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# Comparative Analysis of Hybrid Diversity Schemes under AWGN and Impulsive Noise Models for Rayleigh Fading Channels

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***Abstract*—The widespread presence of impulsive noise caused by electro-mechanical switching devices, electromagnetic interference prompts the performance of diversity combining ventures. In this research work, we develop the performance survey in terms of BER (Bit error rate) versus SNR (Signal to noise ratio) over three wireless noise models; additive white Gaussian noise (AWGN), Middleton class-A and Symmetric alpha stable (S$\alpha$S) noise model under Rayleigh fading channel. We aim to employ the probability density function (PDF) of the generated Class-A and S$\alpha$S noise distribution to compare the better performance rate with parameter variation. Statistical analyzation has been done in the presence of three noise models on the BER response of data transmission of SC-MRC (Hybrid Selection-Maximal ratio Combiner) and SC-EGC (Hybrid Selection-Equal Gain Combiner) techniques in SIMO (Single input Multiple Output) device. We verified that for each noise model hybrid diversity combining schemes show better performance. The theory is authenticated by our simulation results.**

***Index Terms*—Impulsive noise, Hybrid diversity combining, Middleton class-A, Symmetric alpha stable (S$\alpha$S), SIMO.**

## I. Introduction

In wireless communication, diversity techniques are a powerful receiver combining technique which provides wireless communication signal linkage improvement. Effects of natural noise phenomena in diversity combining schemes are assumed to be AWGN. However, digitized television, Power line communication (PLC) and underwater acoustic transmission in telecommunication systems are affected by an unwanted noise named impulsive noise, which corrupts the reception signal performance more than AWGN. Impulsive noise can be divided into two categories, man made, which is prompted by electrical equipment connected through a communication system (electromagnetic interference, adverse channel environment) and natural phenomena due to atmospheric behavior and solar statics such as thunderstorms. Man made impulsive noise consists of chains of random, non-overlapping short duration spikes of on/off pulses with flat frequency response and large amplitude over the spectrum, which causes complex error as it is difficult to separate from the signal.

The performance of BER degrades with impulsive noise compared to Gaussian noise in Post detection combining (PDC) than Maximum ratio combining (MRC) in Rayleigh fading channel [1].As the channel becomes more impulsive, MRC and EGC are negatively impacted, whereas SC shows superior performance. The output performance of a non-linear combiner is better than that of a linear detector with higher complexity [2]. The techniques used for adjusting Gaussian noise may not be operative for a signal possessing impulsive noise. To negate the adverse influence of impulsive noise with robust output signals non-linear techniques are more productive. The pure diversity combining schemes MRC, Selection Combiner (SC), Equal Gain combiner (EGC) and PDC retains the diversity order under the dependent noise condition of Middleton class-A [3]. When evaluating multipath received signal, it was discovered that BER performance rate is lowest for AWGN and highest for Rayleigh and Rician fading channels [4]. However, the Rician fading channel outperforms the Rayleigh channel in terms of performance [5]. As Rician channel consist of Line of sight (LOS) and multipath, it has superior SNR performance than Rayleigh channel in direct transmission path under AWGN, which has no LOS from transmitter to receiver [6]. Class-A impulsive noise refers to the Electromagnetic Interference (EMI) which is encountered due to telecommunication operated applications [7]. Over complex numbers and impulsive noise channels, encoding and decoding of error-correcting codes is explored using QAM modulation, which is analogous to OFDM (Orthogonal frequency-division multiplexing) modulation. [8]. The presence of impulsive noise in an OFDM system was investigated using various combinations and modulations in [9]. Middleton class-A is materialized as conditionally Gaussian, namely as compound Gaussian [10].

Adaptive spatial diversity receiver is used to model telecommunication for flat and slow fading additive non-Gaussian im-

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pulsive noise to improve wireless communication [11]. Symbol error probability (SEP) is accurately estimated for MRC over independent Nakagami-q and Rician fading channel [12]. The properties of baseband noise for additive white Symmetric alpha stable (AWS$\alpha$S) are discussed using passband to passband conversion scheme deriving a bi-variate characteristic function in [13]. The uncoded and block coded transmission performance is considered for Additive white class-A (AWCN) channel to generalize an optimum receiver with minimum complexity [14]. In comparison to AWGN, linear multi-user reception performs poorly in terms of non-Gaussian noise. [15]. Perseval's theorem is used in single/double finite ranged integrals under different fading channel to evaluate exact performance of EGC diversity system [16].

The approach of Cumulative distribution function (CDF) versus SNR is equally associated in all fading channels [17]. [18] proposes three models to detect multivariate density function for class-A interference.

However, we worked on the performance response of hybrid diversity combining schemes in this study. Our goal in this paper is to work on basic MRC, hybrid SC-MRC and SC-EGC under two branches of impulsive noise (Middleton class-A, S$\alpha$S) and Gaussian noise (AWGN). Here we considered the BPSK modulation under Rayleigh fading channel to observe the channel fading of the data transmission signal. The models having hybrid diversity schemes proved to have better performance with minimum BER although the impulsive noise channel deteriorates the overall transmission. It appears that SC-MRC possesses better output production than SC-EGC or any basic diversity scheme.

In this research paper, we will examine the performance output of hybrid diversity combining schemes under three noise models. In section II, we analyze the system diagram of the project in the presence of impulse noise. Section III discusses about the working principle of three noise models. Section IV presents the output analysis and simulation results and section V concludes the paper.

## II. System Model

In the proposed system model in Fig. 1 a number of $d$ symbols have been modulated through BPSK modulation to $s$ transmitted symbols. Count of channel is $r_{NL}$ which have been created by passing having path of $h_{NL}$ Rayleigh fading channel and $NL$ noise (AWGN, Middleton class-A, S$\alpha$S) models. The symbols are given input to hybrid diversity combiner Fig. 2 which consists of $N$ SC module. Each module chooses a signal with the strongest instantaneous SNR in the midst of $L$ antennas. In the second stage the signals are further given input to MRC module in the case of SC-MRC hybrid combiner, where the SNR of combined signals are weighted and then equalized to detect the data $\hat{s}$ from the faded noisy signal. On the other hand, in case of the SC-EGC combiner, the input is given to EGC where the signals are weighted equally. It 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 as $\hat{s}$. At last, the computed signal is sent to demodulator to get the best output symbol $\hat{d}$.

## III. Noise Model

There are different branches of impulsive noise models, which can be categorized as follows,

1) Memoryless impulse noise model
   a) Middleton Class-A noise model
   b) Symmetric Alpha-Stable distribution (S$\alpha$S)
   c) Bernoulli-Gaussian distribution
2) Memory-based impulse noise model
   a) Markov-Middleton noise model
   b) Markov-Gaussian noise model

The area of our study is based on two branches of memoryless impulse noise models, Middleton Class-A and S$\alpha$S.

*1) Middleton Class-A Noise model:* Middleton class-A noise is a manifestation of Poisson noise model. The probability density function (PDF) of Middleton class-A of a noise sample $n_l$ is based of the literature of [19],

$$f_M\left(n_l\right) = \sum_{q=0}^{\infty} P_q \mathcal{N}\left(n_l; 0, \sigma_q^2\right) \tag{1}$$

where, $\mathcal{N}(x_l; \mu, \sigma^2)$ is the PDF of Gaussian noise. Another form of probability density function is

$$f_M(x) = e^{-A} \sum_{q=0}^{\infty} \frac{A^q}{q! \sqrt{2\pi\sigma_q^2}} e^{-\frac{x^2}{2\sigma_q^2}} \tag{2}$$

where $\sigma_q^2$ is given by the following equation

$$\sigma_q^2 = \frac{\frac{q}{A} + \Gamma}{1 + \Gamma} \tag{3}$$

The parameter $A$ signifies impulsive factor and $\Gamma$ denotes Gaussian noise factor which is the power ratio of the AWGN (background noise) and the impulsive noise.

$$\Gamma = \frac{\sigma_G^2}{\sigma_I^2} \tag{4}$$

It has a closed form expression. The tails of the distribution are controlled by $P$ and $A$. As the probability of $P$ and $A$ increases (increase in impulsive index) the tails of the PDF distribution become wider. The wider the PDF tail, the noise becomes more impulsive, which represents poor signal transmission. Noise bandwidth of Class-A model is Narrow with thick PDF tails.

*2) Symmetric Alpha Stable distribution Noise Model:* Symmetric alpha stable distribution for impulse noise modelling is recently becoming more widespread in literature. It is known as broadcast noise as the bandwidth of noise is greater than the receiver and can be substituted for Middleton class-B.

S$\alpha$S distribution does not abide by the modelling phenomena of Gaussian distribution, rather follows their probability distribution representing thick tails in comparison to Gaussian distribution.

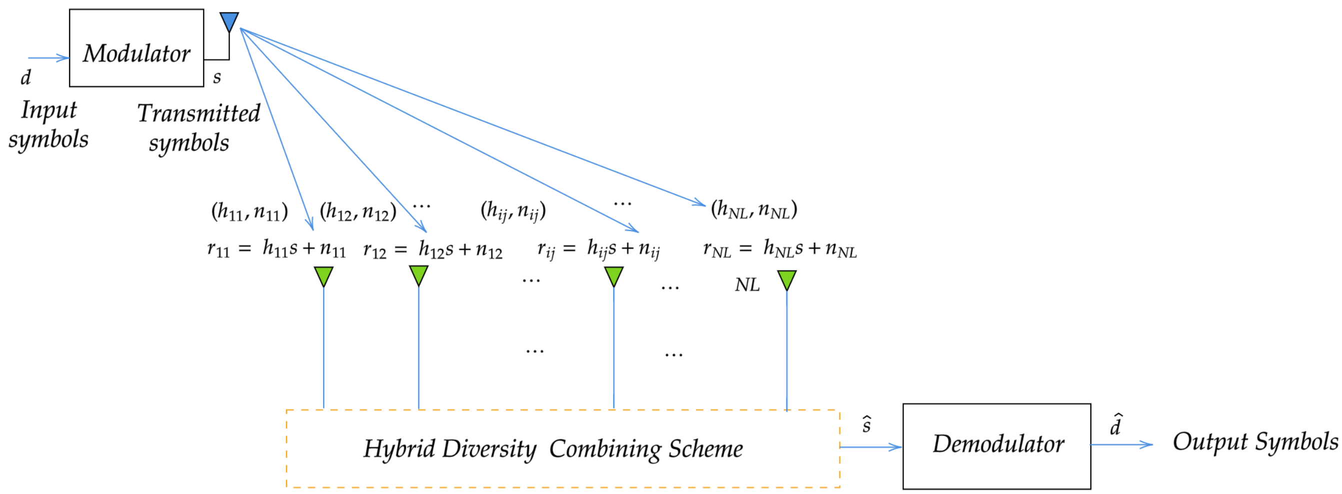



Fig. 1. System Model

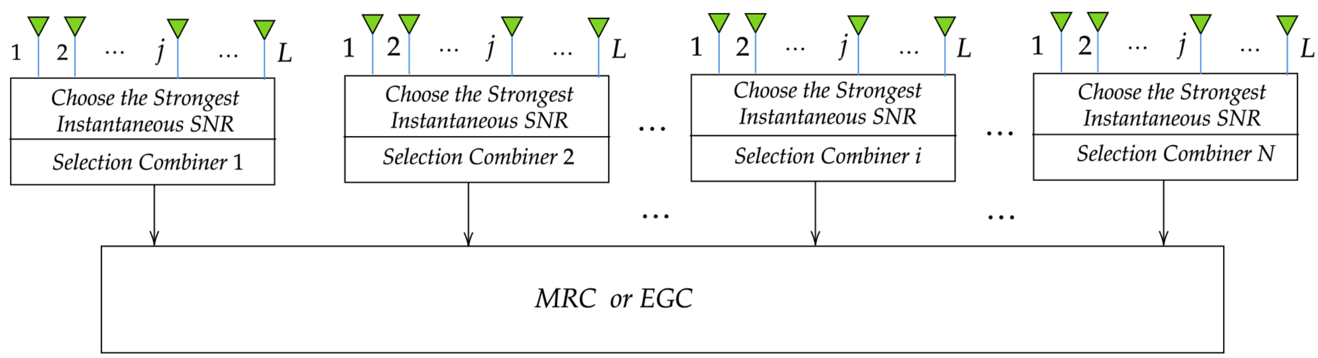



Fig. 2. Hybrid Diversity Combining Schemes

The probability density function of S$\alpha$S is,

$$f_S(x) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \varphi(t)e^{-jxt}dt \tag{5}$$

which describes the inverse Fourier transform of the characteristics equation.

$$\varphi(t;\alpha,\beta,c,\mu) = \exp\left(jt\mu - |ct|^{\alpha}(1 - j\beta\,\mathrm{sgn}(t)\Phi)\right) \tag{6}$$

where,

$$\Phi = \begin{cases} \tan\left(\frac{\pi\alpha}{2}\right) & \alpha \neq 1 \\ -|\frac{2}{\pi}\log(ct)| & \alpha = 1 \end{cases} \tag{7}$$

The parameters describing S$\alpha$S distribution are, $\alpha$= characteristic exponent, which represents the tail thickness/width of the distribution where, 1$\leq \alpha \leq$2, with change in this parameter the tails of the PDF becomes wider than AWGN distribution for $\alpha \leq 2$.

$\beta$ = Symmetry parameter, represents skewness of the distribution where -1$\leq \beta \leq$1.

when $\beta \geq 0$ the distribution becomes right skewed and when $\beta \leq$0 the distribution becomes left skewed.

$\gamma$ = Scale parameter/dispersion, $\gamma >$0

$\delta$= Location parameter, represents the location of the distribution. -$\infty \leq \delta \leq \infty$

The shape of the distribution is represented by $\alpha$ and $\beta$, whereas $\gamma$ and $\delta$ are represented as variance and mean similar to Gaussian distribution. The tails of the PDF distribution of S$\alpha$S is controlled by $\alpha$. As $\alpha$ decreases, the tails become wider.S$\alpha$S noise model does not exhibit burst noises like Middleton class-A. The PDF shows wide tails.

*3) Additive White Gaussian Noise Model (AWGN):* Additive white Gaussian noise is symbolized as thermal noise or background noise (random noise occurrence in nature) which corrupts the information system. It has a uniform bandwidth with an normal distribution in time domain. AWGN consists of a mean of zero and normalized variance of 1. The robustness of the noise generated is dependable on the input SNR level.

The probability density function of AWGN Noise is given by,

$$f_G(x) = \frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{8}$$

where $\mu$ is the mean and $\sigma$ is the variance of the distribution.

$$\sigma = \sqrt{\frac{N_o}{2}} \tag{9}$$

Here, $N_o$ is the signal power to SNR ratio. For a transmitted signal $T_s$ of length L, the generated Gaussian noise,

$$n_G = \begin{cases} \sigma \times \mathcal{N}_L(0,1) & \text{if } T_s \text{ is real} \\ \sigma \times [\mathcal{N}_L(0,1) + j * \mathcal{N}_L(0,1)] & \text{if } T_s \text{ is complex} \end{cases} \tag{10}$$

It has a closed form expression with wide noise bandwidth. AWGN consists of random burst noises. The PDF shows thin tails.

## IV. Performance Analysis

Simulation for different combining schemes under different noise models was done in MATLAB software to visualize the results.

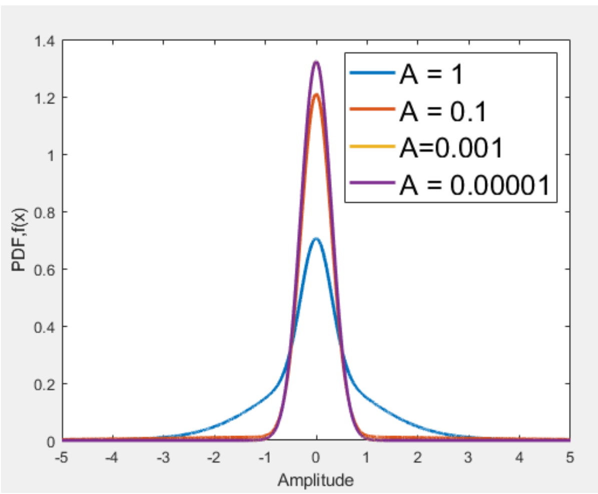



Fig. 3. Middleton class-A PDF generation under various impulsive index

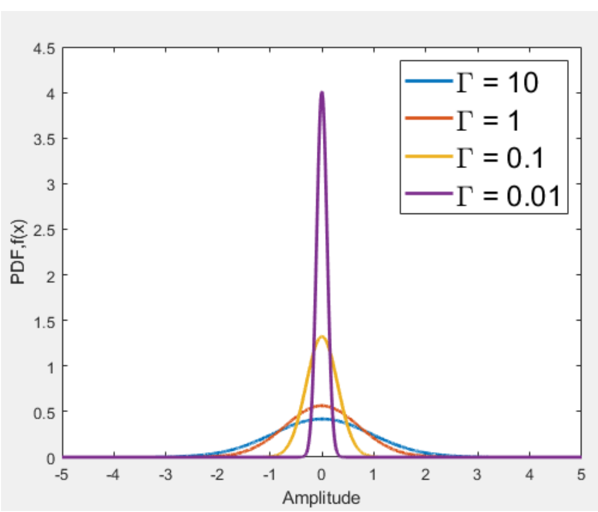
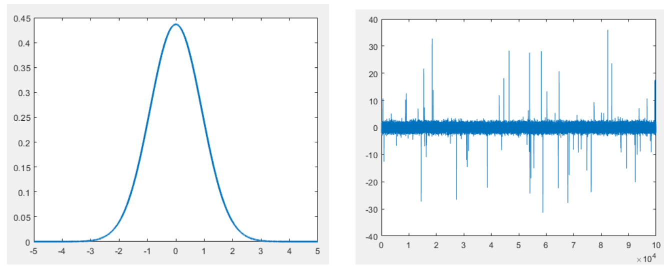



Fig. 4. Middleton class-A PDF generation under various Gaussian Factor $\Gamma$

Fig. 3 represents the variation of the impulsive index $A$ in PDF of Middleton class-A. With decreasing $A$, the PDF reaches high slender peak and for A=1 the amplitude is the lowest since having AWGN effect.

Fig. 4, this time PDF was observed for varying Gaussian Factor $\Gamma$ under constant impulsive index A= 0.0001. for $\Gamma >$ 1, the PDF does not show significant sharpness having more Gaussian effect for $\Gamma$ <1, the PDF is rigid sharp being too impulsive.



(a) Middleton class-A PDF for $A = 10^{-3}, \Gamma = 5$ (b) Middleton class-A noise signal for $A = 10^{-3}, \Gamma = 5$

Fig. 5. PDF and noise signal of Middleton class-A used in simulation

Fig. 5 is the PDF and noise signal of Middleton class-A impulsive noise, which has been used to simulate the combining technique. where, $\Gamma$=5 and $A$=0.001.

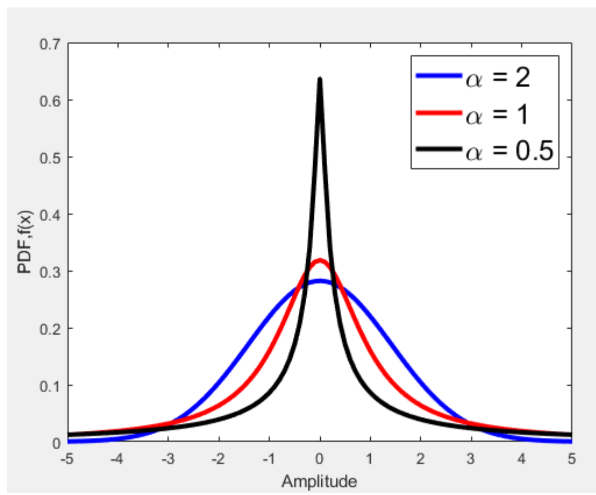
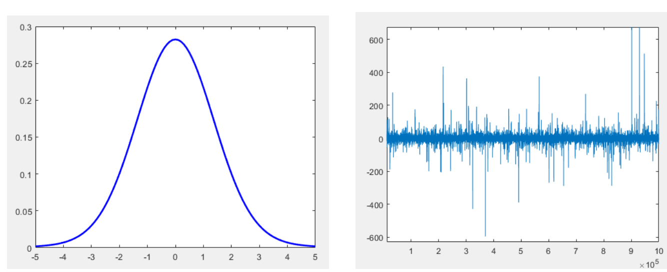



Fig. 6. Symmetric alpha stable (S$\alpha$S) noise under varying $\alpha$



(a) S$\alpha$S for $\alpha = 1.9$ (b) S$\alpha$S noise signal for $\alpha = 1.9$

Fig. 7. PDF and noise signal of S$\alpha$S used in simulation

The second noise model considered is S$\alpha$S noise. In Fig. 6, the dominant parameter characteristic exponent, $\alpha$ is varied having other parameter $\delta$,$\beta$ and $\gamma$ constant as these two parameters do not show noticeable changes in PDF.

Fig. 7 shows the PDF and noise signal of S$\alpha$S noise which has been used to simulate the combining technique, where characteristic exponent $\alpha = 1.9$, $\gamma = 1$, $\delta = 0$, $\beta = 0$. Values are chosen in terms of AWGN effect in impulsive noise as pure impulsive noise is not found generally and it is detrimental to signal channels and devices.

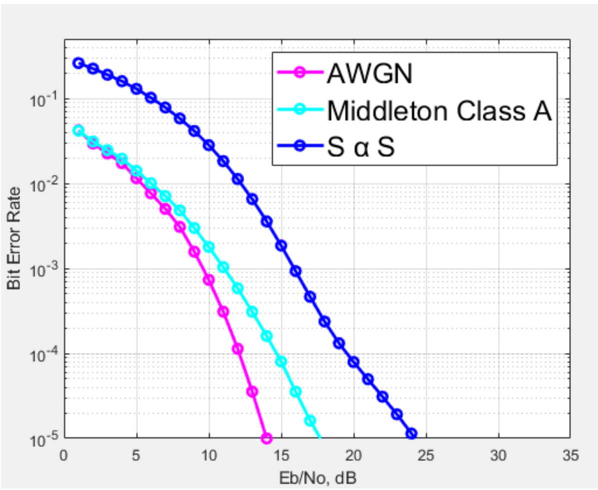



Fig. 8. Bit Error Rate response for SC combining in Rayleigh channel under various noise model (modulation- BPSK)

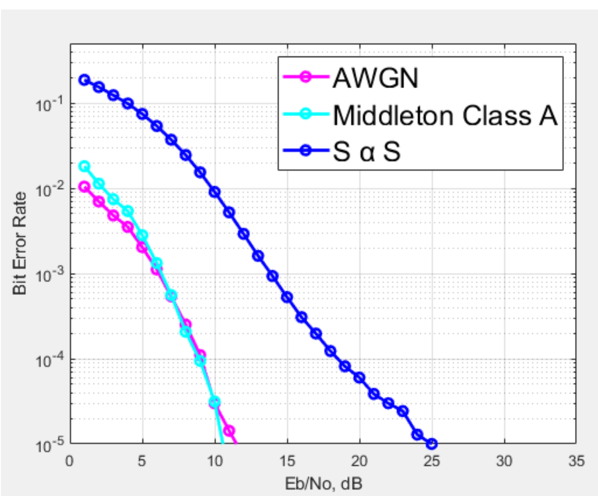



Fig. 9. Bit Error Rate response for MRC combining in Rayleigh channel under various noise model (modulation- BPSK)

At first we observed the responses of AWGN, Class-A and S$\alpha$S noise in basic SC, MRC and EGC combining.

Fig. 8 shows responses of three noises in SC combining under BPSK modulation. It is observed that AWGN noise brings out the optimum BER performance whereas S$\alpha$S noise gives the worst response.

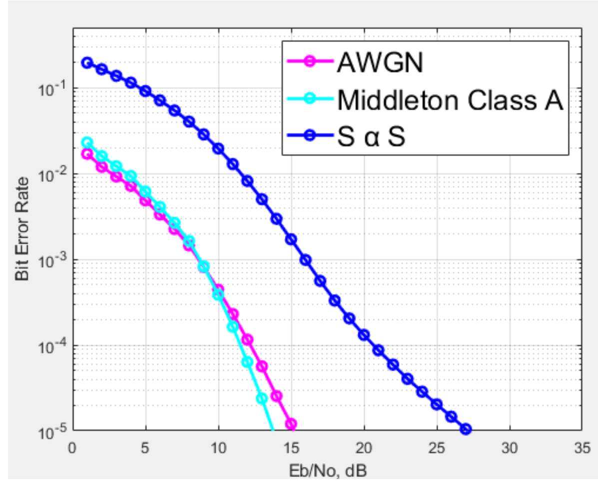



Fig. 10. Bit Error Rate response for EGC combining in Rayleigh channel under various noise model (modulation- BPSK)

Similar response is observed in basic MRC combining (although slightly better) where the best performance serial goes along AWGN, Class-A and S$\alpha$S noise in Fig. 9.

For basic EGC, three noise performance was monitored in Fig. 10. EGC shows very close BER vs SNR gain similar to MRC without changing the noise distortion serial.

For the hybrid SC-MRC Fig. 11, the best -to-worst BER performance serial according to added noise remains AWGN, Class-A and S$\alpha$S. However, as anticipated the overall BER response improved slightly.

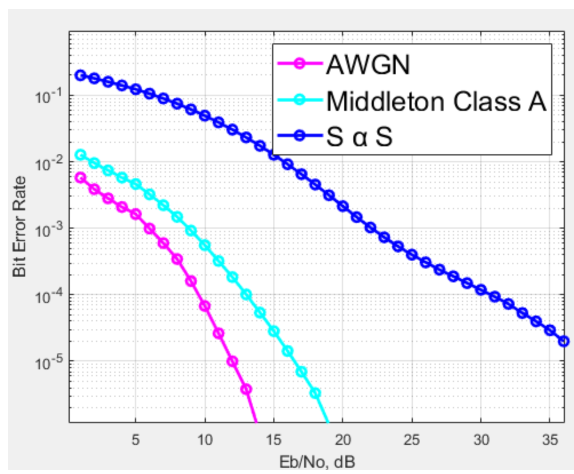



Fig. 11. Bit Error Rate response for SC-MRC Hybrid combining in Rayleigh channel under various noise model (modulation- BPSK)

Same comparison is simulated for hybrid SC-EGC combining where AWGN performed better following class-A ($A$=0.001, $\gamma$=5) and S$\alpha$S noise performance shown in Fig. 12 in Rayleigh channel under various noises.

A comparative analysis is done in Table I for different noise models. It is verified that hybrid diversity combiner performs better than basic combiners in terms of SNR gain for a fixed BER. For a particular parameter, AWGN shows better BER

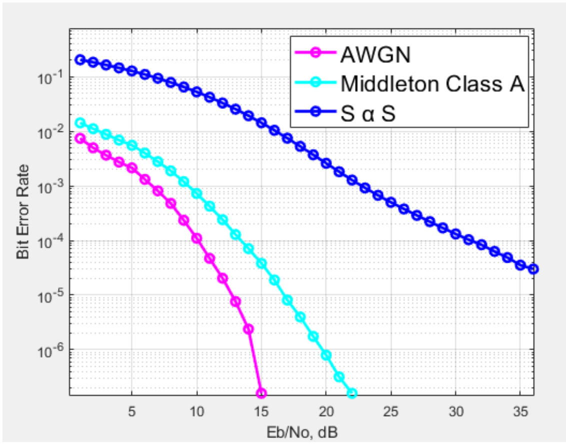



Fig. 12. Bit Error Rate response for SC-EGC Hybrid combining in Rayleigh channel under various noise model (modulation- BPSK)

TABLE I
SNR GAIN FOR CONSTANT BER $10^{-3}$

| Noise Model | MRC | EGC | SC | SC-MRC | SC-EGC |
|---|---|---|---|---|---|
| **AWGN** | 6 | 8 | 9 | 6 | 6 |
| **Class-A (A=** $10^{-3}$**,** $\Gamma=$**5)** | 6 | 8 | 11 | 7 | 8 |
| **S**$\alpha$**S (**$\alpha=$**1.9)** | 14 | 16 | 17 | 23 | 24 |

response whereas S$\alpha$S shows the worst as impulsive noise degrades the SNR by a substantial degree. However, a close yet better result was found comparing Middleton Class A with A=1, $\Gamma$=0.1 in [1] with A=$10^{-3}$, $\Gamma$=5 in this paper, both having Gaussian traits, obtaining SNR of 12 and 9 respectively considering BER=$10^{-4}$.

## V. Conclusion

The Bit Error Rate and SNR response of a wireless communication system is a significant tool used to determine the rigidity of data transmitted through the system. In this paper, two branches of impulsive noise Middleton class-A and S$\alpha$S noise were studied by observing their PDF and noise signal. The effect was observed for basic SC, basic MRC, hybrid SC-EGC and SC-MRC for varying parameter. The noises having Gaussian characteristics stand out with the best BER response, whereas impulsive noise models make poor BER response. Further investigation can be conducted engaging MIMO with QPSK, M-QAM and other modulation schemes over Rician and Nakagami-m fading channels. However, the performance of hybrid combining scheme was better than the basic combining techniques. Irrespective of the combining scheme, whether it is basic or hybrid, BER response is the worst for S$\alpha$S noise.

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