC is useful at the receiver end. The signal is usually normalized by combining the branch with the strongest SNR and the channel sample.

Maximum ratio combining (MRC). The MRC involves the combination of all signals received by the receiver in order to ascertain the peak SNR obtained by the receiver all the time. MRC unlike SC, have all signal branch used at the same time. Each of the signal branch is combined with the conjugate coefficient of each channel sample. This makes MRC the best combining technique in antenna diversity.

Equal gain combining (EGC): in EGC all received signal paths are phased together and their various weights are summed up. EGC possess modest requirement for transmit amplifier when compare with MRC due to the fact that EGC does not need or require any antenna magnification io order to modify the various transmitted signal amplitudes. SC only requires a switch which will choose the strongest SNR between numerous antenna outputs. SC is noted for being the only diversity combining that has a widely used expression for EGC.

This work employed BER, SER and quadrature phase shift key in analyzing the performance of the selected antenna diversity techniques. The binary scheme of a digital data consists of only two symbols i.e. 1 and 0. The pulse/ waveform is assign to 0 and 1symbols and it is then transmitted over a channel and identified at the receiving end. In quadrature phase shift key scheme, a symbol may consists of either 0 and 1 or both. Quadrature phase shift key and Rayleigh fading channel are used in analyzing BER and SER. Also considered is the density function for each of the diversity combiners in order to determine the best diversity technique for orthogonal frequency division multiplexing system performance. The simulation is done using MATLAB.

2. Materials and method

The simulation work was done by using simulink in MATLAB. The OFDM parameters used in the performance analysis include; a 20MHZ bandwidth with a subcarrier frequency spacing of 312.5KHZ. Quadrature phase shift key modulation technique was employed along with the Rayleigh fading channel. The distance between the transmitting and receiving antenna was the transit diversity (Multiple-Input Multiple-Output). The Doppler shift was 10Hz.

Since the focus is evaluating each scheme by comparing the BER, SER to the SNR, the results obtained in the simulation is then used to produce the Matlab code for the analysis of each modulation schemes under consideration. The first step in the simulation process was to use the integer calculator to generate a stream of bits, these bits were imputed into the OFDM and modulation was done subject to quadrature phase shift key modulation, Rayleigh channel along with selection combiner to produce signal to noise ratio values and there after the system was simulated. The BER calculator displayed the simulated BER for selection combiner, equal gain combiner and the maximum ratio combiner. In each of these combiners, the corresponding values of SNR and SER were obtained.

2.1 Rayleigh fading model

The Rayleigh model is applied in an environment where the receiver and transmitter are far apart, in such case, a direct line of sight is not attainable. Enclosed signal an antennae receives in a number of reflective medium is often described as the Rayleigh fading. The Rayleigh fading distort the signals sent through the link of communication. Hence, the signal makes use of multipath, in this situation, central limit theorem is applied to each path and modeled as Gaussian complex random variable having time as variable.

The Rayleigh model is applicable in an area having large deflectors and blockades. The input signal received $r(t)$by the receiver is represented by equation (1).

$$r(t) = S(t)\, x\, h(t) + n(t) \qquad (1)$$

Where $n(t)$ is the AWGN, $h(t)$ is the Rayleigh distribution matrix of the random channel and $S(t)$ is the transmitted signal.

Usually, the magnitude x, is the Rayleigh distribution of the summation of two independent orthogonal Gaussian random variables that are equal. The density function is.

$$f(X) = \frac{x}{\sigma^2} e^{\frac{x^2}{2\sigma^2}}, \ X \geq 0 \qquad (2)$$

The mean value$E(x)$, and the variance of Rayleigh distribution is obtained by using equation (3).

$$E(x) = \sigma\sqrt{\frac{k}{2}} \quad Variance\, Var(x) = \sigma^2 \frac{4-n}{2} \qquad (3)$$

Where σ is the mode.

Hence, the Rayleigh fading model is given by equation (4) for K diversity branches. Therefore the signal received at the ith branch is;

$$r_i(t) = g_i S(t) + n_i, \quad i = 1,2,\ldots k \qquad (4)$$

Where g_i is the channel gain and n_i is the additive white Gaussian noise variable with zero mean and variance $\sigma_n^2 = \frac{N_0}{2}$

Calculating the signal power for a symbol period T_s, we use equation (5)

$$p_s = \frac{1}{T_s}\int_0^{T_s}|g_i|^2\,|S(t)|^2 dt = |g_i|^2\frac{1}{T_s}\int_0^{T_s}|S(t)|^2\,dt = |g_i|^2 \quad (5)$$

Removing the term $|g_i|^2$ out of the integral and assuming that it is constant over T_s, we have a slow fading situation and if $S(t)$ possess a unit power, then, the SNR of the ith path will be,

$$\gamma_i = \frac{|g_i|^2}{\sigma_n^2} = \frac{2|g_i|^2}{N_0} \quad (6)$$

The average SNR at each branch *Γ* is evaluated using equation (7);

$$\Gamma = \mathrm{E}(\gamma_i) = \frac{2|g_i|^2}{\sigma_n^2} = \frac{2E|g_i|^2}{N_0} \quad (7)$$

The Rayleigh fading for bit error rate is given by equation (8);

$$BER = \int_0^{\infty}\frac{2|g_i|}{p_0}e^{-\frac{|g_i|^2}{P_0}}ercf\left(\sqrt{2\frac{|g_i|}{\sigma_n}}\right)d(|g_i|) \quad (8)$$

Where the error function $ercf(x) = \frac{2}{\sqrt{\pi}}\int_x^{\infty}e^{-t^2}\,dt$

In selection combiner (9), received signal with the highest SNR is used in computing the BER.

$$\omega_i = \begin{cases} 1 & \gamma_i = Max \\ 0 & otherwise \end{cases} \quad (9)$$

In equal gain combining, the combiner sets all the received signals to a level gain by multiplying the gains by the signal attenuation equation (10).

$$g_i * e^{j<g_i} = G^T e^{j<g_i},$$
$$G = [g_1, g_2, \dots, g_N] \quad (10)$$

Where $e^{j<g_i}$ is the signal attenuation gain.

In maximum ratio combining, the received signal r_i(t) is linearly combined with the signal having high SNR with the weighing coefficient ω_i and then sum the entire combination of ith branches. The result is given by equation (11).

$$r_i(\mathrm{t}) = \sum_{i=1}^{M}\omega_i r_i(\mathrm{t}) = \mathrm{S}\,(\mathrm{t})\sum_{i=1}^{M}\omega_i g_i + \sum_{i=1}^{M}\omega_i\, n_i \quad (11)$$

Equation (12) is used for calculating the SER for the diversity combiners

$$BER = SERLOG2(M) \quad (12)$$

Where M= Modulation techniques used, M = 4 for QPSK

3. Results and Discussion

The values below are calculated based on the OFDM parameters presented in chapter three. The SNR is set within the range of 0 and 25dB, the BERs of each diversity combining technique SC, EGC, and MRC are calculated accordingly. The SERs for corresponding BERs are also calculated.

After simulation, the results obtained are presented as performance graphs shown in figure (1) for selection combining BER against SNR.

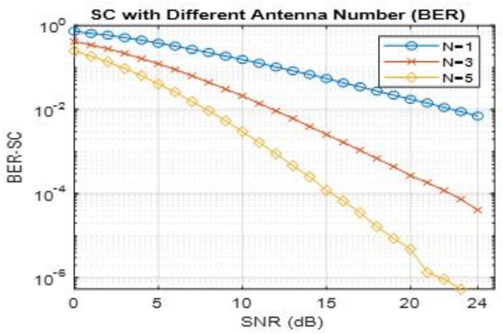

Figure1: BER vs. SNR plot for Selection combining with 1, 3 and 5 numbers of antenna.

According to the curve in figure 1 above, SNR = 24dB with bit error of 10^{-2} is observed for N=1 antenna. N=3 antennas yields a lower bit error of 10^{-4} for an SNR value of 24dB. Out of the three plots, the N=5 antennas exhibit the best performance, with a bit error of precisely 10^{-6} received and an SNR of less than 24dB.

For equal gain combining, the simulation result, is shown in figure (2).

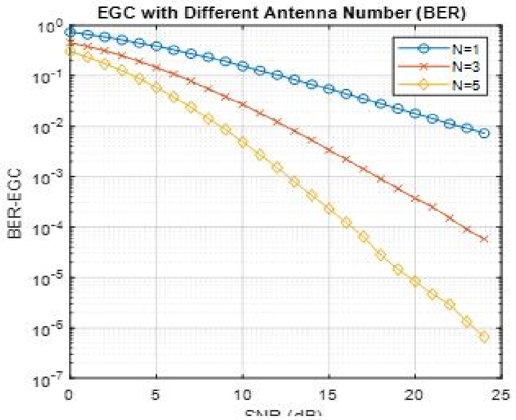

Figure 2: BER vs SNR plot for equal gain combining.

Figure 2 displays an SNR value of 24 dB for the three plots. The N=1 antenna performs the worst, with a bit error of 10^{-2}. The N=3 antennas perform marginally better than the N=1 antennas, with a bit error of 10^{-4}, but they do not demonstrate the expected tangible improvement. In contrast, the N=5 antennas in this figure exhibit a noticeable improvement over the N=1 antenna, with the least received bit error being slightly less than 10^{-6}.

For Maximum Ratio Combining, the simulation result, is shown in figure (3).

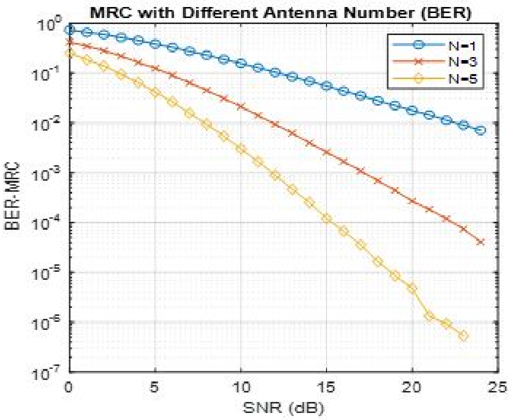

Figure 3: BER vs. SNR plot for Maximum Ratio Combining.

While the N=3 antennas perform better, the N=1 antenna in Figure 3 displays the same performance as in Figures 1 and 2. With a lower SNR of 23dB and the least bit error of less than 10^{-6}, the N=5 antennas perform better than the N=1 and N=3 antennas in this instance. It's crucial to remember that, generally speaking, a BER of 10^0 indicates that 100% of the transmitted bits were received incorrectly. The three plotted graphs show that, for N=1, 3, and 5 antennas, the BERs between 0dB and 5dB SNR values lie between 10^0 and 10^{-1}. This indicates that, regardless of the number of antennas, performance is typically poor at lower SNR values. The graph shows that the N=1 antenna's performance did not increase; the BER values for the SC, EGC, and MRC are the same across all three graphs. This suggests that with a single transmitting antenna, there would still be comparatively more mistakes received even at high SNR values. With three to five antennas, however, fewer errors will be received; with many antennas, approximately nil errors will be received.

The performance graphs of SER against SNR for selection combining is shown in figure 4

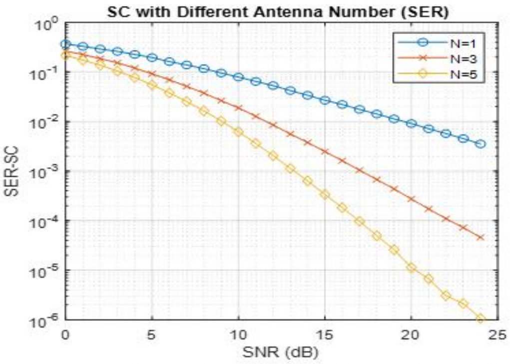

Figure 4: SER vs. SNR plot for Selection Combining

Figure 4, which displays the data transmission performance in symbol for SER against SNR values ranging from 0dB to 25dB using Selection Combining, indicates that SER is below zero for all three plots when SNR is at 0dB. For SNR at 24dB, the SER values of N=1 antenna are 10^{-2}, N=3 antennas are 10^{-4}, and N=5 antennas are 10^{-6}. Therefore, it is noted that N=3 antennas perform better than N=1 antennas. The highest performance across all three graphs is displayed by N=5 antennas, with SER = 10^{-6}, or one symbol mistake out of every million bits transferred.

For equal gain combining, the simulation result, is shown in figure (5).

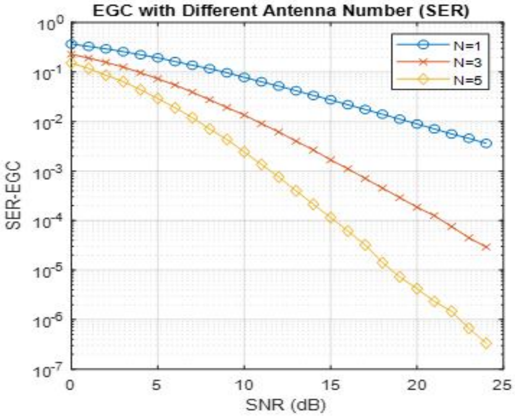

Figure 5: SER vs SNR plot for equal gain combining.

Figure (5) displays the simulation result for equal gain combining. The SER for N=5 antennas in Figure 5 is 10^{-1}, which is in close proximity to a 0dB SNR value. This demonstrates a minor improvement in SER for the EGC plots when compared to figure 4. Additionally, examining the entire graph, we can see that the N=5 antennas performed better than the N=1 and N=3 antennas for the same SNR value. At SNR = 24dB, SER is now closer to 10^{-7} than it was previously.

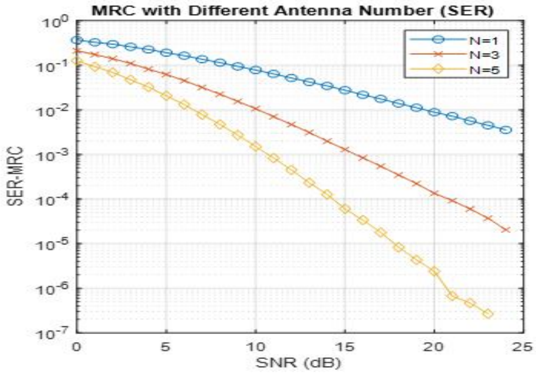

Figure 6: SER vs SNR plot for maximum ration combining.

Figure 6 above illustrates a performance gain that is more noticeable. Here, N=3 antennas perform better than N=1 antenna at the same SNR = 24dB and appear closer to 10^{-5} than in Figures 4 and 5. At the same SNR of 24dB, the N=5 antennas with the greatest performance improvement display a SER that is closer to 10^{-7} than in Figure 5. Thus, once more, in this plot, the N=5 antennas perform noticeably better than the N=1 and N=3 antennas. Once more, examining the SER versus SNR graphs for SC, EGC, and MRC, we can see that, in contrast to the BER against SNR graphs, there is a noticeable improvement in the SER values as the number of antennas rises with an increase in SNR value across the graph. The three graphs all exhibit the same common pattern, which is that for lower SNR levels between 1dB and 5dB, there is only a slight difference in SER between the plots. However, we can acknowledge that each of the three plots shows a notable improvement in performance as the SNR rises, making it simpler to choose which design produces the greatest results.

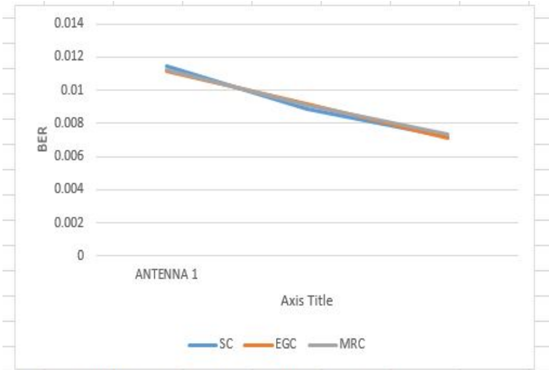

figure 7: BER Performance of SC, EGC, MRC for antenna 1

Figure 7 presents the performance study utilizing three SNRs: 23 dB, 24 dB, and 25 dB. Plotted BER data for SC, EGC, and MRC using an N=1.

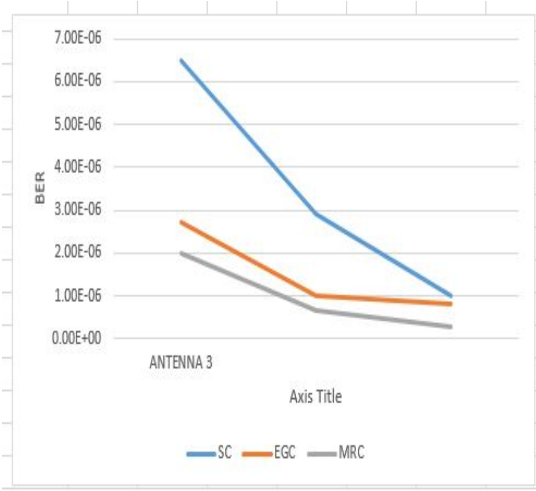

Figure 8: BER performance of SC, EGC and MRC for antenna 3.

A graph for N=3 antennas is shown in Figure 8 that compares the BER values for SC, EGC, and MRC for three different SNR values: 23dB (blue), 24dB (orange), and 25dB (gray). Here, we observe an intriguingly sharp increase in BER values with increasing SNR. This is an impressive display, even with only three antennas. Interestingly, figure 7 above for N=1 antennas with a BER of 0.0000468 and SNR = 25dB indicates that the SC, which has the least performance curve with SNR = 23dB, has a BER of 0.000006, which is significantly better. Once more, MRC displays a BER of 0.000000267 for SNR = 25dB in this graph. This basically indicates that a negligible amount of error is received.

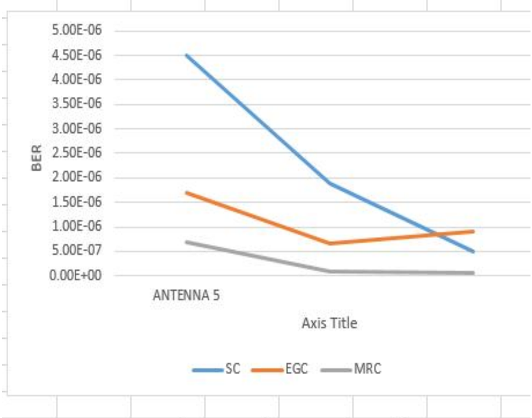

Figure 9: BER performance of SC, EGC and MRC for antenna 5.

Figure 9. Shows that as the number of antenna increases, there is the tendency for a significant reduction in signal attenuation.

4. CONCLUSION

Using an OFDM system, a comprehensive simulation study on transit antenna diversity strategies has been conducted; three diversity combining techniques, which include Selection Combining (SC), Equal Gain Combining (EGC), and Maximum Ratio Combining (MRC) were examined in comparison. Two modulation schemes were taken into consideration: Quadrature Phase Shift Keying (QPSK) and the Rayleigh fading channel. The necessary OFDM block was simulated using the intended OFDM settings using the MATLAB communication toolbox. The performance of the SC and EGC is highly consistent, while the findings with MRC show even greater consistency. By increasing the number of antennas in the diversity technique, the received signal's performance is improved and the amount of bit error is significantly reduced. The transmitted signal strength would most likely not significantly increase with fewer antennas. Better performance can only be attained at the expense of high SNR when using fewer antennas.

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