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PERFORMANCE ANALYSIS OF RICIAN FADING CHANNELS USING M-PAM MODULATION SCHEME IN SIMULINK ENVIRONMENT

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Abstract— **In a wireless mobile communication system a signal can travel from transmitter to receiver over multipath reflective paths. This phenomenon, referred to as multipath propagation, can cause fluctuations in the received signal's amplitude, phase, and angle of arrival, giving rise to the terminology multipath fading. When a strong stationary path such as a line of sight path is introduced into the Rayleigh fading environment, the fading becomes Rice-distributed fading. Ricean fading is suitable for characterizing satellite communications and in some urban environments. In this paper, the performance analysis of Ricean Fading Channels using M-PAM Modulation Scheme is implemented using Simulink tool.**

Keywords- fading, Ricean, M-PAM, Simulink

1. INTRODUCTION TO THE CHALLENGE OF COMMUNICATING OVER FADING CHANNELS

In the analysis of communication system performance, the classical (ideal) additive-white-Gaussian noise (AWGN) channel, with statistically independent Gaussian noise samples corrupting data samples free of intersymbol interference (ISI), is usual starting point for developing basic performance results. An important source of performance degradation is thermal noise generated in the receiver. Another source of degradation stems from both natural and man-made sources of noise and interference that enter the receiving antenna, and can be quantified by a parameter called antenna temperature. Thermal noise typically has a flat power spectral density over the signal band and a zero mean Gaussian voltage probability density function (pdf). In mobile communication systems, the external noise and interference are often more significant than the receiver thermal noise. When modelling practical systems, the next step is the introduction of band limiting filters. Filtering in the transmitter usually serves to satisfy some regulatory requirement on spectral containment. Filtering in the receiver is often the result of implementing a matched filter. Due to the band limiting and phase-distortion properties of filters, special signal design and equalization techniques may be required to mitigate the filter-induced ISI.

If a radio channel's propagating characteristics are not specified, one usually infers that the signal attenuation versus distance behaves as if propagation takes place over ideal free space. The model of free space treats the region between the transmit and receive antennas as being free of all objects that might absorb or reflect radio frequency (RF) energy. It also assumes that, within this region, the atmosphere behaves as a perfectly uniform and non absorbing medium. Furthermore, the earth is treated as being infinitely far away from the propagation signal. Basically, in this idealized free-space model, the attenuation of RF energy between the transmitter and receiver behaves according to an inverse-square law. The received power expressed in terms of transmitted power is attenuated by a factor *Ls(d)*, where this factor is called path loss or free space loss. When the receiving antenna is isotropic, this factor is expressed mathematically as follows

$$L_S(d) = \left(\frac{4\pi d}{\lambda}\right)^2$$

(1)

In (1), d is the distance between the transmitter and the receiver, and λ is the wavelength of the propagating signal. For this case of idealized propagation, received signal power is very predictable. For most practical channels, where signal propagation takes place in the atmosphere and near the ground, the free-space propagation model is inadequate to describe the channel behaviour and predict system performance. In a wireless mobile communication system, a signal can travel from transmitter to receiver over multipath reflective paths. This phenomenon, referred to as multipath propagation, can cause fluctuations in the received signal's amplitude, phase, and angle of arrival, giving rise to the terminology multipath fading. Another name, scintillation, which originated in radio astronomy, is used to describe the fading caused by physical changes in the propagation medium, such as variations in the electron density of the ionospheric layers that reflect high frequency (HF) radio signals. Both fading and scintillation refer to a signal's random fluctuations; the main difference is that scintillation involves mechanisms that are much smaller than a wavelength. The end-to-end modelling and design of systems that incorporate techniques to mitigate the effects of fading are usually more challenging than those whose sole source of performance degradation is AWGN.

2. CHARACTERIZING MOBILE-RADIO PROPAGATION

It starts with two types of fading effects that characterize mobile communications namely, large-scale fading and small-scale fading. Large-scale fading represents the average signal power attenuation or the path loss due to motion over large areas. This phenomenon is affected by prominent terrain contours like hills, forests, bill boards and clumps of buildings between the transmitter and receiver. The receiver is often said to be shadowed by such prominences. The statistics of large-scale fading provide a way of computing an estimate of path loss as a function of distance. This is often described in terms of a mean-path loss (*n*th-power law) and a log-normally distributed variation about the mean. Small-scale fading refers to the dramatic changes in signal amplitude and phase that can be experienced as a result of small changes as small as a half-wavelength in the spatial positioning between a receiver and transmitter. A small scale fading manifests itself in two mechanisms, namely time-spreading of the signal and time-variant behaviour of the channel. For mobile-radio applications, the channel is time-variant because motion between the transmitter and receiver results in propagation path changes. The rate of changes of these propagation conditions accounts for the fading rapidity and rate of change of the fading impairments. Small-scale fading is called Rayleigh fading if there are multiple reflective paths that are large in number, and if there is no line-of-sight component, the envelope of such a received signal is statistically described by a Rayleigh pdf. When there is a dominant non fading signal component present, such as a line-of-sight propagation path, the small-scale fading envelope is described by a Rician pdf [1]. In other words, the small-scale fading statistics are said to be Rayleigh whenever the line of sight path is blocked and Rician otherwise. A mobile radio roaming over a large area must process signals that experience both types of fading: small-scale fading superimposed on large-scale fading. Large-scale fading (attenuation or path loss) can be considered as a spatial average over the small-scale fluctuations of the signal. It is generally evaluated by averaging the received signal over 10 to 30 wavelengths, in order to decouple the small-scale which are mostly Rayleigh fluctuations from the large-scale shadowing effects which are typically log-normal. There are three basic mechanisms that impact signal propagation in a mobile communication system namely reflection, diffraction and scattering.

Reflection occurs when a propagating electromagnetic wave impinges upon a smooth surface with very large dimensions relative to the RF signal wavelength (λ). Diffraction occurs when the propagation path between the transmitter and receiver is obstructed by a dense body with dimensions that are large relative to λ, causing secondary waves to be formed behind the obstructing body. Diffraction is a phenomenon that accounts for RF energy travelling from transmitter to receiver without a line-of-sight path between the two. It is often termed shadowing because the diffracted field can reach the receiver even when shadowed by an impenetrable obstruction. Scattering occurs when a radio wave impinges on either a large, rough surface or any surface whose dimensions are on the order of λ or less, causing the energy to be spread out or reflected in all directions. In an urban environment, typical signal obstructions yielding scattering include lampposts, street signs, and foliage. The name scatterer applies to any obstruction in the propagation path that causes a signal to be reflected or scattered.

3. A REVIEW ON RICIAN FADING CHANNELS

When a strong stationary path such as a line of sight path is introduced into the Rayleigh fading environment, the fading becomes Rice-distributed fading. Ricean fading is suitable for characterizing satellite communications or in some urban environments. Ricean fading is also a small-scale fading. In this case, the probability of deep fade is much smaller than that in the Rayleigh Fading case. Based on the central limit theorem, the joint pdf of amplitude r and phase ϕ may be represented as derived in [2] as follows

$$\rho_{r,\phi}(r,\phi) = \frac{r}{2\pi\sigma^2} e^{-\frac{r^2+A^2-2rA\cos\phi}{2\sigma^2}}$$

(2)

where A is the amplitude of the dominant component and σ is the same as that for Rayleigh fading,. This joint pdf is not separable, and the pdf of r or ϕ can be obtained by integrating over the other quantity. The pdf of the amplitude is a Rice distribution [3] and is mathematically expressed as follows

$$\rho_r(r) = \frac{r}{\sigma^2} e^{-\frac{r\ \ +A^2}{2\sigma^2}} I_0(\frac{rA}{\sigma^2}), 0 \le r < \infty$$

(3)

where $Z_0(x)$ is the modified Bessel function of the first kind and zero order, and is defined as follows

$$Z_0(x) = \frac{1}{2\pi}\int_0^{2\pi} e^{-x\cos\theta} d\theta$$

(4)

The mean square value of r is given by

$$\rho_r = 2\sigma^2 + A^2$$

(5)

The Rice factor K*r* is defined as the ratio of the dominant component to the power in all the other components and it is given by the equation $K_r = \frac{A^2}{2\sigma^2}$.The Rice distribution approximates the Rayleigh distribution with mean value A as Kr<<1, and reduces to it at Kr=0. It approximates the Gaussian distribution with mean value A as Kr>>1, and reduces to the Gaussian as $K_r \to \infty$ .The factor Kr typically shows an exponential decrease with range, and varies from 20 near the BS to zero at a large distance[4]. The dominant component changes the phase distribution from the uniformly random distribution of Rayleigh fading to clustering around the phase of the dominant component. The stronger the dominant component, the closer the resulting phase to the phase of the dominant component. This is similar to a delta function. Flat Ricean fading channel is suitable for characterizing a real satellite link.

3.1. OUTAGE PROBABILITY:

Fading channels lead to an oscillating SNR at different locations, and a mobile user will experience rapid variations in SNR, γ. An average SNR can be used to characterize the channel and to compute the BER. For many applications, BER is not the primary concern as long as it is below a threshold [5]. A more meaningful measure is the outage probability, Pout, which is the percentage of time that an acceptable quality of communication is not available. Pout can be calculated by the minimum SNR for the system to work properly. This minimum SNR, γ_{min}, can be calculated from the minimum acceptable BER as follows

$$P_{out} = P_r(\gamma < \gamma_{\min}) = \int_0^{\gamma_{\min}} \rho_\gamma(\gamma) d\gamma$$

(6)

where $\rho_\gamma(\gamma)$ is the pdf of γ .

3.2. DOPPLER FADING:

Multipath components lead to delay dispersion, while the Doppler effect leads to frequency dispersion for a multipath propagation. Doppler spread is also known as time-selective spread. Frequency-dispersive channels are known as time-selective fading channels. Signals are distorted in both the cases. Delay dispersion is dominant at high data rates, while frequency dispersion is dominant at low data rates [6].The two dispersions are equivalent, since the Fourier transform can be applied to move from the time domain to the frequency domain. These distortions cannot be eliminated by just increasing the transmit power, but can be reduced or eliminated by equalization or diversity.

3.3 DOPPLER SPECTRUM:

For a moving MS, different multipath components arrive from different directions, and this gives rise to different frequency shifts *v*, leading to a broadening of the received spectrum [7]. According to the Clarke or Jakes Model, the angle distribution of scattering is assumed to be uniform from all azimuthal directions, that is, $\rho_\theta(\theta) = \frac{1}{2\pi}$, for a symmetrical antenna like a dipole. This spectrum has a U-Shape, and it is known as the classical Doppler or Jakes spectrum. It can be derived via the Wiener-Khintchine theorem, that is, the Fourier transform of the auto correlation of the complex envelope of the received signal

3.4 LEVEL CROSSING RATES:

From the Doppler spectrum, the occurrence rate of fading dips, known as the envelope level crossing rate(LCR), and the average duration of fades can be derived[12,13]. LCR is defined as the number of positive-going crossings of a reference level in unit time, while average duration of fades is the average number of positive-going zero-crossings per second for a signal. For Ricean and Rayleigh fading, these parameters can be derived in closed form [13].

3.5 AVERAGE DURATION OF THE FADES:

The average duration of the fades is the average time that the envelope level is below the level R. The probability of the envelope level being low R is given by the mathematical expression as follows

$$P_r(\alpha \le R) = \int_0^R \rho(\alpha) d\alpha = \frac{\sum_i t_i}{T}$$

(7)

where t_i is the duration of the *i*th continuous period that is below *R*, and *T* is the total period. For the Rice distribution $P_r(\alpha \le R)$ can be expressed by as follows:

$$P_r(\alpha \le R) = 1 - Q(\sqrt{2K_r}, \rho\sqrt{2(K_r+1)})$$

(8)

where Q (a, b) is the Marcum-Q function defined by the following expression

$$Q(a,b) = 1 - \int_0^b z e^{-\frac{z^2+a^2}{2}} I_0(za) dz$$

(9)

where I_0(.) being the modified Bessel function of the first kind and zero order.

4. PULSE AMPLITUDE MODULATION SCHEMES

An information-bearing signal must conform to the limitations of its channel. While the bit streams which are wished to transmit are inherently discrete-time, all physical media are continuous-time in nature. Hence, the need to represent the bit stream as a continuous-time signal for transmission is mandatory by a process called modulation. Pulse Amplitude Modulation (PAM) is widely used in a variety of applications and is an extremely important technique in its own right. Secondly, the simplicity of PAM facilitates our development of the basic principles of receiver design.

A baseband PAM transmitter sends the information by modulating the amplitudes of a series of pulses, so that the transmitted signal is expressed as follows

$$s(t) = \sum_{m=-\infty}^{\infty} a_k g(t - kT)$$

(10)

where 1/T is the symbol rate, where g(t) is the pulse shape, and where the set of amplitudes$\{a_k\}$ are referred to as symbols. This signal can be interpreted as a sequence of possibly overlapping pulses with the amplitude of the k-th pulse determined by the k-th symbol. Such signals are termed pulse-amplitude modulated (PAM) signals, regardless of the pulse shape [8]. PAM and its generalization to pass band are by far the most common signaling methods in digital communications. There is a confusing array of techniques (e.g., QAM, PSK, BPSK, PRK, QPSK, DPSK, and AM-PM) which are all special cases of pass band PAM, perhaps with some special coding. In a PAM transmitter, a sequence of source bits is mapped to a sequence of symbols $\{a_k\}$,which in turn drives a transmit filter with impulse response g(t). The job of a receiver is to recover the transmitted symbols from a continuous-time PAM signal that has been distorted by a noisy channel. The noiseless case is sufficient to explore the relationship between the bandwidth and symbol rate, which is a primary objective of this section.

In a baseband PAM system, the freedom to design the transmit and receive filters and is allowed, but for the channel it is restricted [9]. The impulse responses can be chosen to force the ISI to zero, so that the overall pulse shape satisfies the Nyquist criterion. One difficulty with such a strategy is that the channel is rarely known at the time when the filters are designed. Furthermore, even when the channel is known, the filters required to exactly satisfy the Nyquist criterion which may be difficult or expensive to realize. In practice, the overall pulse shape is rarely Nyquist. With suboptimal filtering, it is useful to quantify the degradation of the signal. A useful graphical illustration of the degradation is the eye diagram, so called because its shape is similar to that of the human eye.

An eye diagram is easily generated using an oscilloscope to observe the output of the receive filter, where the symbol timing serves the trigger. Such displays have historically served as a quick check of the performance of a modem in the field. The eye diagram is also a useful design tool during the analytical and simulation design phase of the system. An eye diagram consists of many overlaid traces of small sections of a signal. If the data symbols are random and independent, it summarizes several features of the signal. In presence of intersymbol interference, when the pulse shape does not satisfy the Nyquist criterion, the eye diagram, will tend to close vertically [10]. For error-free transmission in the absence of noise, the eye must maintain some vertical opening, since otherwise there are intersymbol interference waveforms that will cause errors. When there is incomplete vertical closure, the Intersymbol interference will reduce the size of the additive noise required to cause errors. Hence, the wider the vertical opening, the greater the noise immunity. The ideal sampling instant is at the point of maximum (vertical) eye opening, but this can never be achieved precisely by a practical timing recovery circuit. Thus the horizontal eye opening is also practically important, since the smaller this opening the greater the sensitivity to errors in timing phase (the instant at which the signal is sampled). The shape of the eye is determined by the pulse shape. In particular, the vertical eye opening is determined by the size of the pulses at multiples of T, and the horizontal eye opening is determined by the size of the tails of the pulse p(t). It is important to note that the beneficial effect of increasing the excess bandwidth, noise immunity, and the complexity of the timing recovery circuitry.

Many practical communication channels are pass band in nature, meaning that their frequency response is that of a band pass filter. Such channels do not support transmission of baseband signals. Most physical transmission media are incapable of transmitting frequencies at d.c., and near d.c., whereas baseband PAM signals usually contain d.c. and low-frequency components. There are several strategies for communicating across a pass band channel. The starting point will be a suboptimal strategy known as pulse-amplitude-modulation double-sideband (PAM-DSB), although this strategy is inefficient and not recommended, it is nevertheless a useful stepping stone to more efficient strategies. The pass band channel has bandwidth and is denoted as B. The basic idea of PAM-DSB is to start with a real-valued baseband PAM signal with bandwidth B/2, and to modulate it by multiplying it by a sinusoid with frequency equal to the channel centre frequency f_c. Specifically, a PAM-DSB signal takes the form as expressed in the following expression:

$$s(t) = \pm\sqrt{2}\cos(2\pi f_c t)\sum_k a_k g(t-kT)$$

(11)

The above signal will pass undistorted through the channel when the pulse shape g(t) is low-pass with bandwidth B/2. To avoid ISI, the maximal symbol rate is twice the pulse shape bandwidth, or 1/T=B. The maximal spectral efficiency of PAM-DSB with real alphabet A is thus $\log_2|A|$, which is half that of baseband PAM. There are two ways to modify PAM-DSB so as to make it more efficient. The first is to recognize that the upper and lower sidebands of s(t) are redundant; because the underlying baseband PAM signal is real, its Fourier transform displays Hermitian symmetry, meaning that its negative frequencies are uniquely determined by its positive frequencies [11]. Thus doubling of the spectral efficiency by adopting the single-sideband (SSB) strategy of transmitting only one of the sidebands, say the upper sideband can be successfully implemented. PAM-SSB can be implemented by passing the baseband PAM signal through the phase splitter which rejects the negative frequencies, before being modulated by the sinusoid. One disadvantage of PAM-SSB is the difficulty in realizing the sharp discontinuity of the phase splitter near zero frequency.

A more common way to modify PAM-DSB so as to improve efficiency is to recognize that a PAM-DSB carrier information only in the in-phase component, the quadrature component of the PAM-DSB signal is zero. The quadrature component represents an extra source that the PAM-DSB strategy ignores. Thus, the doubling of the spectral efficiency of PAM-DSB by transmitting a second baseband PAM signal in quadrature, leads to the following mathematical expression

$$s(t) = \sqrt{2}\cos(2\pi f_c t)\sum_k a_k^I g(t-kT) - \sqrt{2}\sin(2\pi f_c t)\sum_k a_k^Q g(t-kT)$$

(12)

This defines pass band PAM. The bandwidth of this signal is no greater than that of PAM-DSB, yet it conveys twice as much information. We have assumed that both the baseband PAM signals use the same pulse shape, and that the symbols modulating in-phase and quadrature components are denoted as $\{a_k^I\}$ and $\{a_k^Q\}$ respectively.

The spectral efficiency of pass band PAM is easily quantified. What changes for the pass band case is the relationship between the symbol rate and bandwidth. With a baseband channel of bandwidth W, the maximal symbol rate using baseband PAM is 2W. With a pass band channel with bandwidth W, however, the maximum symbol rate using pass band PAM is only W. This is because the bandwidth of a pass band PAM signal is equal to the twice the bandwidth of the pulse shape. It follows that the spectral efficiency of pass band PAM with excess bandwidth α is given by the following expression

$$v = \frac{R_b}{W} = \frac{\log_2 |A|}{1+\alpha} \tag{13}$$

5. PERFORMANCE ANALYSIS OF RICIAN FADING CHANNELS USING M-PAM IN SIMULINK:

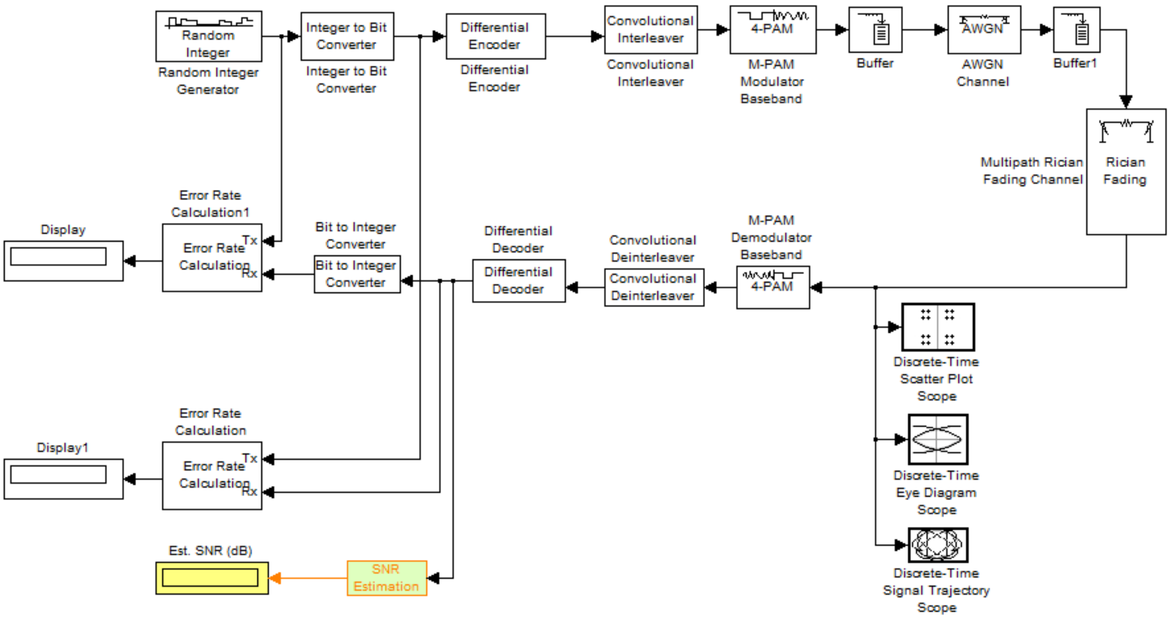

Fig. 1. Screenshot for the performance analysis of Rician fading channels in M-PAM modulation in Simulink

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

5.1 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.

5.2. 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.

5.3 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.

5.4 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.

5.5 M-PAM MODULATOR BASEBAND: This block modulates the input signal using the pulse amplitude modulation method. Here the M-ary number value must be an even integer.

5.6. M-PAM DEMODULATOR BASEBAND: This block demodulates the input signal using the pulse amplitude modulation method. The M-ary number value must be an even integer.

5.7 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

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

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

5.10 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.

5.11 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.

5.12 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.
5.13 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.
5.14 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.
5.15 SNR ESTIMATION: The SNR estimation block gives the estimated SNR in decibels.
5.16 DISPLAY: This unit gives the total number of bits transmitted, the number of errors and finally displays the Bit Error Rate.

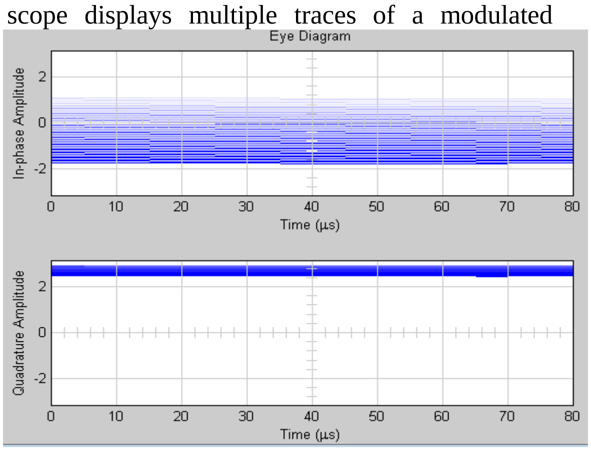

Fig. 1.Eye diagram for the performance analysis of Rician Fading Channels in MPAM scheme

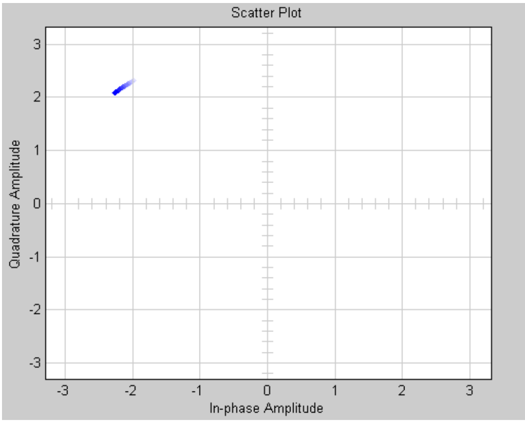

Fig. 2. Scatter plot for the performance analysis of Rician Fading Channels in MPAM

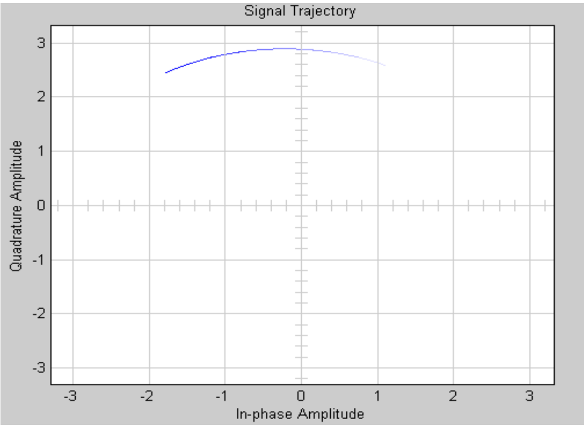

Fig. 3. Signal Trajectory for the performance analysis of Rician Fading Channels in MPAM scheme

Table 1: BER for Rician Fading Channels in MPAM scheme

SNR	BER	K_r (Ricean factor)
5.509	0.02790	100
7.648	0.02734	200
8.757	0.02727	300
9.274	0.02724	400

6.CONCLUSION

A short survey about the challenges of communicating over the fading channels is provided followed by the characterization of mobile radio propagation is also reviewed in this paper. The analysis of Rician fading channels in M-PAM modulation schemes is discussed and the results are provided. It is evident from table 1 that when the Ricean factor (K_r) is gradually increased then the Signal-to-Noise Ratio increases and as a result the Bit Error Rate naturally decreases. For high values of K_r, a very low bit error rate is achieved. The eye diagram, signal trajectory diagram and the scatter plot diagram have also been provided for the scenario. Future works may include finding the bit error rate by evaluating the performance of Rician fading channels by using various modulation schemes and by altering the Ricean factor parameters

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