

# Performance Comparison of Rayleigh and Rician Fading Channels In QAM Modulation Scheme Using Simulink Environment

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## ABSTRACT:

Fading refers to the fluctuations in signal strength when received at the receiver and it is classified into two types as fast fading and slow fading. 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 between the transmitter and the receiver and a Rician distribution if one such path is available. The Performance comparison of the Rayleigh and Rician Fading channels in Quadrature Amplitude Modulation using Simulink tool is dealt in this paper.

**KEYWORDS:** Fading, Rayleigh, Rician, QAM, Simulink

## I. INTRODUCTION TO THE LINE OF SIGHT TRANSMISSION:

With any communication system, the signal that is received will differ from the signal that is transmitted, due to various transmission impairments. For analog signals, these impairments introduce random modifications that degrade the signal quality. For digital data, bit errors are introduced, a binary 1 is transformed into a binary 0, and vice versa. Some of the most significant impairments are attenuation and attenuation distortion, free space loss, noise, atmospheric absorption, multipath and refraction.

**1.1 ATTENUATION:** The strength of a signal falls off with distance over any transmission medium. For guided media, this reduction in strength, or attenuation, is generally exponential and thus is typically expressed as a constant number of decibels per unit distance. For unguided media, attenuation is a more complex function of distance and the makeup of the atmosphere. Attenuation introduces three factors for the transmission engineer. Firstly, a received signal must have sufficient strength so that the electronic circuitry in the receiver can detect and interpret the signal. Secondly, the signal must maintain a level sufficiently higher than noise to be received without error. Thirdly, attenuation is greater at higher frequencies, causing distortion. The first and second factors are dealt with by attention to signal strength and the use of amplifiers or repeaters. For a point-to-point transmission, the signal strength of the transmitter must be strong enough to be received intelligibly, but not so strong as to overload the circuitry of the transmitter or receiver, which would cause distortion. Beyond a certain distance, the attenuation becomes unacceptably great, and repeaters or amplifiers are used to boost the signal at regular intervals [2]. These problems are more complex when there are multiple receivers, where the distance from transmitter to receiver is variable. The third factor is known as attenuation distortion. Because the attenuation varies as a function of frequency, the received signal is distorted, reducing intelligibility. Specifically, the frequency components of the received signal have different relative strengths than the frequency components of the transmitted signal. To overcome this problem, techniques are available for equalizing attenuation across a band of frequencies. One approach is to use amplifiers that amplify high frequencies more than lower frequencies.

**1.2 FREE SPACE LOSS:** For any type of wireless communication the signal disperses with distance. Therefore, an antenna with a fixed area will receive less signal power the farther it is from the transmitting antenna [5]. For satellite communication this is the primary mode of signal loss. Even if no other sources of attenuation or impairment are assumed, a transmitted signal attenuates over distance because the signal is being spread over a larger and larger area. This form of attenuation is known as free space loss, which can be expressed

in terms of the ratio of the radiated power  $P_t$  to the power  $P_r$  received by the antenna or, in decibels, by taking 10 times the log of that ratio. For the ideal isotropic antenna, free space loss is

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

(1)

where  $P_t$  is the signal power at the transmitting antenna,  $P_r$  is the signal power at the receiving antenna,  $\lambda$  is the carrier wavelength,  $f$  is carrier frequency,  $d$  is propagation distance between antennas and  $c$  is the speed of light.

**1.3 NOISE:** For any data transmission event, the received signal will consist of the transmitted signal, modified by the various distortions imposed by the transmission system, plus additional unwanted signals that are inserted somewhere between transmission and reception. These unwanted signals are referred to as noise. Noise is the major limiting factor in communications system performance. Noise may be divided into four major categories as thermal noise, inter modulation noise, crosstalk and impulse noise. Thermal noise is due to thermal agitation of electrons. It is present in all electronic devices and transmission media and is a function of temperature. Thermal noise is uniformly distributed across the frequency spectrum and hence is often referred to as white noise. When signals at different frequencies share the same transmission medium, the result may be inter modulation noise [3]. Crosstalk can occur by electrical coupling between nearby twisted pairs or, rarely, coax cable lines carrying multiple signals. Crosstalk can also occur when unwanted signals are picked up by microwave antennas. Impulse noise, however, is non continuous, consisting of irregular pulses or noise spikes of short duration and of relatively high amplitude. It is generated from a variety of causes, including external electromagnetic disturbances, such as lightning, and faults and flaws in the communications system.

**1.4 ATMOSPHERIC ABSORPTION:** An additional loss between the transmitting and receiving antennas is atmospheric absorption. Water vapour and oxygen contribute most to attenuation. A peak attenuation occurs in the vicinity of 22 GHz due to water vapour. At frequencies below 15 GHz, the attenuation is less. The presence of oxygen results in an absorption peak in the vicinity of 60 GHz but contributes less at frequencies below 30 GHz. Rain, fog and suspended water droplets cause scattering of radio waves that results in attenuation. This can be a major cause of signal loss. Thus, in areas of significant precipitation, either path lengths have to be kept short or lower-frequency bands should be used.

**1.5 MULTIPATH:** For wireless facilities where there is a relatively free choice of where antennas are to be located, they can be placed so that if there are no nearby interfering obstacles, there is a direct line-of-sight path from the transmitter to receiver. This is generally the case for many satellite facilities and for point-to-point microwave. In other such cases, such as mobile telephony, there are obstacles in abundance [4]. The signal can be reflected by such obstacles so that multipath copies of the signal with varying delays can be received. In fact, in extreme cases, the receiver may capture only reflected signals and not the direct signal. Reinforcement and cancellation of the signal resulting from the signal following multiple paths can be controlled for communication between fixed, well-sited antennas, and between satellites and fixed ground stations.

## II. A REVIEW ON 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 LOS path. This represents a worst case scenario. Fortunately, Rayleigh fading can be dealt with analytically, providing insights into performance characteristics that can be used in difficult environments, such as downtown urban settings. In the mobile radio channels, the Rayleigh distribution is usually used to describe the statistical time varying nature of the envelope detected at the receiver for a flat faded environment [6]. The Rayleigh probability density function (pdf) for a distributed envelope  $r(t)$  can be expressed as follows

$$p(r) = \left\{ \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2}\right) \right\} \text{ for } 0 \leq r \leq \infty$$

$$p(r) = \{0\} \text{ for } r < 0$$

(2)

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

$$P(R) = p_r(r \leq R) = \int_0^R p(r)dr \approx 1 - \exp\left(-\frac{R^2}{2\sigma^2}\right)$$

(3)

Similarly,  $r_{\text{mean}}$  for such distribution is given as the following expression

$$r_{\text{mean}} = E[r] = \int_0^{\infty} rp(r)dr = \sigma\sqrt{\frac{\pi}{2}}$$

(4)

And the variance in Rayleigh distribution  $\sigma_r^2$  (ac power in the envelope) can be derived as

$$\sigma_r^2 = E[r^2] - E^2[r]$$

(5)

$$\sigma_r^2 = \int_0^{\infty} r^2 p(r)dr - \frac{\sigma^2 \pi}{2} = 2\sigma^2 - \frac{\sigma^2 \pi}{2} = 0.429\sigma^2$$

(6)

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(R) as 0.5 and solving the following expression as follows

$$0.5 = \int_0^r p(r)dr$$

(7)

This provides  $r_m$  as  $1.777\sigma$ , which differs slightly from the  $r_{\text{mean}}$  value. Sometimes the dominant non fading signal due to line-of-sight in the channel superimposes itself on the random multipath components. 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

$$p(r) = \left\{ \frac{r}{\sigma^2} \exp\left(-\frac{r^2 + A^2}{2\sigma^2}\right) I_0\left(\frac{Ar}{\sigma^2}\right) \right\} \quad \text{for } A \geq 0, r \geq 0$$

(8)

$$p(r) = \{0\} \quad \text{for } r < 0$$

(9)

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

$$K = 10 \log \frac{A^2}{2\sigma^2} \text{ dB}$$

(10)

This shows that for the absence of direct line-of-sight signal  $K \rightarrow -\infty$  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. QAM MODULATION SCHEME

QAM is a modulation scheme which communicates data by changing (modulating) the amplitude of two sinusoidal carrier waves, which are out of phase with each other by 90 degrees. Unlike MPAM or MPSK, which has one degree of freedom for encoding the information, MQAM encodes information in both the amplitude and phase of the transmitted signal. Thus, MQAM is more spectrally efficient by encoding more bits per symbol for a given average energy. Unlike MPSK, where all the M signals are distributed on a unit circle with equidistance, the output signals generated by the rectangular MQAM modulator are distributed on an orthogonal grid on the constellation diagram. The M symbols are gray-encoded. Three types of QAM constellations are popular, namely type-I, type-II and type-III constellations. The type-I (star) constellation places a fixed number of signal points uniformly on each of the N concentrated rings, where N is the number of amplitude levels. This is also known as star-QAM. The points on the inner ring are very close in distance, and

are thus most affected by errors. The type-II constellation improves the error performance of type-I, by decreasing the number of points on the inner circles, and making the distance between two adjacent points on the outer circles to be approximately equal to that on the inner circles. The type -III (square) constellation has a very small performance improvement over type-II constellation, but its implementation is much simpler.

Square MQAM is the most popular QAM scheme. It usually takes the form of a square constellation such as 4QAM, 16QAM, 64 QAM, and 256QAM. 4QAM is the same as QPSK. These constellations are more often used, due to the relative ease of their circuit implementation. Square MQAM implementation for 32 QAM, 128 QAM, and 512 QAM is also possible. The square QAM has a maximum possible minimum Euclidean distance  $d_{\min}$  among its phasors, for a given average symbol power. It is most appropriate for the AWGN channel. Star MQAM may also be used due to its relatively simple detector and lower PAPR [1]. Star MQAM can be treated as multi-level MPSK, each level having different amplitude. Although it is not optimum in terms of  $d_{\min}$  under the constraint of average phasor power, it allows the use of efficient differential encoding and decoding methods. This makes it suitable for fading channels. The method of differential coding for star QAM is determined depending on the purpose, based on either avoiding carrier recovery or enabling differential detection of signals. Good constellation mappings may be hard to find for MQAM signals, especially for irregular constellation shapes. It may be also hard to find a Gray code mapping where all the symbols differ from their adjacent symbols by exactly one bit. An MQAM system requires a smaller minimum carrier-to-noise power ratio than an MPSK system does. A higher level of encoding requires a higher minimum carrier-to-noise power ratio. Gray codes are used to map binary symbols to phasor states in the constellation.

MQAM modulation is most widely used in various wireless systems. Lower-order QAM schemes have better cell overlap control and good tolerance to distortion, but lower spectral efficiency. Higher-order QAM schemes provide higher data rates at the cost of stricter C/N requirements, smaller coverage radii for the same availability, and hardware complexity, and more severe cell-to-cell interference. For satellite communication systems, QPSK is usually used in the uplink direction at a lower frequency channel, and MQAM is used in the downlink k direction at a higher frequency band. Due to the high spectral efficiency, MQAM are widely used in broadband wireless and satellite multimedia communication systems, such as DVB. In IEEE 802.11n, the 256 QAM modulations are used in order to achieve a data rate in excess of 600 Mbit/s. In WiMAX, adaptive modulation is applied, higher-order modulation being used for MSs that are closer to the BS. In LTE, QPSK, 16QAM, and 64QAM are used in the downlink. MQAM is also used in DVB-S/C/T.

#### IV. PERFORMANCE ANALYSIS OF RAYLEIGH AND RICIAN FADING CHANNELS USING QAM

The environment is created as shown in the fig. 1 and fig. 5 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 of 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  $k$ th 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.

**QAM MODULATOR BASEBAND:** This block modulates the input signal using the quadrature amplitude modulation method. The block only accepts integers as input.

**QAM DEMODULATOR BASEBAND:** This block demodulates the input signal using the quadrature amplitude modulation 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.

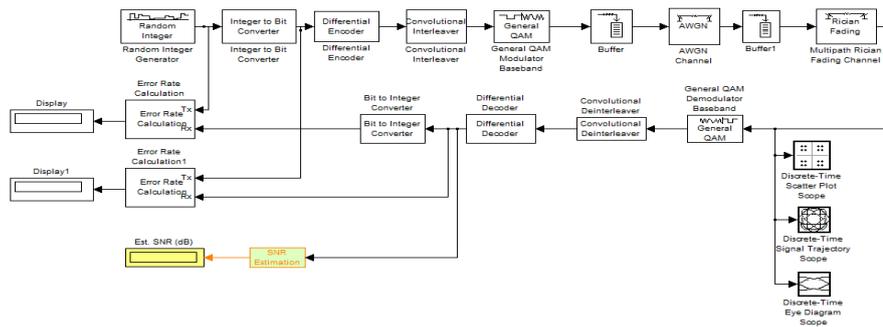


Fig. 1. Simulink Scenario for the Performance Analysis of Rician Fading Channels in QAM modulation

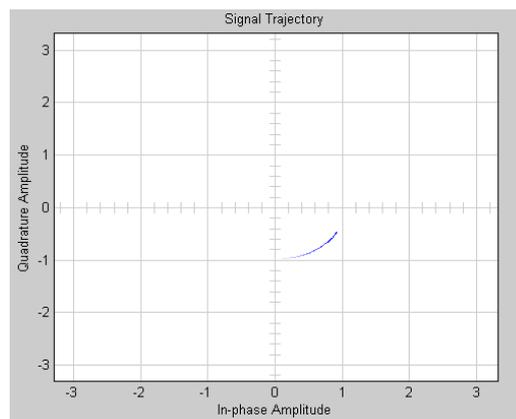


Fig. 2. Signal Trajectory for the Performance Analysis of Rician Fading Channels in QAM modulation scheme

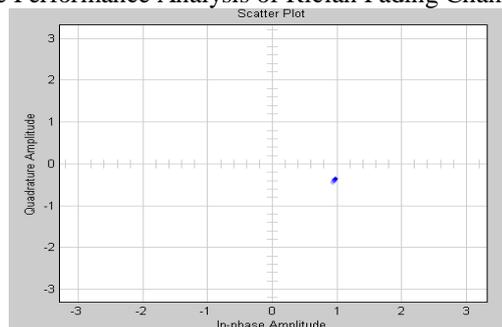


Fig. 3. Scatter plot for the Performance Analysis of Rician Fading Channels in QAM modulation scheme

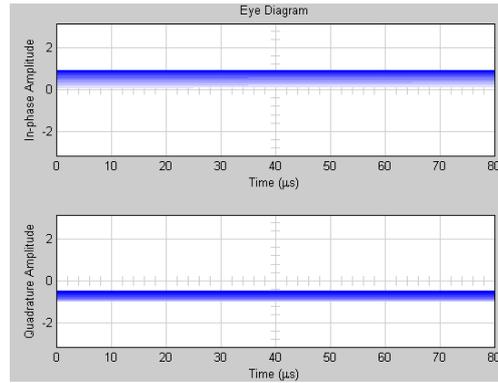


Fig. 4. Eye diagram for the Performance Analysis of Rician Fading Channels in QAM modulation scheme

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

RICEAN FACTOR	SNR	BER
600	300	0.02673
800	400	0.01986
1000	500	0.01982

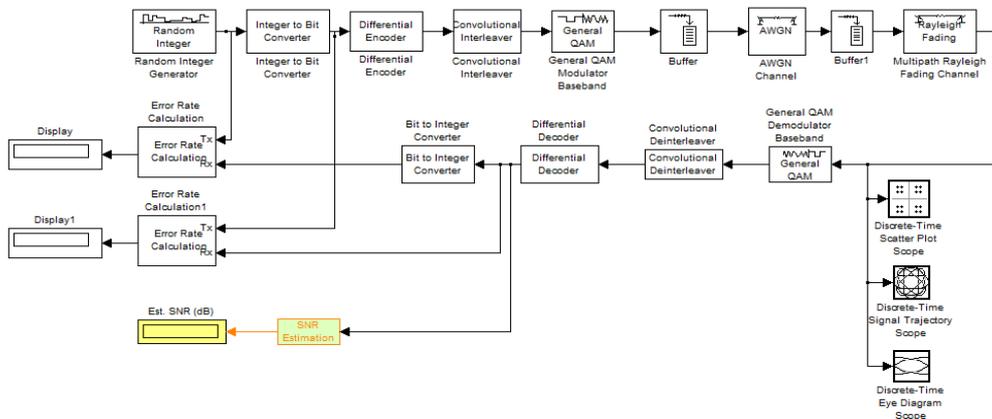


Fig. 5. Simulink Scenario for the Performance Analysis of Rayleigh Fading Channels in QAM modulation

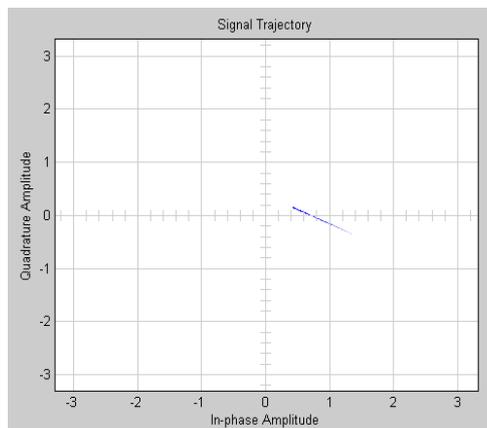


Fig. 6. Signal Trajectory for the Performance Analysis of Rayleigh Fading Channels in QAM modulation scheme

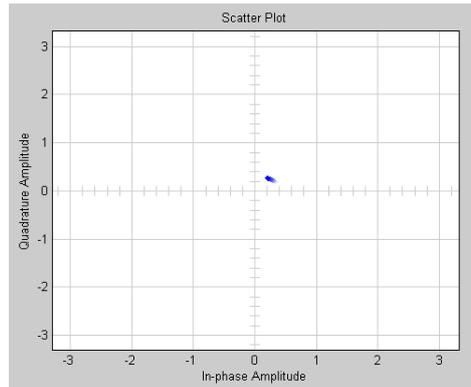


Fig. 7. Scatter plot for the Performance Analysis of Rayleigh Fading Channels in QAM modulation scheme

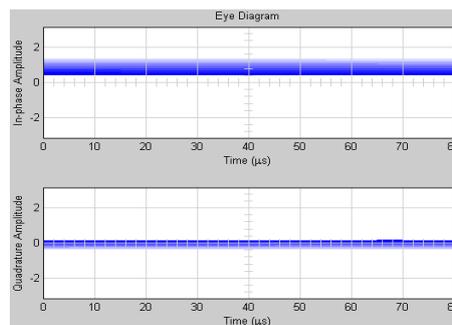


Fig. 8. Eye diagram for the Performance Analysis of Rayleigh Fading Channels in QAM modulation scheme

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

SNR	BER
300	0.02020
400	0.01648
500	0.01123

#### IV. CONCLUSIONS

An introduction to the line of sight transmission followed by a review on Rayleigh and Rician fading channels is provided. It is apparent 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 SNR a low bit error rate is achieved. The Quadrature Amplitude Modulation scheme can produce a very low bit error rate for the same signal to noise ratio in Rayleigh fading channels than in the Rician fading channels. Future works may include the effective use of different modulation schemes in the Simulink scenario to produce a very low bit error rate.

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