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Improvement of Bit Error Rate performance with receive diversity using reinforcement learning for AWGN channel

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Abstract:

The diversity principle can be employed to combat the fading nature of wireless communication. In the case of receiver diversity the independent fading paths are connected with multiple receive antennas and the resultant signal can be obtained by combining outputs from antennas. This resultant signal is passed through a standard demodulator. The Bit Error Rate (BER) is the most important parameter in communication system design. Always the reducing nature of BER has been desirable which makes the communication more reliable. In this work selection combining (diversity) scheme is used as receive diversity and the performance of 4-Quadrature Amplitude Modulation (4-QAM) and Differential Phase Shift Keying (DPSK) modulation schemes are compared in terms of average BER and multiple number of receiving antennas.

Keywords: 4-Quadrature Amplitude Modulation (4-QAM), Differential Phase Shift Keying (DPSK), Bit Error Rate (BER)

1. INTRODUCTION

In wireless communication, transmitted signal suffers from multipath fading and interference before it arrives at the receiver[1]. Propagation phenomenon named as multipath where the signal travels from transmitter through more than one number of paths. In multipath propagation, there are constructive and destructive interferences. Due to the multipath propagation the quality of signals are degrade in digital radio communications. Arrival of signals can be delayed at the receiver end. Furthermore, the signal scatters through each major path due to reflections of signal from the different objects. Combinations of these signal elements cause the multipath fading[2]. In urban areas, multipath fading with large delay spread is encountered which severely degrades the BER performance. These difficulties can be combated with the help of receiving diversity. This technology offers more reliable communication between transmitter and receiver through diversity principle[3]. In this work, we investigated bit error rate performance of Differential Phase Shift Keying and 4-Quadrature Amplitude Modulation techniques for selection combining at the receiver section in the presence of Rayleigh fading. The Rayleigh fading channel can be considered as conventional AWGN channel along with time varying SNR which is Rayleigh distributed. It is desirable that bit error rate should be very small but practically it is not the case. Data will be erroneous due to the presence of noise in the transmission path. So system performance needs to be assessed in terms of bit error rate. Error functions are different for different modulation techniques which perform differently in presence of noise. In selection combining, the receiver selects an antenna which is having a maximum gain in magnitude, and discards the observations from the other antennas[4]. Co-phasing of multiple antennas is not required because only one antenna output is used. This technique can be used in coherent as well as differential modulation. Average BER is calculated using bit error probability of each modulation technique and probability density function (pdf) for SNR and this pdf is calculated using outage probability[5]. Closed form of average BER expression is used for simulation purpose[6].

This paper is organized as mentioned here. Section II represents the system model, closed form expression for average BER. Section III shows simulated results from which some discussion made. In Section IV, some conclusions are drawn.

2. DIGITAL MODULATION TECHNIQUES

QUADRATURE AMPLITUDE MODULATION (QAM):

It is a combination of Amplitude Shift Keying (ASK) and Phase Shift Keying (PSK). In QAM, incoming signal is splits into In-phase signal and Quadrature phase signal. I-phase component is a cosine waveform and Q-phase component is sine waveform. It can be seen as a two channel system. The orthogonal modulated signals are generated. In the case of 4-QAM, four message points and two bits per symbol (message) point are used and transmitted through the channel. It has a wide range of applications, not only in the field of mobile communications but also in cable TV transmission, digital video broadcasting, satellite communications and other fields.
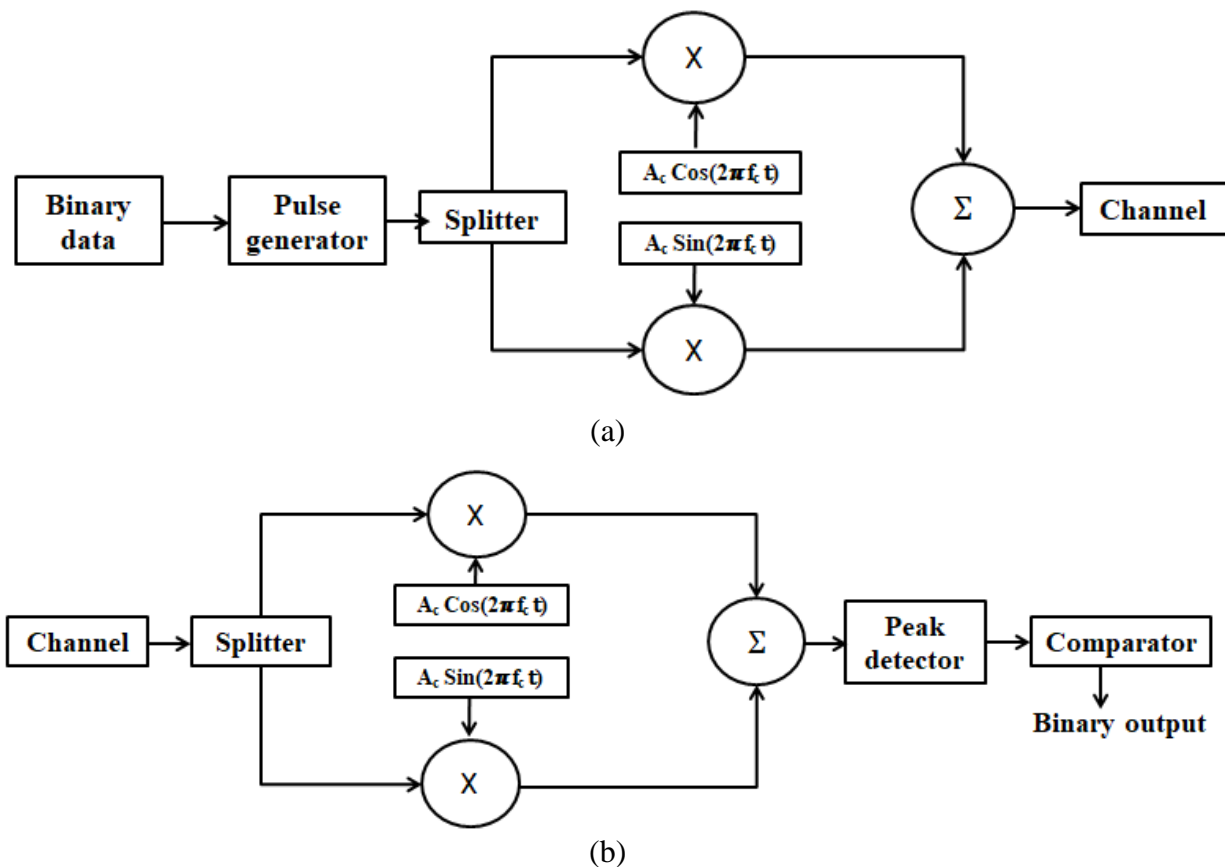
(a)

(b)

Figure 1.4-QAM (a) Modulation Scheme and (b) Demodulation Scheme

DIFFERENTIAL PHASE SHIFT KEYING (DPSK):

It is a non-coherent digital modulation technique for which synchronous carrier is not required at demodulator section. Incoming pulse multiplied by the preceding pulse which can be considered

as locally generated pulse. Input sequence is modified such that next bit depends on the previous bit. At receiver previous received bits are used to detect the present bit.
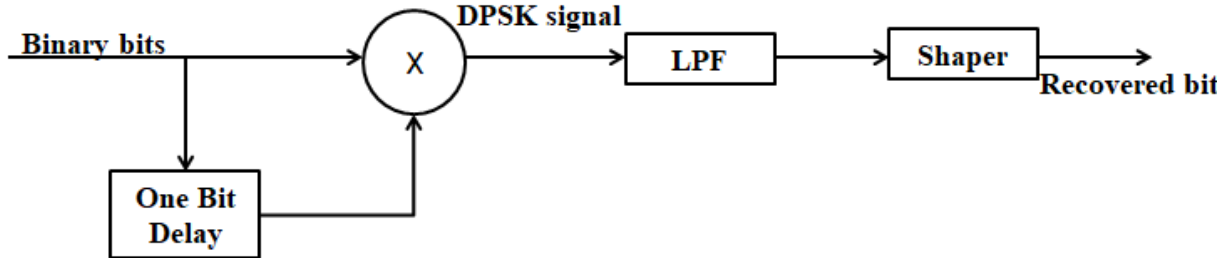

Figure 2. DPSK Modulation and Demodulation Scheme

3. ADDITIVE WHITE GAUSSIAN NOISE (AWGN)

The AWGN channel can be considered as simplest channel that can be used to represent the performance of communication system. To decide performance of a digital communication system which can be indicated by bit error rate, thermal noise plays a crucial role here. In the context of wireless communication system, main source of thermal noise is composition of random undesired signals. In this kind of system noise is added with the transmitted signal [7]. It has uniform power across whole frequency band. As noise is random variable therefore statistical parameter like probability density function must be defined and pdf of noise is Gaussian in nature with zero mean.

4. BIT ERROR RATE:

The bit error rate (BER) is a ratio of number of bits in error and the total number of transferred bits during a time interval [8], [9]. BER is a unit less performance measure, often expressed as a percentage. It is an important parameter to measure the performance of any communication channel for any modulation technique.

5. SYSTEM MODEL:

SELECTION DIVERSITY

Consider a system with one transmitting antenna and receiving antennas. DPSK and 4-QAM modulation techniques are employed here. The transmitter sends two bits per symbols for 4-QAM

and one bit per symbol for DPSK with energy $E_s = 2E_b$, where energy per bit is E_b. The mathematical model of the received signal is given as follows,

$$y = h\,s + n$$

where, s is transmitted signal and n is additive white Gaussian noise. Channel gain vector is denoted by $h = [h_1, h_2, \ldots h_m]^T$. Noises on each antenna is independently and identically distributed and Additive White Gaussian Noise (AWGN) channel is used for the analysis. This channel adds a white Gaussian noise to the message signal and the transmitted signal gets distorted. Noise can be modeled using a Gaussian probability density function as is given by the following equation[10].

$$p(n) = \frac{1}{\sqrt{2\pi\sigma^2}} \cdot exp\left(-\frac{(n-\mu)^2}{2\sigma^2}\right)$$

where, mean $\mu = 0$, variance $\sigma^2 = \frac{N_0}{2}$.

Average Bit Error Rate

The averaged probability of error is computed by integrating the error probability in AWGN over the fading distribution[11]

$$\overline{P_s} = \int_0^\infty P_s(\gamma)p_{\gamma_s}(\gamma)d\gamma$$

where $P_s(\gamma)$ denotes the symbol error probability in AWGN and SNR per symbol is γ. In Rayleigh fading, amplitude r of the received signal has the following Rayleigh distribution

$$p(r) = \frac{r}{\sigma^2} e^{-\frac{r}{2\sigma^2}}$$

and the signal power is exponentially distributed with mean $2\sigma^2$. The instantaneous value of SNR per bit is denoted by γ_i which is defined as ratio of energy per bit to noise power spectral density. Distribution of the SNR is given as follows,

$$p(\gamma_i) = \frac{1}{\overline{\gamma_i}} e^{-\frac{\gamma_i}{\overline{\gamma_i}}}$$

Where $\bar{\gamma}_i$ is average SNR per symbol. In Rayleigh fading the outage probability is for a target γ_0 on the ith path becomes

$$P_{out} = p(\gamma_s < \gamma_0) = \int_0^{\gamma_0} p(\gamma_i) d\gamma = \int_0^{\gamma_0} \frac{1}{\bar{\gamma}_i} e^{-\frac{\gamma_i}{\bar{\gamma}_i}} d\gamma_i = 1 - e^{-\frac{\gamma_0}{\bar{\gamma}_i}}$$

The outage probability[12] of an M-branch selection combiner for the target γ_0 is given by,

$$P_{out}(\gamma_0) = \prod_{i=1}^{M} p(\gamma_i < \gamma_0) = \prod_{i=1}^{M} \left[1 - e^{-\frac{\gamma_0}{\bar{\gamma}_i}} \right]$$

If all the branches are having same the average SNR ($\bar{\gamma}_i = \bar{\gamma}$ for all i), then the above equation reduces to

$$P_{out}(\gamma_0) = \left[1 - e^{-\frac{\gamma_0}{\bar{\gamma}}} \right]^M$$

Differentiating the above equation yields the probability density function for SNR,

$$p_{\gamma_s}(\gamma) = \frac{M}{\bar{\gamma}} \left[1 - e^{-\frac{\gamma}{\bar{\gamma}}} \right]^{M-1} e^{-\frac{\gamma}{\bar{\gamma}}}$$

The average SNR of the selection combiner output in i.i.d. Rayleigh fading is

$$\bar{\gamma}_r = \int_0^{\infty} \gamma \, p_{\gamma_r}(\gamma) \, d\gamma = \int_0^{\infty} \gamma \frac{M}{\bar{\gamma}} \left[1 - e^{-\frac{\gamma}{\bar{\gamma}}} \right]^{M-1} e^{-\frac{\gamma}{\bar{\gamma}}} \, d\gamma = \bar{\gamma} \sum_{i=1}^{M} \frac{1}{i}$$

The average probability of symbol error of DPSK is given by

$$\bar{P}_s = \int_0^{\infty} P_s(\gamma) p_{\gamma_s}(\gamma) d\gamma = \int_0^{\infty} \left\{ \frac{1}{2} e^{-\gamma} \right\} \cdot \left\{ \frac{M}{\bar{\gamma}} \left[1 - e^{-\frac{\gamma}{\bar{\gamma}}} \right]^{M-1} e^{-\frac{\gamma}{\bar{\gamma}}} \right\} \, d\gamma$$

where, $\left\{ \frac{1}{2} e^{-\gamma} \right\}$ is the bit error probability and the SNR per bit is denoted by γ. The closed from expression of average probability of symbol error of DPSK modulation is given by

$$\bar{P}_s = \frac{M}{2} \sum_{m=0}^{M-1} (-1)^m \binom{M-1}{m} \frac{1}{1+m+\bar{\gamma}}$$

The average probability of symbol error of 4-QAM[13] is given by

$$\overline{P_s} = \int_0^\infty P_s(\gamma)p_{\gamma_s}(\gamma)d\gamma = \int_0^\infty \left\{\frac{1}{2}erfc(\sqrt{\gamma})\right\} \cdot \left\{\frac{M}{\overline{\gamma}}\left[1 - e^{-\frac{\gamma}{\overline{\gamma}}}\right]^{M-1} e^{-\frac{\gamma}{\overline{\gamma}}}\right\} d\gamma$$

where, $\left\{\frac{1}{2}erfc(\sqrt{\gamma})\right\}$ is the bit error probability and the SNR per bit is denoted by γ. The closed from expression of average probability of symbol error of 4-QAM modulation is given by

$$\overline{P_s} = \frac{1}{2}\sum_{m=0}^{M}(-1)^m \binom{M}{m}\left(1 + \frac{m}{\overline{\gamma}}\right)^{-\frac{1}{2}}$$

4. RESULTS AND DISCUSSIONS:

In this section, simulated data is presented in tabulation form for selection combining system using DPSK and 4-QAM modulation techniques. These results have been shown graphically for different number of receiving antennas at the receiver side.

In the case of Selection Combining technique or Multiple Receiving Antenna, average BER of DPSK modulation scheme is compared for different values of SNR shown in Table I. For any fixed value of SNR, it can be observed that as the number of receiving antenna increases bit error rate decreases. For example at 0 dB SNR average BER for 1 receiving antenna is 0.25 which decreases at 0.03571 when number of receiving antenna is 5.

TABLE I

Average BER comparison of DPSK modulation scheme for varying SNR (dB) in the case of Selection Combining Technique (i.e. Multiple Receiving Antenna)

| $[E_b/N_0]$ in dB	Average BER $[P_e]$ of DPSK				
	No. Receiving Antenna=1	No. Receiving Antenna=2	No. Receiving Antenna=3	No. Receiving Antenna=4	No. Receiving Antenna=5
-14	0.7072	0.4653	0.3455	0.2742	0.227
-10	0.6494	0.4189	0.3065	0.2404	0.1971
-6	0.5325	0.3276	0.2312	0.1761	0.1409
-2	0.3496	0.1926	0.1247	0.08861	0.06681
0	0.25	0.125	0.075	0.05	0.03571
2	0.1619	0.07061	0.03793	0.02304	0.01519
4	0.09467	0.03435	0.01582	0.008427	0.00495
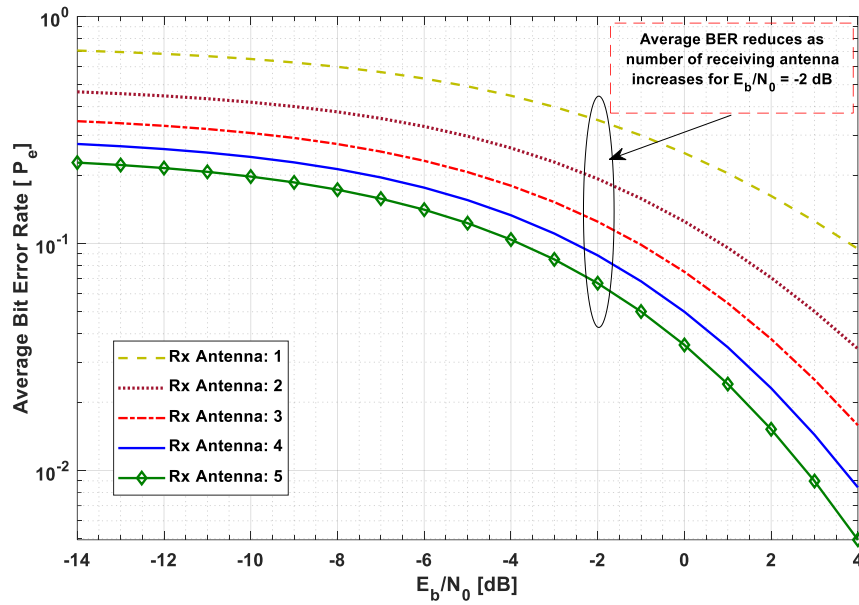
Fig.3: Average Bit Error Rate as a function of E_b/N_0 for selection combining system using DPSK modulation technique

Figure 3 graphically represents the variation of average BER with increasing values of SNR (E_b/N_0) and it can be visualized from the same figure that average BER decreases as SNR increases for DPSK modulation technique. For any fixed value of SNR (in dB) e.g. -2 dB if the number of receiving antenna increases, then average BER will reduce.

In the case of Selection Combining method, average BER of 4-QAM modulation scheme is compared for different values of SNR shown in Table II. It can be observed that average BER reduces as the number of receiving antenna increases for a fixed value of SNR. For example at 0 dB SNR average BER for 1 receiving antenna is 0.1464 which decreases at 0.03289 when number of receiving antenna is 5.

TABLE II

Average BER comparison of 4-QAM modulation scheme for varying SNR (dB) in the case of
Selection Combining Technique (i.e. Multiple Receiving Antenna)

| $[E_b/N_0]$ in dB	Average BER $[P_e]$ of 4-QAM				
	No. Receiving Antenna=1	No. Receiving Antenna=2	No. Receiving Antenna=3	No. Receiving Antenna=4	No. Receiving Antenna=5
-14	0.4022	0.3742	0.3588	0.3485	0.3409
-10	0.3492	0.3076	0.2853	0.2705	0.2597
-6	0.276	0.219	0.19	0.1716	0.1586
-2	0.189	0.1229	0.09317	0.07602	0.06474
0	0.1464	0.08157	0.05537	0.04144	0.03289
2	0.1085	0.04942	0.02885	0.01913	0.01373
4	0.07714	0.02734	0.01309	0.007367	0.004596
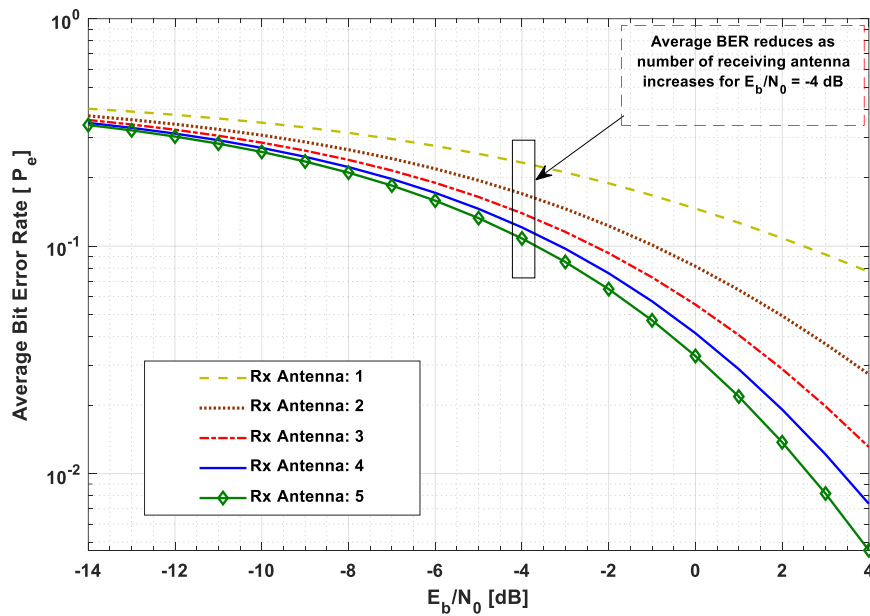
Fig 4. Average Bit Error Rate as a function of E_b/N_0 for selection combining system using 4-
QAM modulation technique

Figure. 4 represents the variation of average BER with the values of SNR (E_b/N_0) and it
can be seen from the above figure that average BER decreases as SNR increases for 4-QAM
modulation. For any fixed value of SNR (in dB) e.g. -4 dB if the number of receiving antenna
increases, then average BER will decrease.

Table III shows simulated values of average BER for different SNR when DPSK and 4-QAM modulation schemes are employed for multiple receiving antenna scenario. From the table it is noticed that average bit error rate is less for 4-QAM as compared to DPSK modulation technique at all SNR values taken in our work and for any fixed number of receiving antennas. For example at 0 dB SNR average BER is 0.125 for DPSK which reduces to 0.08157 when 4-QAM modulation technique is used.

TABLE III

Average BER comparison of DPSK and 4-QAM modulation schemes for varying SNR (dB) in the case of Selection Combining Technique (i.e. Multiple Receiving Antenna)

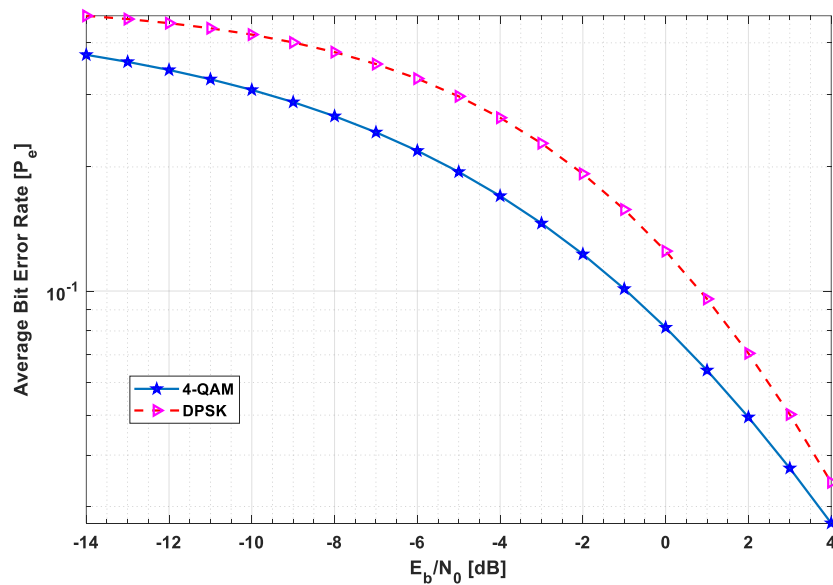| $[E_b/N_0]$ in dB	Average BER $[P_e]$ comparison	
	DPSK	**4-QAM**
-14	0.4653	0.3742
-10	0.4189	0.3076
-6	0.3276	0.219
-2	0.1926	0.1229
0	0.125	0.08157
2	0.07061	0.04942
4	0.03435	0.02734

Fig 5. Comparison of Average Bit Error Rate of DPSK and 4-QAM modulation techniques For varying E_b/N_0 in selection combining system

Fig. 5 shows the graphical representation of the betterment of average BER for 4-QAM modulation technique than DPSK modulation scheme. As SNR increases average BER reduces along with that observation it also can be said from the above figure that for any fixed value, say -4 dB, of SNR, BER of 4-QAM is less as compared with DPSK modulation.

5. CONCLUSION:

This paper provides a comparison between the performance of 4-QAM and DPSK modulation techniques in terms of average BER parameter for multiple receiving antenna scenario. Simulation result depicts that the bit error rate plays an important role for the analysis of the performance of a communication system. Average BER analysis can be used to improve the functionalities of any digital communication process. For both, the modulation schemes, it also can be observed that average BER will reduce as the increment of number of receiving antennas for any fixed value of SNR. As per the performance concern 4-QAM scheme performs better as compared to a DPSK scheme in terms of average BER which also will reduce as SNR increases.

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