Performance evaluation of Rayleigh and Rician Fading Channels using M-DPSK Modulation Scheme in Simulink Environment

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ABSTRACT

The Computation of Bit Error Rate is a mandatory requirement for the analysis of multipath fading channels in any modulation scheme .Fading is nothing but the attenuation in signal strength when it is obtained at the receiver side and it is broadly classified into two types as fast fading and slow fading. If a line of Sight exists between the transmitter and receiver then Rician fading is modelled and in the absence of a line of Sight path Rayleigh fading can be modelled. The multipath intensity profile of a mobile radio channel depends critically on the type of terrain. The Performance comparison of the Rayleigh and Rician Fading channels in Differential Phase Shift Keying modulation using Simulink tool is dealt in this paper.

Keywords: Fading, Rayleigh, Rician, DPSK.

I. AN INTRODUCTION TO CHARACTERISTICS OF THE WIRELESS CHANNELS

The wireless channel (transmission medium) is susceptible to a variety of transmission impediments such as path loss, interference, and blockage. These factors restrict the range, data rate, and the reliability of the wireless transmission. The extent to which these factors affect these transmission affect the transmission depends upon the environmental conditions and the mobility of the transmitter and receiver. Typically, the transmitted signal has a direct-path component between the transmitter and receiver [1]. Other components of the transmitted signal known as multipath components are reflected, diffracted, and scattered by the environment, and arrive at the receiver shifted in amplitude, frequency, and phase with respect to the direct-path component. The various characteristics of the wireless channel such as path loss, fading, interference, and Doppler shift along with the two key constraints namely Nyquist's and Shannon's theorems, that govern the ability to transmit information at different data rates, are presented.

PATH LOSS: Path loss can be expressed as the ratio of the power of the transmitted signal to the power of the same signal received by the receiver, on a given path. It is a function of the propagation distance. Estimation of path loss is very important for designing and deploying wireless communication networks. Path loss is dependent on a number of factors such as the radio frequency used and the nature of the terrain [2]. Since several of these factors cannot be used to describe the characteristics of every transmission. Therefore, in designing a network, several models are required to describe the variety of transmission environments. The free space propagation model is the simplest path loss model in which there is a direct-path signal between the transmitter and the receiver, with no atmospheric attenuation or multipath components. In this model the relationship between the transmitted power P_t and the received power P_r is given by the following expression

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \qquad (1)$$

where G_t and G_r are the transmitter and receiver antenna gains, respectively, in the direction from the transmitter to the receiver, d is the distance between the transmitter and receiver, and $\lambda = \frac{c}{f}$ is the wavelength of the signal

FADING: Fading refers to the fluctuations in signals strength when received at the receiver. Fading can be classified into two types as fast fading/small-scale fading, and slow fading/large-scale fading. Fast fading refers to the rapid fluctuations in the amplitude, phase, or multipath delays of the received signal, due to the interference between multiple versions of the same transmitted signal arriving at the receiver at slightly different times. The time between the reception of the first version of the signal and the last echoed signal is called delay spread. The multipath propagation of the transmitted signal, which causes fast fading, is because of the three propagation mechanisms described as reflection, diffraction and scattering. The multiple signal paths may sometimes add constructively or sometimes destructively at the receiver, causing a variation in the power level of the received signal. The received signal envelope of a fast-fading signal is said to follow a Rayleigh distribution if there is no line-of-sight path between the transmitter and the receiver and a Ricean distribution if one such path is available. Some of the common measures used for countering the effects of fading are diversity and adaptive modulation. Diversity mechanisms are based on the fact that independent paths between the same transmitter and receiver nodes experience independent fading effects, and therefore, by providing multiple logical channels between the transmitter and receiver, by providing multiple logical channels between the transmitter and receiver, and sending parts of the signal over each channel, the error effects due to fading can be compensated.

INTERFERENCE: Wireless transmissions have to counter interference from a wide variety of sources. Two main forms of interference are adjacent interference and co-channel interference. In the adjacent channel interference case, signals in nearby frequencies have components outside their allocated ranges, and these components may interfere with on-going transmissions in the adjacent frequencies [3]. It can be avoided by carefully introducing guard bands between the allocated frequency ranges. Co-channel interferences, sometimes also referred to as narrow-band interference, is due to another nearby systems using the same transmission frequency. Intersymbol interference is another type of interference, where distortion in the received signal is caused by the temporal spreading and the consequent overlapping of individual pulses in the signal. When this temporal spreading of individual pulses goes above a certain limit, the receiver becomes unable to reliably distinguish between changes of state in the signal, that is, the bit pattern interpreted by the receiver is not the same as that sent by the sender.

DOPPLER SHIFT: The Doppler Shift is defined as the change/shift in the frequency of the received signal when the transmitter and the receiver are mobile with respect to each other. If they are moving toward each other, then the frequency of the received signal will be higher than that of the transmitted signal, and if they are moving away from each other, the frequency of the signal at the receiver will be lower than that at the transmitter. The Doppler Shift f_d is given by $f_d = \frac{v}{\lambda}$ where v is the velocity between the transmitter and receiver, and λ is the wavelength of the signal.

TRANSMISSION RATE CONSTRAINTS: Two important constraints that determine the maximum rate of data transmission on a channel are Nyquist's theorem and Shannon's theorem. The two theorems are presented as follows

NYQUIST THEOREM: The signaling speed of a transmitted signal denotes the number of times per second the signal changes its value/voltage. The number of changes per second is measured in terms of baud. The baud rate is not the same as the bit rate/data rate of the signal since each signal value may be used to convey multiple bits [4]. For example, if the voltage values used for transmission are 0,1,2 and 3, then each value can be used to convey two bits (00,01,10 and11). Hence the bit rate here would be twice the baud rate. The Nyquist theorem gives the maximum data rate possible on a channel. If B is the bandwidth of the channel (in Hz) and L is the number of discrete signals levels/voltage values used, then the maximum channel capacity C according to the Nyquist theorem is given by

$$C = 2 \times B \times \log_2 L \quad \text{bits/sec} \qquad (2)$$

The above condition is valid only for a noiseless channel.

SHANNON'S THEOREM: Noise level in the channel is represented by the SNR. It is the ratio of signal power (S) to noise power (N), specified in decibels, that is, $SNR = 10\log_{10}(\frac{S}{N})$. One of the most important contributions of Shannon is his theorem on the maximum data possible on a noisy channel. According to Shannon's theorem, the maximum data rate C is given by the following expression

$$C = B \times \log_2(1 + (\frac{S}{N})) \quad \text{bits/sec,} \qquad (3)$$

where B is the bandwidth of the channel (in Hz).

II. AN INSIGHT ABOUT RAYLEIGH AND RICIAN FADING CHANNELS

Rayleigh fading occurs when there are multiple indirect paths between the transmitter and receiver and no distinct dominant path, such as Line of Sight path. Fortunately, Rayleigh fading can be dealt analytically, providing a clear understanding into performance characteristics that can be used in arduous environments, such as downtown urban settings [5]. In the context of mobile radio channels, the Rayleigh distribution is usually used to explain the statistical time varying nature of the envelope detected at the receiver for a flat faded environment. The Rayleigh probability density function (pdf) for a distributed envelope s(t) can be expressed as follows

$$p(s) = \{\frac{s}{\gamma^2}\exp\left(-\frac{s^2}{2\gamma^2}\right)\} for 0 \le s \le \infty \qquad (4)$$

$$p(s) = \{0\} for s < 0$$

where γ is the rms value of the received voltage signal and σ^2 is the time average power at the envelope detector respectively. The probability that the received signal is up to a specified given value S can be given as follows

$$P(S) = p_s(s \le S) = \int_0^S p(s)ds \approx 1 - \exp\left(\frac{S^2}{2\gamma^2}\right) \qquad (5)$$

Similarly, s_{mean} for such distribution is given as the following expression

$$s_{mean} = E[s] = \int_0^\infty sp(s)ds = \gamma\sqrt{\frac{\pi}{2}} \qquad (6)$$

And the variance in Rayleigh distribution γ_S^2 (ac power in the envelope) can be derived as follows

$$\gamma_s^2 = E[s^2] - E^2[s] \qquad (7)$$

$$\gamma_s^2 = \int_0^\infty s^2 p(s)ds - \frac{\gamma^2\pi}{2} = 2\gamma^2 - \frac{\gamma^2\pi}{2} = 0.429\gamma^2 \qquad (8)$$

The middle value of the envelope is more often useful for analysis of faded data under different fading distributions as sometimes the mean value varies widely. This middle value may be computed by treated P(S) as 0.5 and solving the following expression as follows

$$0.5 = \int_0^s p(s)ds \qquad (9)$$

This provides s_m as 1.777γ, which differs slightly from the r_{mean} value. Sometimes the dominant non fading signal due to line-of-sight in the channel superimposes itself on the random multipath components[6]. The effect of the dominant signal over the weaker multipath weaker signal gives rise to a Rician distribution. The Rician distribution degenerates to Rayleigh in the absence of a line of sight dominant signal.

The Rician (pdf) can be expressed as follows

$$p(s) = \{\frac{s}{\gamma^2}\exp-(\frac{s^2+A^2}{2\gamma^2})I_0(\frac{A_s}{\gamma^2})\} \text{ for } A \geq 0, s \geq 0 \qquad (10)$$

$$p(s) = \{0\} \quad \text{for s<0} \qquad (11)$$

Here A is the peak amplitude of the direct Line of Sight (LOS) signal and $I_0(x)$ is the modified Bessel function of the first kind with zero order. The Rician distribution is described by a parameter K, which is the ratio between the direct signal power and the variance of the multipath. This may be expressed in dB as given below

$$K = 10\log\frac{A^2}{2\gamma^2}\text{ dB} \qquad (12)$$

This shows that for the absence of direct line-of-sight signal K → -∞ and Rician distribution degenerates into Rayleigh. In digital wireless systems, channel impairment due to fading is solved using error control codes, equalizers, or appropriate diversity schemes. Random fluctuating signals cause fades which randomly cross a given specific signal level.

III. DPSK MODULATION SCHEME

A differentially encoded phase-modulated signal also allows another type of demodulation that does not require the estimation of the carrier phase. Instead, the received signal in any given signaling interval is compared to the phase off the received signal from the preceding signaling interval. To elaborate, suppose that we demodulate the differentially encoded signal by, multiplying r(t) by cos $2\pi f_c t$ and sin $2\pi f_c t$ integrating the two products over the interval T. At the kth signaling interval, the demodulator output is expressed as follows

$$r_k = [\sqrt{\varepsilon_s}\cos(\theta_k - \phi) + n_{k_1}\sqrt{\varepsilon_s}\sin(\theta_k - \phi) + n_{k_2} \qquad (13)$$

Where Θ_k is the phase angle of the transmitted signal at the kth signaling interval, ϕ is the carrier phase, and $n_k = n_{k_1} + jnk_2$ is the noise vector. Similarly, the received signal vector at the output of the demodulator in the preceding signaling interval is expressed as follows

$$r_{k-1} = \sqrt{\varepsilon_s}e^{j(\theta_{k-1}-\phi)} + n_{k-1}, \qquad (14)$$

The decision variable for the phase detector is the phase detector is the phase difference between these two complex numbers. Equivalently, the projection r_k onto r_{k-1} and use the phase of the resulting complex number; that is,

$$r_k r_{k-1}^* = \varepsilon_s e^{j(\theta_k - \theta_k - 1)} + \sqrt{\varepsilon_s}e^{j(\theta_k - \phi)}n_{k-1}^* + \sqrt{\varepsilon_s}e^{-j(\theta_{k-1}-\phi)}n_k + n_k n_{k-1}^* \qquad (15)$$

which, in absence of noise, yields the phase difference $\theta_k - \theta_{k-1}$. Thus, the mean value of $r_k r_{k-1}^*$ is independent of the carrier phase. Differentially encoded PSK signaling that is demodulated and detected as described above is called differential PSK (DPSK). The main differential PSK (DPSK) sometimes needs clarification because two separate aspects of the modulation/demodulation format are being referred to, namely the encoding procedure and the detection procedure. The term differential encoding refers to the procedure of encoding the data differentially; that is, the presence of a binary one or zero is manifested by the symbol's similarity or difference when compared with that of the preceding symbol [7]. The term differentially coherent detection of differentially encoded PSK, the usual meaning of DPSK, refers to a detection scheme often classified as non coherent because it does not require a reference in phase with the received carrier. Occasionally, different encoded PSK is coherently detected. With non coherent systems, no attempt is made to determine the actual value of the phase of the incoming signal. Therefore, if the transmitted waveform is expressed as

$$s_i(t) = \sqrt{\frac{2E}{T}} \cos[w_0 t + \theta_i(t)] \quad 0 \le t \le T$$ and i=1,….., M (16)

Then the received signal can be characterized by the following mathematical expression

$$r(t) = \sqrt{\frac{2E}{T}} \cos[w_0 t + \theta_i(t) + \alpha] + n(t)$$

$0 \le t \le T$ and i=1,…….,M (17)

where α is an arbitrary constant and is typically assumed to be a random variable uniformly distributed between zero and 2π, and n(t) is an AWGN process. For coherent detection, matched filters are used, for non coherent detection, this is not possible because the matched filter output is a function of the unknown angle α. However, if we assume that α varies slowly relative to two period times (2T), the phase difference between two successive waveforms $\theta_j(T_1)$ and $\theta_k(T_2)$ is independent of α; that is expressed as the following equation

$$[\theta_k(T_2) + \alpha] - [\theta_j(T_1) + \alpha] = \theta_k(T_2) - \theta_j(T_1) = \phi_i(T_2)$$ (18)

The basis for differentially coherent detection of differentially encoded PSK (DPSK) is as follows. The carrier phase of the previous signaling interval can be used as a phase reference for demodulation. Its use requires differential encoding of the message sequence at the transmitter since the information is carried by the difference in phase between two successive waveforms. In general, DPSK signaling performs less efficiently than PSK, because the errors in DPSK tend to propagate due to the correlation between signaling waveforms. One way of viewing the difference between PSK and DPSK is that the former compares the received signal with a clean reference, in the latter, however, two noisy signals are compared with each other. Thus there is twice as much noise associated with DPSK signaling compared to PSK signaling.

IV. PERFORMANCE ANALYSIS OF RAYLEIGH AND RICIAN FADING CHANNELS USING M-DPSK MODULATION SCHEME

The environment is created as shown in the fig. 1. respectively using Simulink tool.

RANDOM INTEGER GENERATOR: The random integer generator generates random uniformly distributed integers in the range [0, M-1], where M is the M-ary number.

INTEGER TO BIT CONVERTER: In the integer to bit convertor unit, a vector of integer-valued or fixed valued type is mapped to a vector of bits. The number of bits per integer parameter value present in the integer to bit convertor block defines how many bits are mapped for each integer-valued input. For fixed-point inputs, the stored integer value is used. This block is single-rated and so the input can be either a scalar or a frame-based column vector. For sample-based scalar input, the output is a 1-D signal with 'Number if bits per integer' elements. For frame-based column vector input, the output is a column vector with length equal to 'Number of bits per integer' times larger than the input signal length.

DIFFERENTIAL ENCODER: Differential encoder differentially encodes the input data. The differential encoder object encodes the binary input signal within a channel. The output is the logical difference between the current input element and the previous output element.

CONVOLUTIONAL INTERLEAVER: This block permutes the symbols in the input signal. Internally, it uses a set of shift registers. The delay value of the kth shift register is (k-1) times the register length step parameter. The number of shift registers is the value of the rows of shift registers parameter.

DPSK MODULATOR BASEBAND: This block modulates the input signal using the differential phase shift keying method. The inputs can be either bits or integers.

DPSK DEMODULATOR BASEBAND: This block demodulates the input signal using the differential phase shift keying method. For sample-based input, the input must be a scalar. For frame-based input, the input must be a column vector.

BUFFER: The buffer converts scalar samples to a frame output at a lower sample rate. The conversion of a frame to a larger size or smaller size with optional overlap is possible. It is then passed to the multipath Rician fading

CONVOLUTIONAL DEINTERLEAVER: The Convolutional deinterleaver block recovers a signal that was interleaved using the Convolutional interleaver block.

DIFFERENTIAL DECODER: The differential decoder block decodes the binary input signal.

BIT TO INTEGER CONVERTER: The bit to integer converter maps a vector of bits to a corresponding vector of integer values. The number of bits per integer parameter defines how many bits are mapped for each output.

ERROR RATE CALCULATION: The error rate calculation is done by computing the error rate of the received data by comparing it to a delayed version of the transmitted data.

SIGNAL TRAJECTORY SCOPE: The discrete-time signal trajectory scope is used to display a modulated signal constellation in its signal space by plotting the in phase component versus the quadrature component.

SCATTER PLOT SCOPE: The discrete-time scatter plot scope is used to display a modulated signal constellation in its signal space by plotting the in phase component versus the quadrature component.

EYE DIAGRAM SCOPE: The discrete-time eye diagram scope displays multiple traces of a modulated signal to reveal the modulation characteristics such as pulse shaping, as well as channel distortions of the signal.

SNR ESTIMATION: The SNR estimation block gives the estimated SNR in decibels.

DISPLAY: This unit gives the total number of bits transmitted, the number of errors and finally displays the Bit Error Rate.

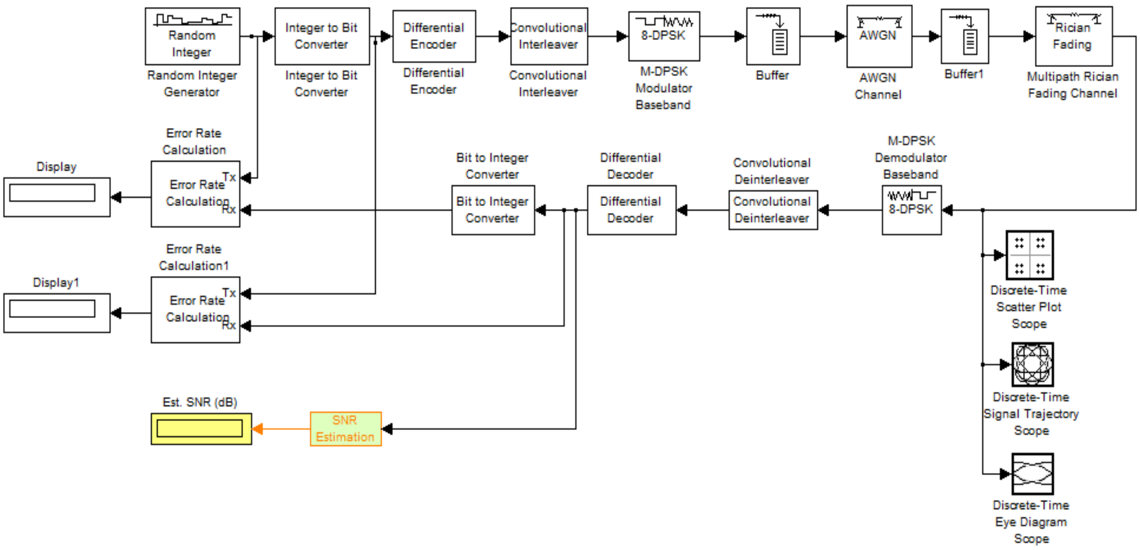

Fig. 1. Simulink Scenario for the Performance Analysis of Rician Fading Channels in M-DPSK modulation

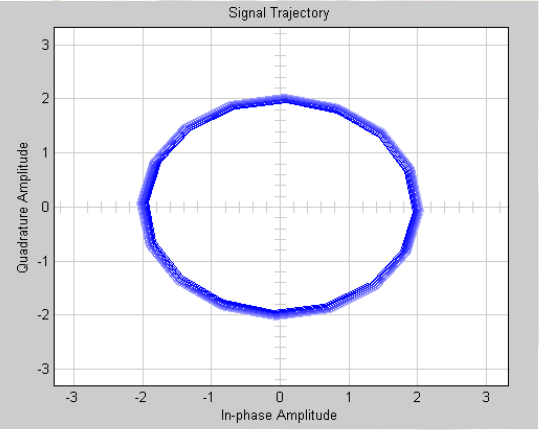

Fig. 2. Signal Trajectory for the Performance Analysis of Rician Fading Channels in M-DPSK modulation scheme

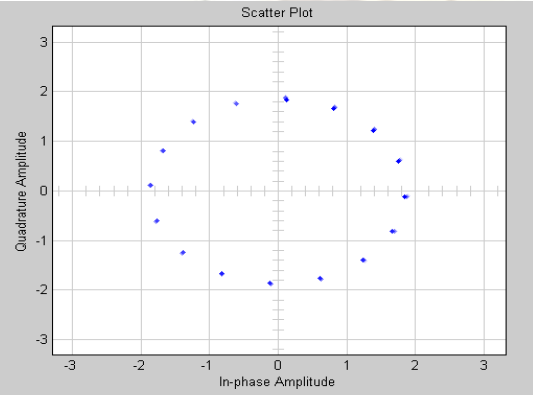

Fig. 3. Scatter plot for the Performance Analysis of Rician Fading Channels in M-DPSK modulation scheme

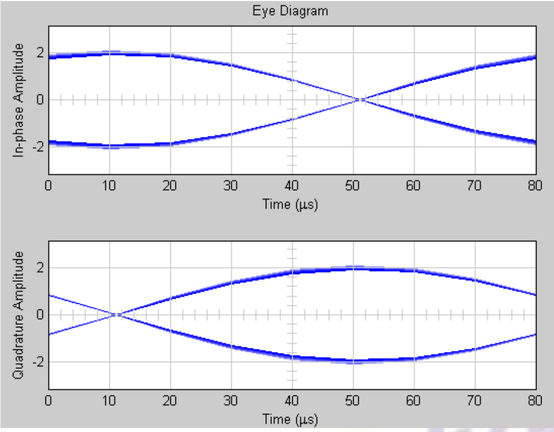

Fig. 4. Eye diagram for the Performance Analysis of Rician Fading Channels in MDPSK modulation scheme

Table 1. Bit Error Rate Analysis of Rician Fading Channels in MDPSK Modulation Scheme

RICEAN FACTOR	SNR	BER
200	100	0.008676
400	200	0.008605
600	300	0.008339
800	400	0.008147

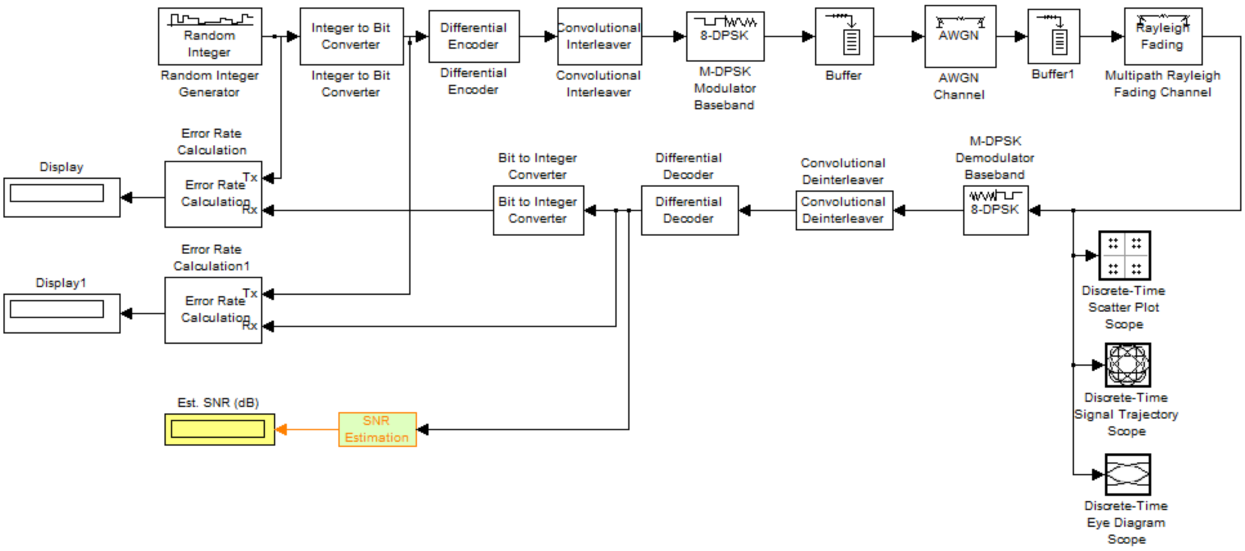

Fig. 5. Simulink Scenario for the Performance Analysis of Rayleigh Fading Channels in MDPSK modulation

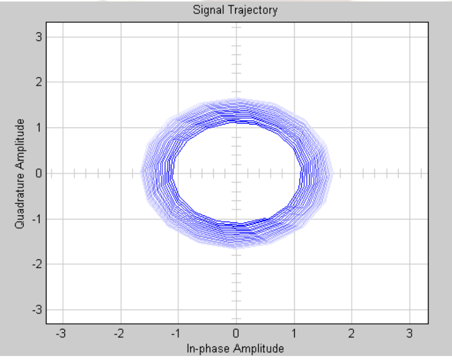

Fig. 6. Signal Trajectory for the Performance Analysis of Rayleigh Fading Channels in MDPSK modulation scheme

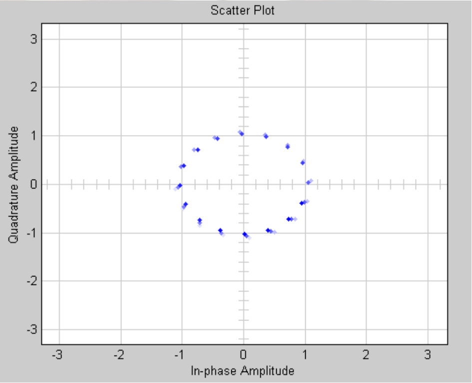

Fig. 7. Scatter plot for the Performance Analysis of Rayleigh Fading Channels in MDPSK modulation scheme

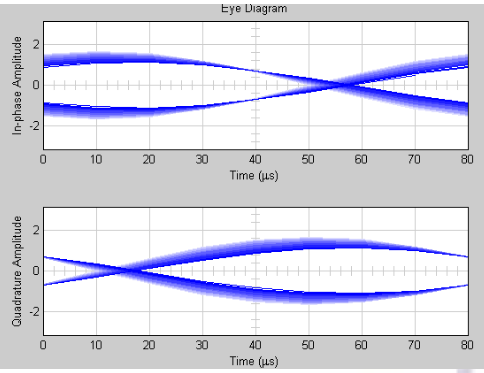

Fig. 8. Eye diagram for the Performance Analysis of Rayleigh Fading Channels in MDPSK modulation scheme

Table 2. Bit Error Rate Analysis of Rayleigh Fading Channels in MDPSK Modulation Scheme

SNR	BER
100	0.009015
200	0.008994
300	0.008972
400	0.008677

V. CONCLUSIONS

An introduction to the characteristics of the wireless channels followed by a review on Rayleigh and Rician fading channels is provided. It is obvious from table 1 that when the Ricean factor and Signal to Noise Ratio increases, the Bit Error Rate decreases gradually. Similarly from table 2 it can be inferred that when the Signal to Noise ratio increases, the Bit Error Rate decreases. It is observed from table 1 and table 2 that for a very high Signal to Noise Ratio a low bit error rate is achieved. The Differential Phase Shift Keying modulation technique can produce a very low bit error rate for the same signal to noise ratio in Rician fading channels than in the Rayleigh fading channels. The signal trajectory, scatter plot and the eye diagrams for the Simulink scenario is also provided. Future implementations may include the effective utilization of different modulation schemes for different fading channels in the Simulink scenario to produce a very low bit error rate.

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