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Multipath Fading Channel Modeling and Performance Comparison of Wireless Channel Models

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Abstract

In this paper, we have proposed multipath fading channel simulation model for wireless communication. We have tested the model for sine wave and complex wave inputs. The effects of noise on fading and scattering property of the channel were tested. The results show that the BER performance is improved dramatically in low SNR than in high SNR. This is reasonable since at low SNR, white Gaussian noise dominate the BER error which can be improved by enhancing SNR while in high SNR, phase estimation error dominate the BER error which cannot be improved simply enhancing SNR. Next we have tested, analyzed and compared the performance of the channel models. The more accurate model is Rayleigh model which can be considered for developing multipath fading channel model.

Keywords: Channel models, fading channels, Rayleigh fading, AWGN Channel, Rician model.

Introduction

The wireless industry has developed and deployed an infrastructure for providing many services for the users. The design, production and deployment of such technological infrastructure have high cost therefore manufacturers search for different alternatives to avoid high costs. One of these alternatives is simulating a real wireless system. The advantage of simulation is that allows less expensive testing of designs. In this paper we have simulated and tested multipath fading channel model for wireless communication.

There has been significant research activity over the past 5-15 years into the performance of wireless channel models. In wireless transmission system where a receiver is in motion relative to a transmitter with no line-of-sight path between their antennas the Rayleigh fading is a good approximation of realistic channel conditions [1]. The term Rayleigh fading channel refers to a multiplicative distortion h(t) of the transmitted signal *s*(*t*), as in y(t) = h(t)·s(t)+ n(t), where *y*(*t*) is the received waveform and n(t) is the noise[1]. Zhifeng Chen has build up a wireless communication simulator including Gray coding modulation, different channel models (AWGN, flat fading and frequency selective fading channels), channel estimation, adaptive equalization, and demodulation [2]. He has tested the effect of different channel models to the data and image in receiver with constellation and BER (bit error rate) plots under QPSK modulation. Chengshan Xiao, Yahong Rosa Zheng, and Norman C. Beaulieu were analyzed the statistical properties of Clarke's fading model with a finite number of sinusoids and an improved reference model is proposed for the simulation of Rayleigh fading channels [13]. Yahong Rosa Zheng and Chengshan Xiao proposed new sum-of-sinusoids statistical simulation models are proposed for Rayleigh fading channels [15].

We have proposed multipath fading channel simulation model in which the effect of a propagation environment on a radio signal such as signal strength variations, phase shift variations in the signal and additive noise has been considered. The model is given by

$$y(t) = g_1 \times s(t) + 0.5 [\tau \times g_2 \times s(t)] + 0.25 [\tau \times g_2 \times s(t)] + n(t)$$

Where, y (t) is output signal, s (t) is input signal, τ is delay or phase shift, g_1 is fixed gain, g_2 is variable gain and n (t) is noise. We have tested multipath fading channel simulation model for sine wave and complex wave inputs. The effects of noise on fading and scattering property of the channel have been tested. We have also tested, analyzed and compared the BER performance of Rayleigh channel model, AWGN Channel Model and Rician channel models and it has been observed that more accurate model is Rayleigh channel model because its BER curves have steepness and values more closely to theoretical analysis. The proposed multipath fading channel simulation model also provides similar performance. The channel model can be used to test the performance of radios in a mobile environment.

Fading and fading channel models

The wireless environment is highly unstable and fading is due to multipath propagation. Multipath propagation leads to rapid fluctuations of the phase and amplitude of the signal. The presence of reflectors in the environment surrounding a transmitter and receiver create multiple paths that a transmitted signal can traverse. As a result, the receiver sees the superposition of multiple copies of the transmitted signal, each traversing a different path. Each signal copy will experience differences in attenuation, delay and phase shift while traveling from the source to the receiver.

This can result in either constructive or destructive interference, amplifying or attenuating the signal power seen at the receiver. Fading may be large scale fading or small scale fading [9]. Based on multipath time delay spread small scale fading is classified as flat fading and frequency selective fading. If bandwidth of the signal is smaller than bandwidth of the channel and delay spread is smaller than relative symbol period then flat fading occurs whereas if bandwidth of the signal is greater than bandwidth of the channel and delay spread is greater than relative symbol period then frequency selective fading occurs. Based on doppler spread small scale fading may be fast fading or slow fading. Slow fading occurs when the coherence time of the channel is larger relative to the delay constraint of the channel. The amplitude and phase change imposed by the channel can be considered roughly constant over the period of use. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building comes in the main signal path between the transmitter and the receiver. Fast fading occurs when the coherence time of the channel is small relative to the delay constraint of the channel. The amplitude and phase change imposed by the channel varies considerably over the period of use. In a fast-fading channel, the transmitter may take advantage of the variations in the channel conditions using time diversity to help increase robustness of the communication.

Nakagami fading model considers the instance for multipath scattering with relatively large delay-time spreads, with different clusters of reflected waves. Within any one cluster, the phases of individual reflected waves are random, but the delay times are approximately equal for all waves. As a result the envelope of each cumulated cluster signal is rayleigh distributed. The average time delay is assumed to differ significantly between clusters. If the delay times also significantly exceed the bit time of a digital link, the different clusters produce serious intersymbol interference, so the multipath self-interference then approximates the case of co-channel interference by multiple incoherent rayleigh-fading signals.

Rayleigh fading model considers the fading is caused by multipath reception. Rayleigh fading model assumes that the magnitude of a signal that has passed through transmission medium will vary randomly, or fade, according to a Rayleigh distribution. Rayleigh fading is a reasonable model when there are many objects in the environment that scatter the radio signal before it arrives at the receiver. Rayleigh fading is most applicable when there is no dominant line-of-sight propagation between the transmitter and receiver.

Rician model considers that the dominant wave can be a phasor sum of two or more dominant signals, e.g. the line-of-sight, plus a ground reflection. This combined signal is then mostly treated as a deterministic (fully predictable) process, and that the dominant wave can also be subject to shadow attenuation. This is a popular assumption in the modeling of satellite channels. Besides the dominant component, the mobile antenna receives a large number of reflected and scattered waves.

Multipath fading channel structure

Fading channel models are often used to model the effects of electromagnetic transmission of information over the air in cellular networks and broadcast communication. Fading channel models are also used in underwater acoustic communications to model the distortion caused by the water.Fig.2 shows the basic block diagram of proposed multipath fading channel model.

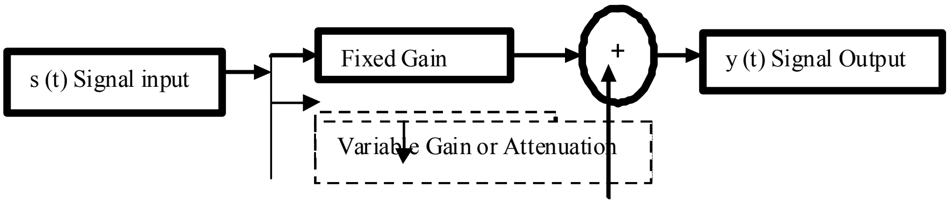

Figure 1: Multipath fading channel structure.

The input signal is passed through two different gains: First is fixed gain and second is variable gain. This model assumes that the magnitude of a signal that has passed through a transmission medium (also called a communications channel) will vary randomly, or fade according to a Rayleigh distribution.

$$y(t) = g_1 \times s(t) + 0.5 [\tau \times g_2 \times s(t)] + 0.25 [\tau \times g_2 \times s(t)] + n(t)$$

Where, y(t) is output signal, s (t) is input signal, τ is delay or phase shift, g_1 is fixed gain, g_2 is variable gain and n (t) is noise. It is a statistical model for the effect of a propagation environment on a radio signal, such as that used by wireless devices. We have used the following function to generate noise.

Syntax: y = AWGN (x, SNR,'measured')

This function adds white Gaussian noise to the vector signal x. The scalar SNR specifies the signal-to-noise ratio per sample, in dB. If x is complex, then AWGN adds complex noise. This syntax assumes that the power of x is 0 dBW. Here, AWGN measures the power of x before adding noise. The relative power of noise in a channel is typically described by quantities such as: 1) Signal-to-noise ratio (SNR) per sample, 2) Ratio of bit energy to noise power spectral density (Eb/N_0), 3) Ratio of symbol energy to noise power spectral density (Es/N0). A bit error ratio is the ratio of the number of bits, incorrectly received to the total number of bits sent during a specified time interval. Signal-to-noise ratio (often abbreviated SNR or S/N) is defined as the ratio of a signal power to the noise power corrupting the signal. In less technical terms, signal-to-noise ratio compares the level of a desired signal (such as music) to the level of background noise. The higher the ratio, the less obtrusive the background noise is.

$$SNR = (P_{signal} / P_{noise}) = (A_{signal} / A_{noise})^2$$

While considering effect of BER on SNR, results shows that the BER performance is improved dramatically in low SNR, while not in high SNR. In low

SNR, white Gaussian noise dominate the BER error, which can be improved by enhancing SNR, while in high SNR, phase estimation error dominate the BER error, which cannot be improved by simply enhancing SNR. Thus, BER performance is worse in flat fading channel and frequency selective fading channel, but best in AWGN channel.

A channel can be modeled physically by trying to calculate the physical processes which modify the transmitted signal. For example in wireless communications the channel can be modeled by calculating the reflection off every object in the environment. The function used to generate a scatter plot for the signal x is Syntax: scatterplot(x). If x is a complex vector, then scatter plot interprets the real part as in-phase components and the imaginary part as quadrature components. If x is a real vector, then scatter plot interprets it as a real signal.

Simulation results

Multipath fading channel model with sine or Complex input

The fig.2 shows the flowchart for obtaining faded output for sine or complex wave input.

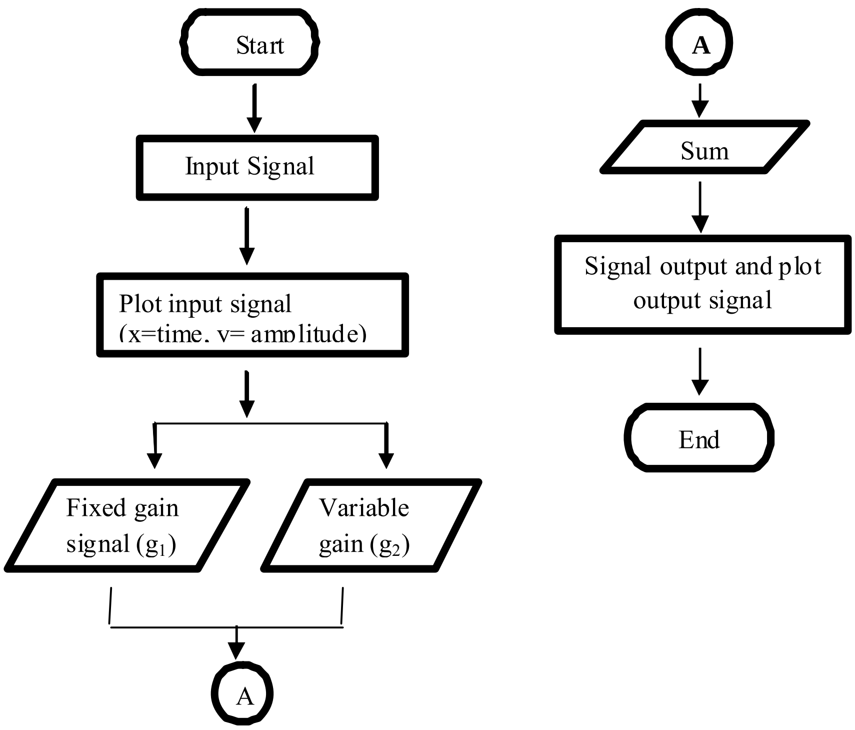

Figure 2: Flow Chart for obtaining faded signal.

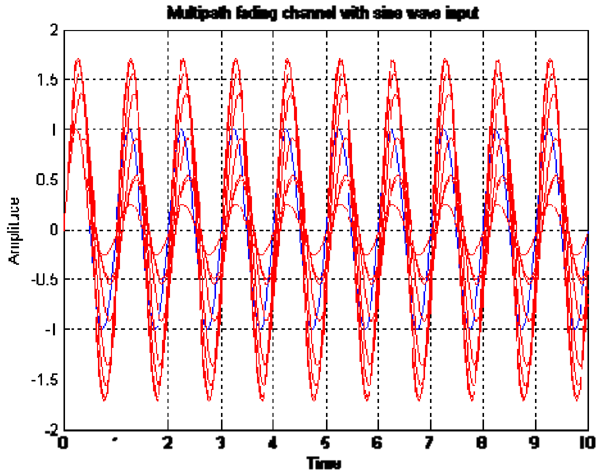

Figure 3: Multipath fading channel output for sine wave input.

The blue coloured signal represents input sine wave. It is observed that when signal passes through the channel, signal gets phase shifted due environmental changes or obstacles along the path. The faded signal outputs have been denoted by the number of red signals.

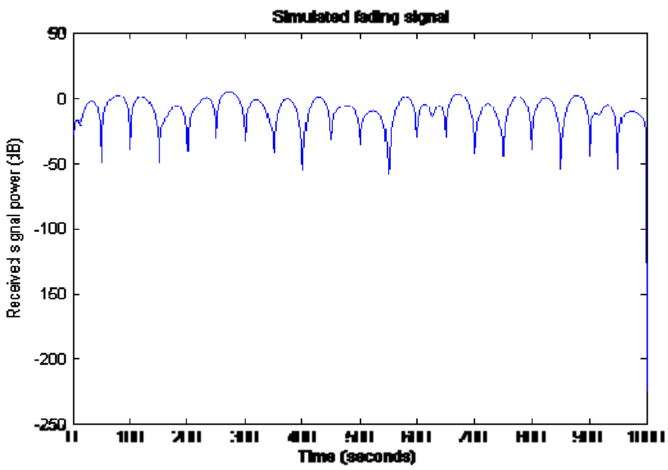

Figure 4: Simulated fading signal.

A typical variation in received signal power with time in multipath fading model is shown in fig.4.

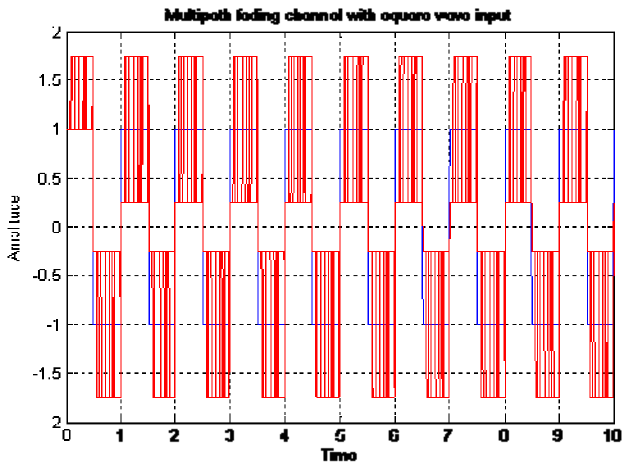

Figure 5: Multipath fading channel output for square wave input.

The blue coloured signal represents input square wave. It is observed that when signal passes through the channel, signal gets phase shifted due environmental changes or obstacles along the path. The faded signal outputs have been denoted by the number of red signals.

Multipath fading channel in presence of noise

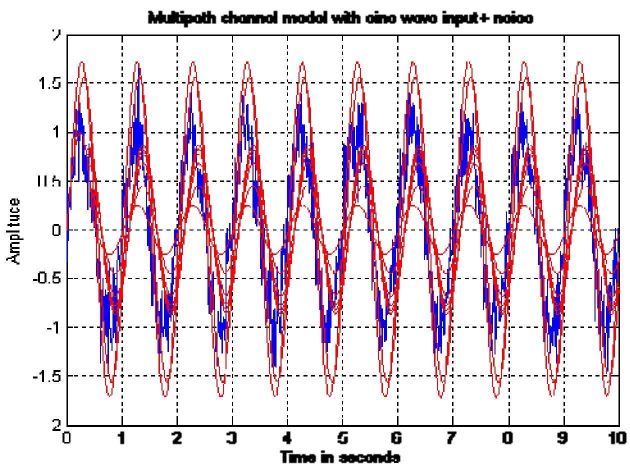

Figure 6: Multipath fading channel output for sine wave input and noise.

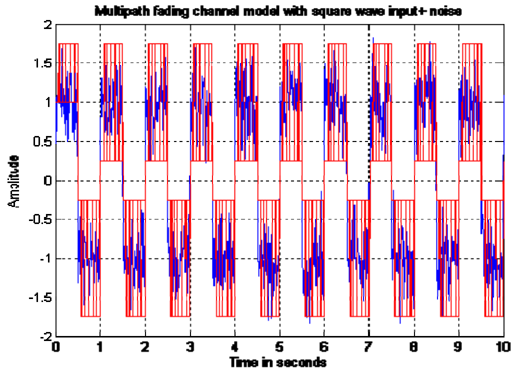

Figure 7: Multipath fading channel output for square wave input and noise.

The fig.6 and fig.7 shows the effect of noise on the fading process. For convenience, we have taken 10 dB SNR and AWGN noise. We have to choose any value of SNR between 1 and 10.

BER Vs SNR

The flowchart for obtaining the BER Vs SNR performance of multipath fading channel is shown in the fig.8.

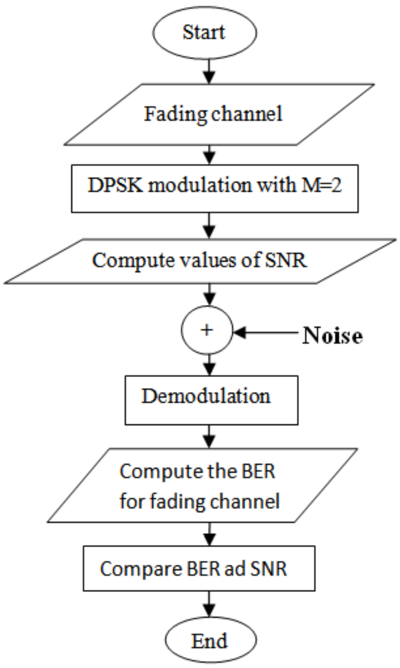

Figure 8: Flow-chart for obtaini.ng BER Vs SNR plot.

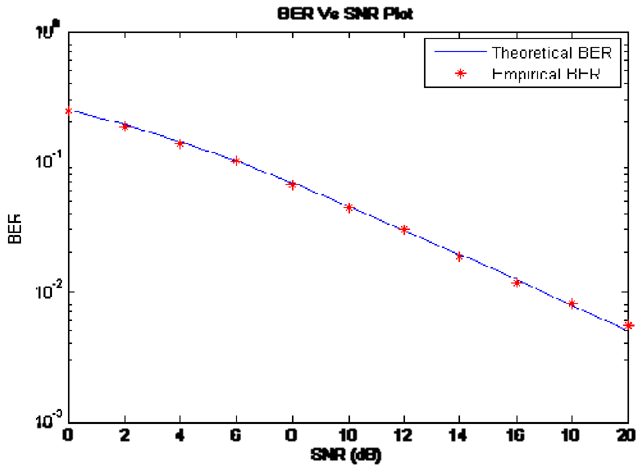

Figure 9: BER Vs SNR for multipath fading channel.

Scattering property of the channel

We have used the following function to generate a scatter plot for the signal x.
Syntax: scatterplot(x)

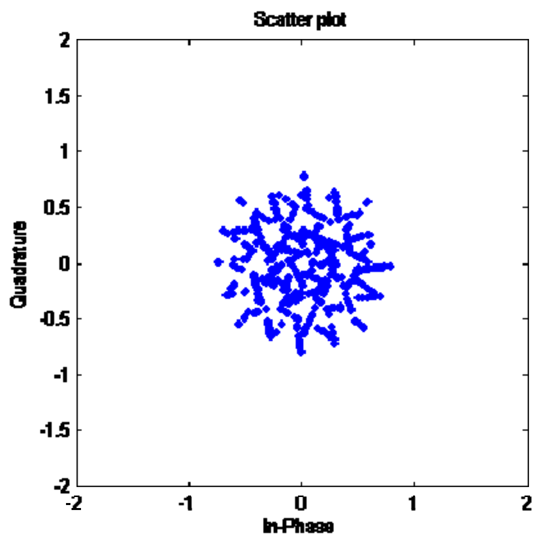

Figure 10: Scattering property of the channel.

The interpretation of x depends on its shape and complexity. If x is a real two-column matrix, then scatterplot interprets the first column as in-phase components and the second column as quadrature components. If x is a complex vector, then scatterplot interprets the real part as in-phase components and the imaginary part as quadrature components. If x is a real vector, then scatter plot interprets it as a real signal.

Performance analysis of the channel models

When multipath fading occurs, the BER will increase for a given channel SNR. The techniques such as diversity, equalization, data interleaving are used to combat multipath fading.

Rayleigh model

The Rayleigh fading channel refers to a multiplicative distortion h (t) of the transmitted signal s (t) and the noise as, y (t) = h (t) {s (t) + n (t)}, Where y (t) is the received waveform and n (t) is the noise.

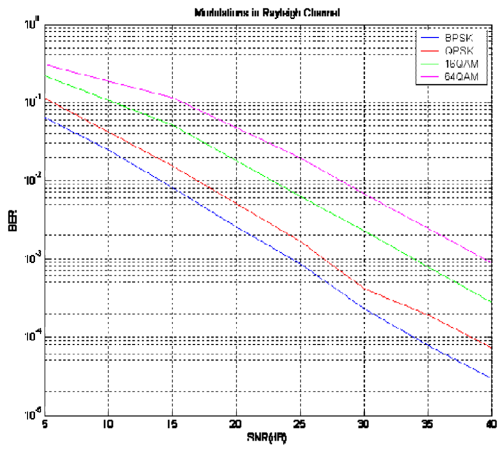

Figure 11: BER Vs SNR in Rayleigh channel model.

Rayleigh fading is the specialized model for stochastic fading when there is no line-of-sight propagated signal, and is sometimes considered as a special case of the more generalized concept of Rician fading. In Rayleigh fading, the amplitude gain is characterized by a distribution. The analysis of the performance on the basis of BER and SNR is shown in the fig.11.

AWGN Channel Model

AWGN channel is very straightforward; we have to just add a white Gaussian noise into signal to meet specified SNR. The Gaussian channel is important for providing an upper bound on system performance. The Gaussian channel model used here is shown in fig.12.

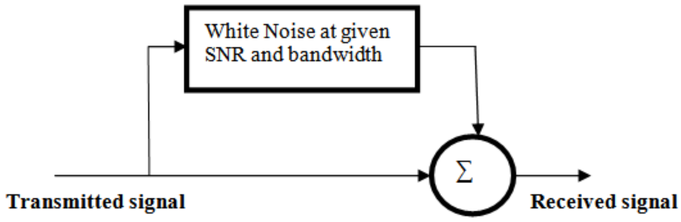

Figure 12: Block diagram of AWGN channel model.

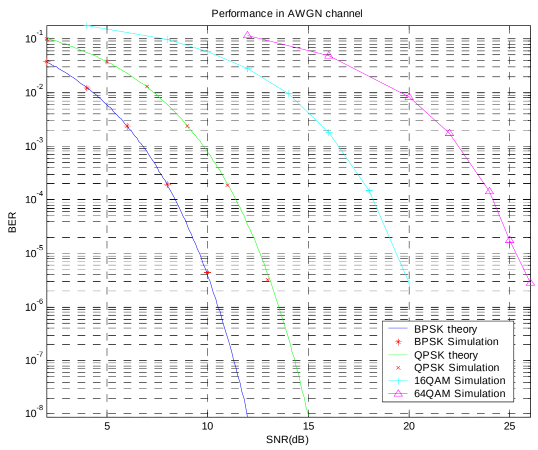

Figure 13: BER Vs SNR in AWGN channel.

Fig.13 shows that simulation result of BER performance is closely identical to theoretical BER performance.

Rician model

Rician fading is a stochastic model for radio propagation. It is considered that the signal arrives at the receiver through two different paths, and at least one of the paths is changing (lengthening or shortening). Rician fading occurs when one of the paths is a line-of-sight and signal is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution. We have considered the following discrete-time memoryless Rician fading channel model,

$$y_i = mx_i + a_i x_i + n_i$$

Where, a_i and n_i are circular zero mean complex Gaussian random variables, independent of each other.

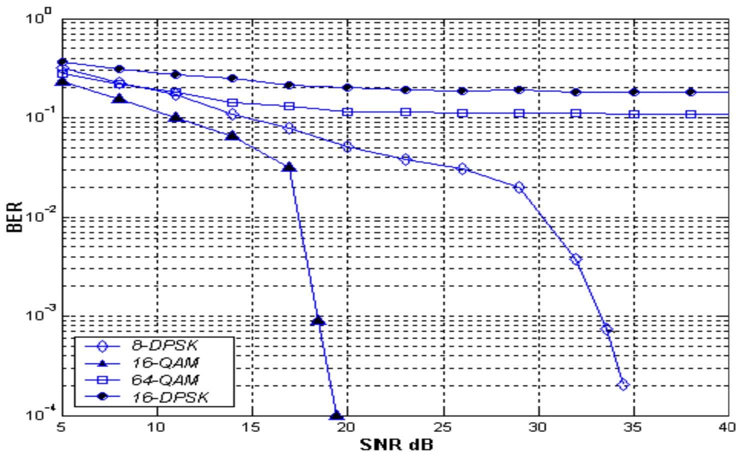

Figure 14: BER vs. SNR in Rician channel model.

The Rician fading channel model is particularly appropriate for direct propagating line-of-sight (LOS) component in addition to the faded component arising from multipath propagation.

Performance comparison of the different channel models

In this section we have compared the performances of the channels at low SNR, at medium SNR, at high enough SNR.

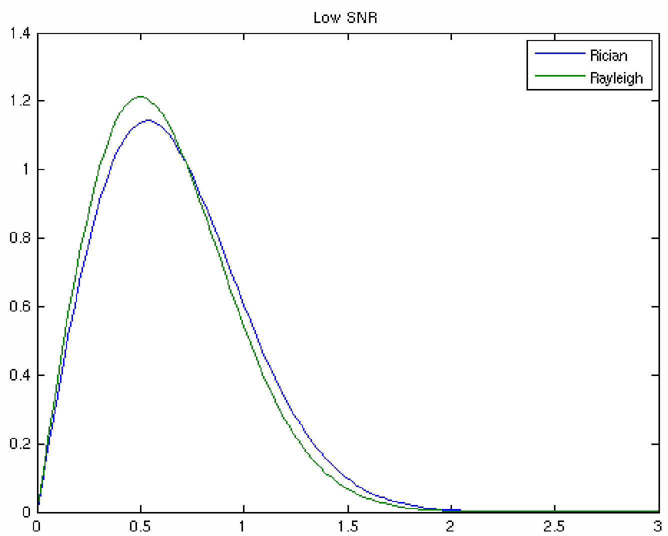

Figure 15: Plot of Rayleigh, Rician distributions at low SNR.

Fig.15 shows that at very low SNR, Rician signal is approximately Rayleigh distributed.

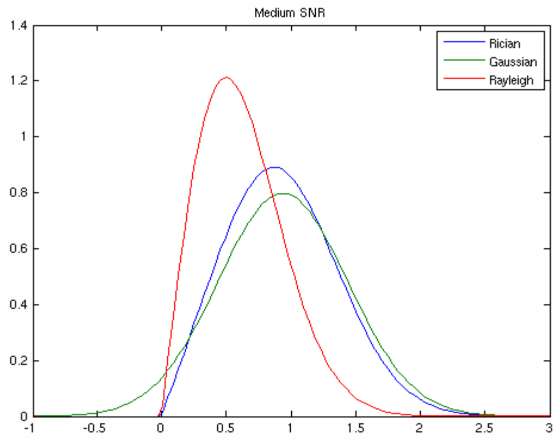

Figure 16: Plot for Rayleigh, Gaussian and Rician distributions at medium SNR.

Fig.16 shows that at low-medium SNR, neither Gaussian distribution nor Rayleigh distribution is a great approximation.

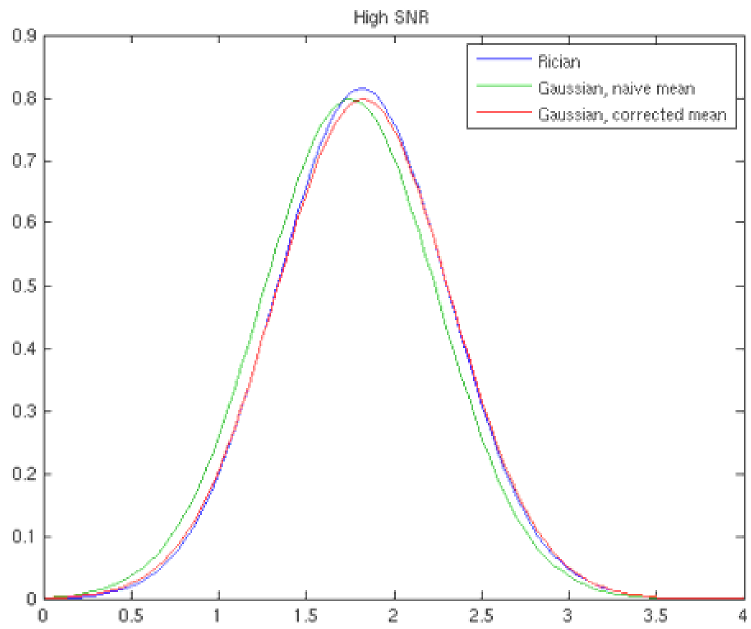

Figure 17: Gaussian and Rician distributions at high SNR.

Fig.17 shows that at high SNR, Rician data is approximately Gaussian. The Rician distribution with zero signals is equivalent to the Rayleigh distribution. At high SNR it is possible to approximate Rician distribution by a Gaussian distribution. It is tempting to add Rayleigh or Gaussian noise (depending on SNR) to existing signal to simulate Rician distributed signal. However, the Rician distribution can be reduced to Rayleigh distribution, when the power ratio is constant.

Table 1: Comparison of simulation performance between Rayleigh, AWGN and Rician channels for BER= $10^{-3.}$

Modulation Techniques	Rayleigh Channel (SNR in dB)	AWGN Channel (SNR in dB)	Rician Channel (SNR in dB)
BPSK	24.00	6.00	-
QPSK	26.50	8.80	-
16-QAM	33.80	16.00	19.90
64-QAM	39.50	22.25	
8- DPSK	-	-	33.90

From the comparison table 1 it is clear that Rayleigh channel supports high SNR than AWGN channel and Rician channels. The modeling of the multipath fading channel is based on the Rayleigh channel modeling and it gives the similar performance.

Conclusion

In this paper, multipath fading channel model has been simulated. In BER Vs SNR plot, we have used DPSK modulation to test the effect of different channels to the received signal. It is possible to more modulation techniques in our model, such as ASK and QAM with different modulation orders. There are various properties of the fading channel except scattering, such as doppler spread, path loss, correlation which can be taken into consideration while studying the characteristics of the channel. The channel model simulator can be used to test the performance of radios in a mobile environment. We have also compared and analyzed the improvement of Rayleigh channel with AWGN channel and Rician channel considering effect of BER and SNR on their performance in slow fading. The conclusion is that more accurate model is Rayleigh channel model because its BER curves have steepness and values more closely to theoretical analysis. It will be of great interest for many workers to implement more functionality support for channel fading.

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