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# A Study on the Performance Analysis of Hybrid Diversity Combining Techniques for Rayleigh and Rician Fading Channels under AWGN

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***Abstract*—In order to deal with multipath propagation, diversity combining is used, where hybrid combining provide better outcomes in comparison with basic combining systems. Consequently, two new hybrid diversity combining schemes SC-MRC and SC-EGC are investigated in this study. In this research work, data is transmitted from a single transmitting antenna and received by 4 distinct antennas for pure combining (MRC, SC, EGC) and 4 modules having 2 antennas per SC module (4 x 2) in hybrid combining (SIMO). Comparison between hybrid SC-EGC and SC-MRC has also been observed for 2 SC modules having 2, 3 and 4 antennas each. The most robust modulation technique, Binary phase shift keying (BPSK), was taken into consideration. The data was conveyed through Rayleigh and Rician fading channels and a performance analysis was done for the BER response in both cases for every possible combination of diversity combining ventures under flat fading conditions. Among them SC-MRC hybrid combining and Rician fading channel brought out a more prominent result as anticipated.**

***Index Terms*—Hybrid diversity, SC-MRC hybrid combining, SC-EGC hybrid combining, Rayleigh fading, Rician fading, BPSK modulation, BER (Bit Error Rate), SNR (Signal to Noise Ratio).**

## I. Introduction

In wireless propagation channel, the transmitted signal strength is subsided by numerous obstacles. This phenomenon is caused by irregular placement of scatterers resulting in different paths with different path lengths, which is called multipath delay spread. In the era of skyscrapers, it is almost impossible to have a line of sight (LOS) for every transmission of signals. Hence, multipath propagation is unavoidable specially in wireless long distance data transmission. On the contrary, distorted and faded data transmission is of no use in advanced data communication technology. In order to cope with the trade-off, various combining techniques were introduced employing different antenna combinations in both transmitter and receiver end.

In previous years we have seen much progress in SIMO and MIMO dominating diversity combining approach. The BER performance in flat faded Rayleigh Channel improves as the number of receiving antennas increases under the cases of temporal and spatial diversity [1]. Maximal Ratio Combining technique (MRC) is proved to be the best while comparing with EGC and systems with no diversity, employed under M-DCSK Nakagami fading channel [2]. Even at low SNR, MRC was found offering commendable service in enhancing security of wireless communication [3]. Comparing pure MRC and EGC methods, MRC stands out to be better than EGC for attaining better SNR through PSK and QAM modulation over Rayleigh fading Channel [4]

In contrast to traditional combining techniques, some distinct systems such as optimum transmission (OT) compared with maximum-ratio transmission (MRT) were developed for MIMO [5]. In addition EGT (Equal gain transmission), combined with either SDC (selection diversity combining), EGC or MRC have been used to acquire diversity advantage [6] over Rayleigh fading Channel in MIMO system. Hybrid MRCS (Selection Maximal Ratio Combining) diversity over Rician fading [7]. A combined transmitter-selection combining receiver–maximal–ratio -combining (TAS/MRC) scheme has been proposed to reduce the diversity complexity which gains larger diversity gain than MRC over Nakagami channel [8]. Symbol error rate (SER) under Hybrid Selection-Maximal Ratio Combining (H-SMRC) using PAM, PSK, QAM MSK and M-array found to be improved with increasing channel number [9], [10].

Hybrid diversity is a popular addition in wireless communication, where two combining techniques are used at a time for a promising result. EGC-MRC hybridized combining scheme outperforms the standalone EGC and MRC schemes at different signal-to-noise ratio and signal paths in a 4, 8-QAM modulation scheme showing the lowest processing time [11]. BER evaluation was examined in SC-MRC with SC and MRC distinctively [12] also SC-MRC and SC-EGC individually [13] over different nakagami-m fading channels having different antenna-module settings. In MRC-SC hybrid combining outage performance improves as the number of MRC branch increases and deep fading decreases with increasing number of SC branches under FSK and PSK modulation [14]. Bit Error Rate (BER) for Spread-Spectrum (SS) diversity with MRC, and antenna diversity with SC are computed and improved BER performance is gained for higher values of branches in SIMO under M-array Rayleigh fading channel [15].

With acute readiness, having notified about the best results, in this paper, a hybrid diversity combining technique with SC-MRC and SC-EGC was performed under Rayleigh And Rician fading channel utilizing BPSK modulation, the optimum modulation scheme [16] and comparison was conducted among pure SC, EGC, MRC, hybrid SC-EGC and SC-MRC. In accordance with it, the BER performance comparison for SC-MRC and SC-EGC was observed for 2 SC modules and having 2, 3 and 4 antennas per module at a row. The systems having hybrid diversity were proved to be better than basic diversity schemes under Rician and Rayleigh fading where Rician channels had quality impact over Rayleigh as expected.

The paper has been organized by the following serial, in section II a brief discussion of the basic and proposed hybrid combining models is given. Following that, the two fading channels Rayleigh and Rician are being discussed. Section III lines up the simulations that were conducted in MATLAB for various hybrid schemes along with their constellation diagram with varying antennas per module. Closing the paper with the conclusion in section IV.

## II. System Model

Combining techniques are generic ways for combining the individual signal components that have been collected. The goal is to reduce channel complexity while maximizing the transmission gain. The renowned techniques of combining are Maximal Ratio Combining, Selection Combining, Equal Gain Combining. Considering an $N_{th}$ order diversity combining model,

$$r_i = h_i s + n_i \tag{1}$$

Where $i$ ranges from 1 to N. Here $r_i$ represents the received signal with $h_i$ Gaussian complex channel with mean, $\mu = 0$ and variance, $\sigma = 1$.

$n_i =$ background noise (AWGN) with respect to $i_{th}$ branch

$s =$ Transmitted BPSK modulated symbol (-1$\leq s \leq$ 1)

### A. Maximal Ratio Combining (MRC)

Maximal ratio combining, capitalizes on the spatial domain and is used to stimulate the weight of the inner product and signal vector. The received signals are weighted and combined for the optimal SNR at MRC combiner output. MRC utilizes both amplitude and phase elements of the signal to maximize the SNR. The operations materialized by MRC are, time alignment of signal branches, co-phasing, matching of channel gain and combining. The weights of the signal in MRC is given by

$$w_L^{MRC} = \hat{h}_L = \left|\hat{h}_L\right| e^{j\angle h_L}, \quad L = 1, \cdots, N \tag{2}$$

The estimated MRC output with additional noise is

$$\begin{aligned} y_L &= \sum_{L=1}^{N} w_L^* r_L = \sum_{L=1}^{N} \hat{h}_L^* \left(h_L s + n_L\right) \\ &= \left(h_1 \hat{h}_1^* + h_2 \hat{h}_2^* + \cdots h_N \hat{h}_N^*\right) s + \text{ noise} \end{aligned} \tag{3}$$

### B. Equal gain combining (EGC)

Equal gain combining comes with the advantage of equally weighted signal followed by coherent detection where phase distortion is removed. The receiver do not have to anticipate the amplitude fading, which is less complicated than MRC. As a result a number of unacceptable inputs achieve the possibility of acceptable signal in this scheme. The equal fading channel and co phasing is generally set to unity for all diversity path given by,

$$w_L^{EGC} = e^{j\angle \hat{h}_L}, \quad L = 1, \cdots, N \tag{4}$$

considering the perfect estimation of phase, the output of EGC is,

$$\begin{aligned} y_L &= \sum_{L=1}^{N} w_L^* r_L = \sum_{L=1}^{N} w_L^* \left(h_L s + n_L\right) \\ &= \left(|h_1| + |h_2| + \cdots + |h_N|\right) s + \text{ noise} \end{aligned} \tag{5}$$

### C. Selection combining (SC)

It is the simplest of all Combining schemes with the advantage of no performance demeaning. For signal detection it chooses the ones with highest SNR among the receiver monitors of each diversity channel. A receiver module having $L$ antennas are sampled and the gains are adjusted to provide an average SNR for all branch. The gain of each fading channel being dominated by $|h_i|$ taking weigh factor $w_L$ where $L$ = arg(max$|h_i|$). the selected best path output is given by

$$y_L = \sum_{L=1}^{L=N} w_L^* r_L = w_i^* r_i = r_i \tag{6}$$

If $\hat{h}_i$ is the best selected path of impulse channel response, the flat fading channel detection is

$$\hat{s} = \frac{\hat{h}_i^*}{\left|\hat{h}_i\right|^2} y_L = \frac{\hat{h}_i^*}{\left|\hat{h}_i\right|^2} r_i \tag{7}$$

The maximum SNR of all diversity branches is the instantaneous SNR at the output combiner,

$$\gamma_{SC} = \arg(\max \gamma_i) \tag{8}$$

### D. SC-MRC hybrid combining scheme

Hybrid SC-MRC combines both selection combining technique and maximal ratio combining technique. In this project, we took a random number of bit streams modulating it by BPSK modulator to transmit signal to the receiver side. SC consist of $N$ modules with $L$ antenna in each branch. The signal was transmitted through complex Gaussian noise channel using Rayleigh and Rician fading, respectively with additional noise elements. Each SC combiner chooses the

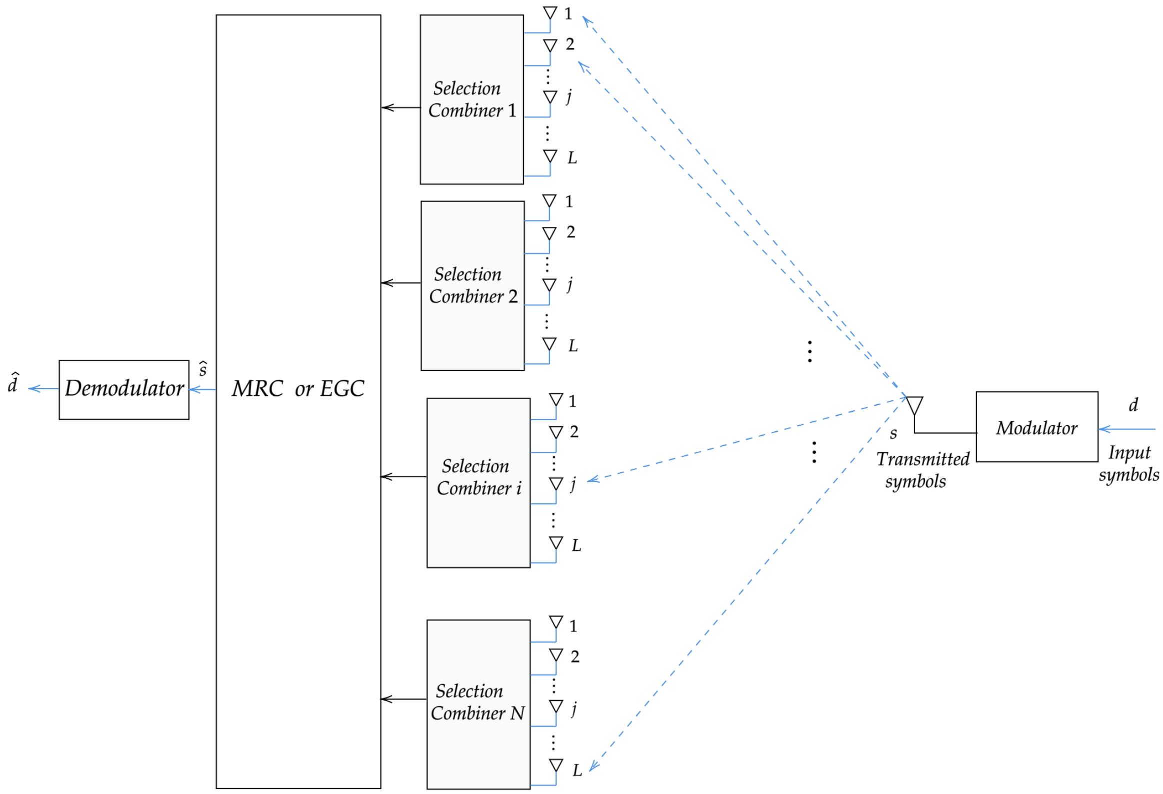



Fig. 1. Hybrid diversity combining scheme

best possible signal with the strongest instantaneous SNR for each branch which is then weighted and combined in MRC combiner. The combined signal with weighted SNR is then equalized to detect the data from the faded noisy signal which is then sent to demodulator to get the best output signal. The architecture of SC-MRC is a bit complex.

### E. SC-EGC hybrid combining scheme

In the estimated hybrid SC-EGC combined scheme, the input symbols have been modulated by BPSK modulator. After that it has been transmitted through Rayleigh and Rician fading channels having additive white Gaussian noise. In the beginning of SC-EGC combiner, we have $N$ selection combiners each having $L$ diversity branches. In each selection combiner among the $L$ Receiver antennas, the one which gets the highest SNR gain is selected and this is how $N$ selection combiner outputs are further given input to Equal Gain Combiner where all $N$ number of signals are weighted equally and removes the phase distortion and compares with the decision level. Finally, the branch that passed above the set threshold value comes at the output of EGC.
The diagram of the estimated Hybrid diversity Combining Scheme for both SC-MRC and SC-EGC are represented in Fig. 1.

### F. Fading Channels

By observing the characteristics of the PDF of the envelops $\alpha(t)$ and phase $\theta(t)$ at any time $t$, the type of fading can be determined [17]. In this paper we have monitored the responses of combining techniques both basic and hybrid over Rayleigh Fading which contains non line of sight (NLOS) with no specular components. LOS scattering has a direct path which is called Rician fading which has also been taken into consideration.

*1) Rayleigh Fading (NLOS propagation):* Let, $Z(t)$ be the complex channel gain,

$$Z(t) = \sum_{n=1}^{N} \alpha_n(t) e^{-j2\pi f_c \tau_n(t)} \quad (9)$$

If $Z_r(t)$ and $Z_i(t)$ are the real and imaginary components of the complex channel gain,

$$Z(t) = Z_r(t) - jZ_i(t) \quad (10)$$

where,

$$Z_r(t) = \sum_{n=1}^{N} \alpha_n(t) \cos\theta_n(t) \quad (11)$$

$$Z_i(t) = \sum_{n=1}^{N} \alpha_n(t) \sin\theta_n(t) \quad (12)$$

here,

$$\theta_n(t) = 2\pi f_c \tau_n(t) \quad (13)$$

and,

$$\alpha(t) = \sqrt{Z_r^2(t) + Z_i^2(t)}, \quad \theta(t) = \tan^{-1}\left[Z_i(t)/Z_r(t)\right] \tag{14}$$

When the envelope $\alpha$(t) of the signal resembles the form of a complex Gaussian random variable, then it is called Rayleigh random variable.

$Z_r(t)$ and $Z_i(t)$ are independent. Gaussian random variables at time $t$ following central limit theorem, with zero mean and equal variance

$$\sigma_z^2 = \frac{1}{2}\sum_{n=1}^{N} E\left[\alpha_n^2\right] \tag{15}$$

the joint PDF of $Z_r(t)$ and $Z_i(t)$ is

$$f_{Z_r}Z_i(x,y) = \frac{1}{2\pi\sigma_z^2}\exp\left[-\frac{x^2+y^2}{2\sigma_z^2}\right], \quad -\infty < x < \infty, -\infty < y < \infty \tag{16}$$

*2) Rician fading (LOS propagation):* In case of Rician fading, the channel gain is written

$$Z(t) = Z_r(t) - jZ_i(t) + \Gamma(t) \tag{17}$$

where,

$$\Gamma(t) = \alpha_\theta(t)e^{-j\theta_0(t)} \tag{18}$$

is the LOS component and $Z_c(t)$–$jZ_s(t)$ is the NLOS component. In case of Rayleigh fading

$$E\left[Z_r(t)\right] = E\left[Z_i(t)\right] = 0 \tag{19}$$

where as for Rician fading,

$$E[Z(t)] = \Gamma(t) \neq 0 \tag{20}$$

Amplitude fading at any time $t$, $\alpha$ is the Rician distribution PDF defined as

$$f_\alpha(x) = \underbrace{\frac{x}{\sigma_z^2}\exp\left(-\frac{x^2}{2\sigma_z^2}\right)}_{\text{Rayleigh}} \cdot \underbrace{\exp\left\{-\frac{\alpha_0^2}{2\sigma_z^2}\right\} \cdot B_f\left(\frac{\alpha_0 x}{\sigma_z^2}\right)}_{\text{modifier}} = \frac{x}{\sigma_z^2}\exp\left(-\frac{x^2+\alpha_0^2}{2\sigma_z^2}\right)B_f\left(\frac{\alpha_0 x}{\sigma_z^2}\right), \quad x \geq 0 \tag{21}$$

Here, $\alpha_o^2$ is the power of LOS component and $B_f$ is the zero-order Bessel function of the first kind which is,

$$B_f(x) = \frac{1}{2\pi}\int_0^{2\pi} \exp(x\cos\theta)d\theta \tag{22}$$

$K$ factor is an important Rician channel parameter which is defined as

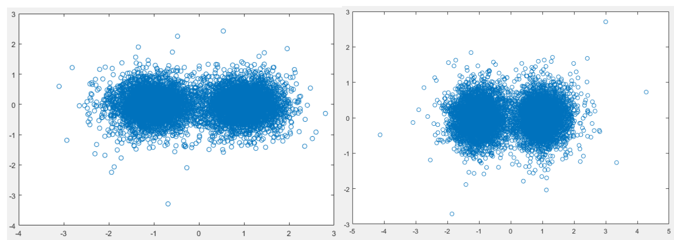
$$\text{K} = \frac{\text{power of LOS component}}{\text{total power of all other components}} = \frac{\alpha_0^2}{2\sigma_z^2} \tag{23}$$

The Rician distribution approaches to Rayleigh distribution if $K$ approaches to zero. Oppositely, if $K$ approaches to infinity, there is no fading but a dominant component. In other words, it becomes an AWGN channel.

## III. Performance Analysis

In this section, we simulated the bit error rate versus signal to noise ratio for various antenna configuration and fading channel schemes for two hybrid diversity techniques of SC-MRC and SC-EGC. Simulations are done according to Monte Carlo simulation in MATLAB software.

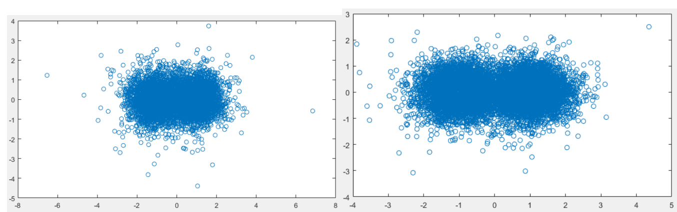
Fig. 2, 3, 4 focuses on the soft estimation of Gaussian distribution of MRC, SC, EGC respectively, for antenna $L$=4 at low SNR having mean value -1$\leq s \leq$1. For MRC, there is a common region for both Rayleigh and Rician fading channels.



(a) Rayleigh (b) Rician

Fig. 2. Constellation diagram of Rayleigh and Rician fading channel for MRC for L=4 at low SNR

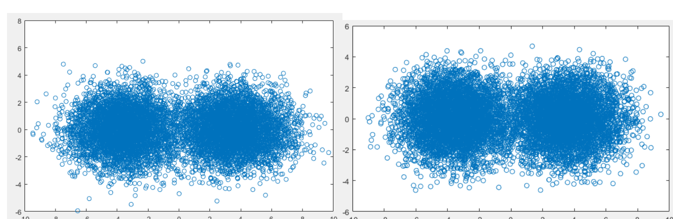
SC combiner shows worse estimation than MRC combiner in both Rayleigh and Rician fading channels.



(a) Rayleigh (b) Rician

Fig. 3. Constellation diagram of Rayleigh and Rician fading channel for SC for L=4 at low SNR

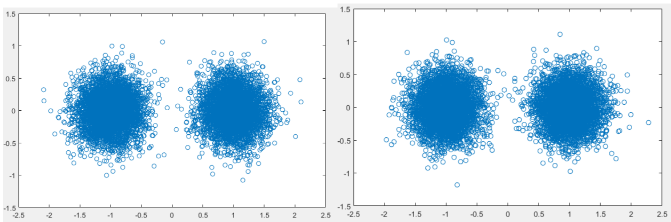
EGC has distinct mean value differences for each BPSK modulation, but with higher SNR the hard decision retains the same position.



(a) Rayleigh (b) Rician

Fig. 4. Constellation diagram of Rayleigh and Rician fading channel for EGC for L=4 at low SNR

In case of the constellation diagram of SC-MRC in Fig. 5 shows a distinct gap between both mean values of BPSK modulation and with higher SNR the hard decision shrinks to one value only. As $L$ increases, the soft estimation becomes more prominent and gives a precise position between -1≤ $s$ ≤1 capitalizing on the power gain and sensitivity increment.



(a) Rayleigh (b) Rician

Fig. 5. Constellation diagram of Rayleigh and Rician fading channel for SC-MRC for L=4 at low SNR

In Fig. 6, for varying numbers of antennas L (2, 3 and 4) on the receiving side of SIMO enhances the production of lower BER in data transmission system. The simulation proves the statement that SC-MRC shows better flexibility to diversity gain than SC-EGC although having higher complexity. SC-EGC shows a certain trade-off between diversity gain with lesser complexity.

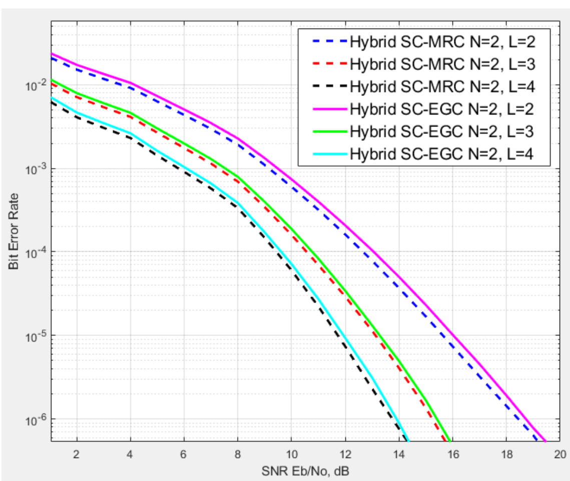



Fig. 6. BER vs SNR Performance comparison between SC-MRC and SC-EGC under AWGN in Rayleigh fading channel

We performed the same procedure under BPSK modulation in Rician fading channel in Fig. 7. It can be observed that Rician fading channel provides a better performance measure with respect to Rayleigh channel. As Rician channel consist of Line of sight (LOS) and multipath, it provides better SNR performance than Rayleigh channel in the direct transmission path under AWGN as Rayleigh fading has no LOS from transmitter to receiver. It can be summarized that in Rician fading channel, with increasing number of receiver antenna the output signal can be detected with better BER.

In Fig. 8 and Fig. 9 we compared the performance of basic SC, EGC, MRC, hybrid SC-EGC and SC-MRC for the same number of data reception antenna. Using different schemes, the simulation proves SC-MRC provides the best transmission, whereas SC-EGC provides transmission close to SC-MRC

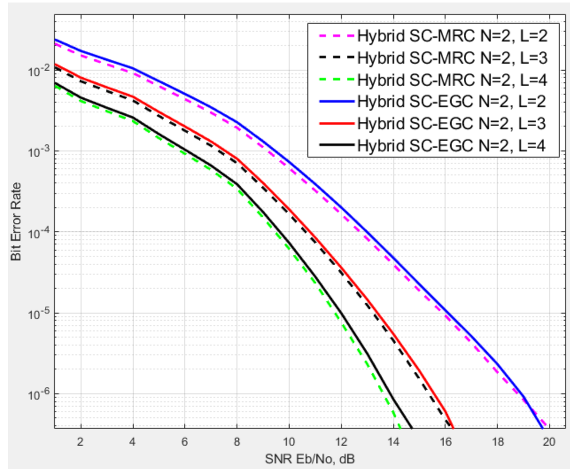



Fig. 7. BER vs SNR Performance comparison between SC-MRC and SC-EGC under AWGN in Rician fading channel

with less complexity. The basic diversity scheme falters due to AWGN noise and a nonlinear scheme such as SC provides a less robust transmission.

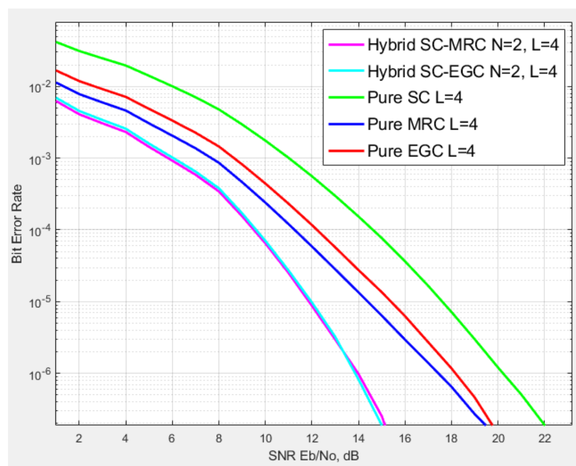



Fig. 8. BER performance for BPSK modulation different combining schemes under Rayleigh fading channel

On the other hand it can be seen that, for a given channel, the transmission of Rician fading channel is slightly robust than in Rayleigh fading channel. Under a fixed modulation technique for a particular BER response, the SNR varies for each diversity scheme foreshadowing better performance. Rician fading channel gives better output due to the direct line-of sight contact between the transmitter and receiver panel.

A notable difference in SC-MRC and SC-EGC is evident in Table I for both fading channels. SC-MRC shows a very high SNR in the presence of AWGN with increasing number of antennas. For a fixed BER ($10^{-4}$) at $L$=4 SC-MRC shows the best robustness among all the output schemes, which corroborates the sensitivity of SC-MRC to diversity order. As for SC-EGC the result is close to SC-MRC with a slight error difference. When $L$=4 the BER curve almost overlaps

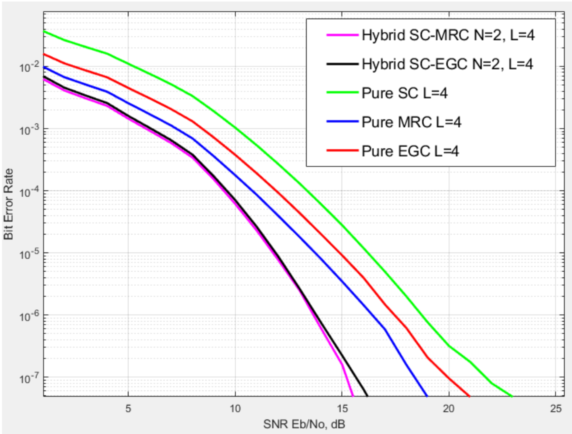



Fig. 9. BER performance for BPSK modulation different combining schemes under Rician fading channel

TABLE I
COMPARISON BETWEEN DIVERSITY COMBINING SCHEMES

| Combiner | SC | EGC | MRC | SC-EGC | SC-MRC |
|---|---|---|---|---|---|
| **Modulation** | BPSK | BPSK | BPSK | BPSK | BPSK |
| **Tx module** | 1 | 1 | 1 | 1 | 1 |
| **Rx module** | 1 | 1 | 1 | 2 | 2 |
| **Rx antenna** | 4 | 4 | 4 | 4 | 4 |
| **BER (Rayleigh)** | $10^{-4}$ | $10^{-4}$ | $10^{-4}$ | $10^{-4}$ | $10^{-4}$ |
| **SNR (Rayleigh)** | 14.614 | 12.185 | 11.205 | 9.615 | 9.443 |
| **BER (Rician,K=3)** | $10^{-4}$ | $10^{-4}$ | $10^{-4}$ | $10^{-4}$ | $10^{-4}$ |
| **SNR (Rician,K=3)** | 13.369 | 11.912 | 10.782 | 9.582 | 9.433 |

the curve of SC-MRC. As SC-EGC has less complicated construction than SC-MRC, for data transmission with a greater diversity order, SC-EGC is the favored scheme due to its superior performance and ease of use.

Comparing with an existing SC-MRC model [18], our proposed model gives a better performance in the case of $N$=2, $L$=4 at BER=$10^{-4}$ both having Gaussian traits, obtaining SNR of 14.2 and 9.443 respectively.

## IV. CONCLUSION

In this paper, we inspected about the newly introduced hybrid diversity techniques SC-EGC and SC-MRC under AWGN noise using BPSK modulation. Two types of fading channel (Rayleigh and Rician) is used to prove the performance analysis of the hybrid diversity scheme. From the output analysis, we used BER versus SNR graph to determine the rigidity of data transmission from transmitter to receiver.

Signal received by SC-MRC shows better performance than the basic diversity schemes (SC, MRC, EGC). Whereas for every increase in antenna in the reception side SC-EGC shows better robustness in contrast to SC-MRC with less complexity. The robustness of the performance can be further studied in the presence of impulsive noise with different modulation schemes (QPSK, M-QAM etc). In conclusion, for higher diversity order SC-EGC is the preferable combining scheme for SIMO transmission with a slight trade-off between diversity BER gain with complex model construction.

## REFERENCES


[1] I. Ahamed and M. Vijay, "Comparison of different diversity techniques in mimo antennas," in *2017 2nd International Conference on Communication and Electronics Systems (ICCES)*. IEEE, 2017, pp. 47–50.

[2] S. Manoharan and V. Bhaskar, "Performance comparison of m-dcsk schemes in mimo nakagami channels with and without diversity combining," in *Proceedings of the International Conference on Advances in Computing, Communications and Informatics*, 2012, pp. 673–677.

[3] F. He, H. Man, and W. Wang, "Maximal ratio diversity combining enhanced security," *IEEE Communications Letters*, vol. 15, no. 5, pp. 509–511, 2011.

[4] N. Kaur and G. Nanak, "Snr and ber performance analysis of mrc and egc receivers over rayleigh fading channel," *International Journal of Computer Applications*, vol. 132, no. 9, pp. 12–17, 2015.

[5] S.-C. Lin, "Performance analysis for optimum transmission and comparison with maximal ratio transmission for mimo systems with cochannel interference," *EURASIP Journal on Wireless Communications and Networking*, vol. 2011, no. 1, pp. 1–12, 2011.

[6] D. J. Love and R. W. Heath, "Equal gain transmission in multiple-input multiple-output wireless systems," *IEEE Transactions on Communications*, vol. 51, no. 7, pp. 1102–1110, 2003.

[7] P. C. Spalevic, M. C. Stefanovic, S. R. Panic, B. S. Jaksic, and M. B. Petrovic, "Performance analysis of selecting maximal ratio combining hybrid diversity system over ricean fading channels," *automatika*, vol. 55, no. 3, pp. 299–305, 2014.

[8] B.-Y. Wang, "Accurate ber of transmitter antenna selection/receiver-mrc over arbitrarily correlated nakagami fading channels," in *2006 IEEE International Conference on Acoustics Speech and Signal Processing Proceedings*, vol. 4. IEEE, 2006, pp. IV–IV.

[9] B. S. Ram and P. Siddaiah, "Performance evaluation of hybrid diversity technique using minimum shift keying over rayleigh fading channel," *International Journal of Applied Engineering Research*, vol. 12, no. 11, pp. 2876–2878, 2017.

[10] S. Haghani, N. C. Beaulieu, and M. Z. Win, "Snr penalty of hybrid diversity combining in rayleigh fading," in *IEEE International Conference on Communications, 2003. ICC'03.*, vol. 4. IEEE, 2003, pp. 2800–2804.

[11] A. O. Akande, "A new hybrid diversity combining scheme for mobile radio communication systems over nakagami fading chanel," *Available at SSRN 3638924*, 2020.

[12] M.-S. Alouini and M. K. Simon, "Performance of coherent receivers with hybrid sc/mrc over nakagami-m fading channels," *IEEE Transactions on Vehicular Technology*, vol. 48, no. 4, pp. 1155–1164, 1999.

[13] P. Sahu and A. Chaturvedi, "Performance evaluation of sc-mrc and sc-egc diversity combining systems in slow nakagami-m fading channel," 2002.

[14] A. Dinamani, S. Das, L. Bijendra, R. Shruti, S. Babina, and B. Kiran, "Performance of a hybrid mrc/sc diversity receiver over rayleigh fading channel," in *2013 International conference on Circuits, Controls and Communications (CCUBE)*. IEEE, 2013, pp. 1–4.

[15] V. S. Sindhoori and V. Bhaskar, "Simo channel capacity using hybrid diversity combining techniques in a rayleigh fading channel," in *2012 International Conference on Devices, Circuits and Systems (ICDCS)*. IEEE, 2012, pp. 374–378.

[16] R. Gupta, "Performance evaluation of wcdma system for different modulations with equal gain combining scheme," *International Journal of Engineering Applied Sciences and Technologies*, vol. 1, no. 7, pp. 10–14, 2016.

[17] J. Mark and W. Zhuang, *Wireless Communications and Networking*. Prentice Hall, 2003. [Online]. Available: https://books.google.com.bd/books?id=cRQfAQAAIAAJ

[18] V. Hima Pradeep and S. Padmarajan, "Hybrid diversity combining techniques for fading channels," *International Journal of Scientific Research in Science, Engineering and Technology*, vol. 1, no. 4, pp. 227–230, 2015.