Available Online at www.ijcsmc.com

International Journal of Computer Science and Mobile Computing

A Monthly Journal of Computer Science and Information Technology

ISSN 2320–088X

IJCSMC, Vol. 2, Issue. 5, May 2013, pg.346 – 352

RESEARCH ARTICLE

Performance Evaluation of Rayleigh Multipath Fading Channel using Rectangular QAM schemes

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Abstract— Fading is nothing but the degradation in signal strength and occurs mainly due to reflections from a stratified atmosphere or from surface land along the path. Such fading also causes multipath effects which result in constructive or destructive interference in the level of the incoming signal. Multipath fading varies with path length, frequency, climate and terrain. In dry, windy, mountainous areas, the multiple path phenomenon is virtually non-existent. Flat terrain along a path tends to increase the incidence of fading. Fading is prominent in hot, humid coastal regions. In this paper Rayleigh Multipath fading channels is considered and the performance analysis of it is done using Rectangular QAM schemes like 16 QAM, 64QAM and 128 QAM using the Simulink tool.

Key Terms: - fading; interference; Rectangular QAM; Simulink

I. INTRODUCTION TO THE CONCEPT OF FADING IN WIRELESS CHANNELS

A simple receiver cannot distinguish between the different Multipath components, it just adds them up, so that they interfere with each other. The interference between them can be constructive or destructive, depending on the phases of the multi path components. The phases, in turn, depend mostly on the run length of the multi path component, and thus on the position of the mobile station and the interacting objects. For this reason, the interference, and thus the amplitude of the total signal, changes with time if either the transmitter, receiver or interacting objects are moving[1]. This effect-namely, the changing of the total signal amplitude due to interference of the different multipath components is called small-scale fading. At 2-GHz carrier frequency, a movement by less than 10 cm can already effect a change from constructive to destructive interference and vice-versa. In other words, even a small movement can result in a large change in signal amplitude. A similar effect is known to all owners of car radios- moving the car by less than 1 meter (e.g., in stop-and-go traffic) can greatly affect the quality of the received signal. For cell phones, it can often be sufficient to move one step in order to improve signal quality[2].

As an additional effect, the amplitudes of each separate multi path components change with time or with location. Obstacles can lead to a shadowing of one or several multi path components. Imagine, for example, the MS (Mobile Station) that at first at a position A has LOS to the Base Station (BS). As the MS moves behind the high-rise building (at position B), the amplitude of the component that propagates along the direct connection (LOS) between BS and MS greatly decreases. This is due to the fact that the MS is now in the radio shadow of the high-rise building, and any wave going through or around that building is greatly attenuated- an effect called shadowing[3]. Of course, shadowing can occur not only for a LOS component, but for any multipath component. It is also noted that the obstacles do not throw sharp shadows, that is, the transition from the “light” zone to the "dark" zone is gradual. The MS has to move over large distances (from a few meters, up to several hundreds of meters) to move from the light to the dark zone. For this reason, shadowing gives rise to large-scale fading.

Large-scale and small-scale fading overlap, so that the received signal amplitude can look like the one depicted in the diagram. Obviously, the transmission quality is low at the times with low signal amplitude. This can lead to bad speech quality for voice telephony, high Bit Error Rate (BER) and low data rate (for data transmission), and if the quality is too low for an extended period of time-to termination of the connection. It is well known from conventional digital communications that for non-fading communications links, the BER decreases approximately exponentially with increasing Signal-to-Noise Ratio (SNR) if no special measures are taken. However, in a fading channel, the SNR is not constant; rather, the probability that the link is in a fading dip dominates the behaviour of the SNR. Consequently, improving the BER often cannot be achieved by simply increasing transmit power.

Due to fading, it is almost impossible to exactly predict the received signal amplitude at arbitrary locations. For many aspects of system development and deployment, it is considered sufficient to predict the mean amplitude, and the statistics of fluctuations around the mean. Completely deterministic predictions of the signal amplitude-e.g., by solving approximations to Maxwell's equation in a given environment-usually show errors of between 3 and 10 dB (for the total amplitude), are even less reliable for the properties of individual multipath components.

II. **PROPERTIES OF THE RAYLEIGH DISTRIBUTION**

A Rayleigh distribution has the following properties which are tabulated below.

PARAMETER	FORMULA
MEAN VALUE	$\bar{r} = \sigma\sqrt{\frac{\pi}{2}}$
MEAN SQUARE VALUE	$\overline{r^2} = 2\sigma^2$
VARIANCE	$\overline{r^2} - (\bar{r})^2 = 2\sigma^2 - \sigma^2\frac{\pi}{2} = 0.429\sigma^2$
MEDIAN VALUE	$r_{50} = \sigma\sqrt{2.\ln 2} = 1.18\sigma$
LOCATION OF MAXIMUM	$\max\{pdf(r)\}$ occurs at r=σ

The cumulative distribution function, cdf(x), is defined as the probability that the realization of the random variable has a value smaller than x. The cdf is thus the integral of the pdf:

$$cdf(r) = \int_{-\infty}^{r} pdf(u)du$$

Applying this equation to the Rayleigh pdf, we get:

$$cdf(r) = 1 - \exp(-\frac{r^2}{2\sigma^2})$$

For small values of r this can be approximated as follows:

$$cdf(r) \approx \frac{r^2}{2\sigma^2}$$

It is straight forward to check whether a measured ensemble of field strength values follows a Rayleigh distribution, its empirical cdf is plotted on so-called Weibull paper. The cdf of the Rayeigh distribution is a straight line on it. For small values of r, an increase of r by 10 dB has to increase the value of the cdf by 10 dB [4]. The Rayleigh distribution is widely used in wireless communications. This is due to several reasons: Firstly, it is an excellent approximation in a large number of practical scenarios, as confirmed by a multitude of measurements. However, it is noteworthy that there are scenarios where it is not valid. These can occur, e.g., in Line of Sight (LOS) scenarios, some indoor scenarios, and in (ultra) wideband scenarios. Secondly, it describes a worst case scenario in the sense that there is no dominant signal component, and thus there is a large number of fading dips. Such a worst case assumption is useful for the design of robust systems[5]. Thirdly, it depends on a single parameter, the mean received power- once this parameter is known, the complete signal statistics are known. It is easier, and less error-prone, to obtain this single parameter either from measurements or deterministic prediction methods than to obtain the multiple parameters of more involved channel models. Finally, for the sake of mathematical convenience that is for the computations of error probabilities and other parameters can often be done in closed form when the field strength distribution is Rayleigh.

2.1. FADING MARGIN FOR RAYLEIGH-DISTRIBUTED FIELD STRENGTH: Knowledge of the fading statistics is extremely important for the design of wireless systems. For noise-limited systems the received field strength determines the performance[6]. As field strength is a random variable, even large mean field strength does not guarantee successful communications at all times. Rather, the field strength exceeds a minimum value only in a certain percentage of situations. The task is to answer the following question that if one is given a minimum receive power or field strength required for successful communications, then how large does the mean power have to be in order to ensure that the communication is successful in x% of all situations. In other words, how large does the fading margin have to be has to be thoroughly analyzed. The cdf gives by definition the probability that a certain field strength level is not exceeded. In order to achieve an x% outage probability, it follows the mathematical expression as follows,

$$x = cdf(r_{\min}) \approx \frac{r_{\min}^2}{2\sigma^2}$$

For the interference-limited case, the situation is somewhat more complicated, not only does the desired signal fade, but so do the interferers. It is thus necessary to compute the statistics of the Signal to Interference Ratio (SIR).

III. DIFFERENT FORMS OF QAM SCHEMES

Coherent M-ary phase shift keying (MPSK) modulation is a well-known technique for achieving bandwidth reduction. Instead of using a binary alphabet with 1 bit of information per channel symbol period, an alphabet with M symbols is used, permitting the transmission of $k = \log_2 M$ bits during each symbol period. Since the use of M-ary symbols allows a k-fold increase in the data rate within the same bandwidth, then for a fixed data rate, use of M-ary PSK reduces the required bandwidth by a factor k[7]. Usually it is observed that QPSK modulation consists of two independent streams. One stream amplitude-modulates the cosine function of a carrier wave with levels +1 and -1, and thus the other stream similarly amplitude-modulates the sine function. The resultant waveform is termed a double-sideband suppressed-carrier (DSB-SC) wave, since the RF bandwidth is twice the baseband bandwidth and there is no isolated carrier term. Quadrature amplitude modulation (QAM) can be considered a logical extension of QPSK, since QAM also consists of two independently amplitude-modulated carriers in quadrature. Each block of k bits (k assumed even) can be split into two (k/2)-bit blocks which use (k/2)-bit digital-to-analog (DA) converters to provide the required modulating voltages for the carriers. At the receiver, each of the two signals is independently detected using matched filters.QAM signalling can also be viewed as a combination of amplitude shift keying (ASK) and phase shift keying (PSK), giving rise to the alternative name, amplitude phase keying (APK). Finally, it can also be viewed as amplitude shift keying in two dimensions, giving rise to the name quadrature amplitude shift keying (QASK).

3.1 QAM PROBABILITY OF BIT ERROR

For a rectangular constellation, a Gaussian channel, and matched filter reception, the probability of bit error is expressed by (12) as

$$P_B = \frac{2(1-L^{-1})}{\log_2 L} Q[\sqrt{(\frac{3\log_2 L}{L^2-1})\frac{2E_b}{N_0}}]$$

Where L represents the number of amplitude levels in one dimension. Also the assumption is present that a sequence of $\log_2 L$ bits are assigned to an L-ary symbol using a Gray code.

3.2 BANDWIDTH-POWER TRADE-OFF

The bandwidth-power trade-off of M-ary QAM at a bit error probability if 10^{-5} is displayed on the bandwidth-efficiency plane with the abscissa measured in average $\frac{E_b}{N_0}$. Also the assumption is that the Nyquist filtering of the baseband pulses so that the DSB transmission bandwidth at IF is $W_{IF}=1/T$, where T is the symbol duration. Thus the bandwidth efficiency is $R/W=\log_2 M$, where M is the symbol set size. For realistic channels and waveforms, the performance must be reduced to account for the increased bandwidth necessary to implement realizable filters. It is noted that QAM represents a method of reducing the bandwidth required for the transmission of digital data. As with M-ary PSK, bandwidth efficiency can be exchanged for power or E_b/N_0, however, in the case of QAM, a much more efficient exchange is possible than in the case of M-ary PSK.

IV. PERFORMANCE ANALYSIS OF RAYLEIGH FADING CHANNELS IN RECTANGULAR QAM SCHEMES

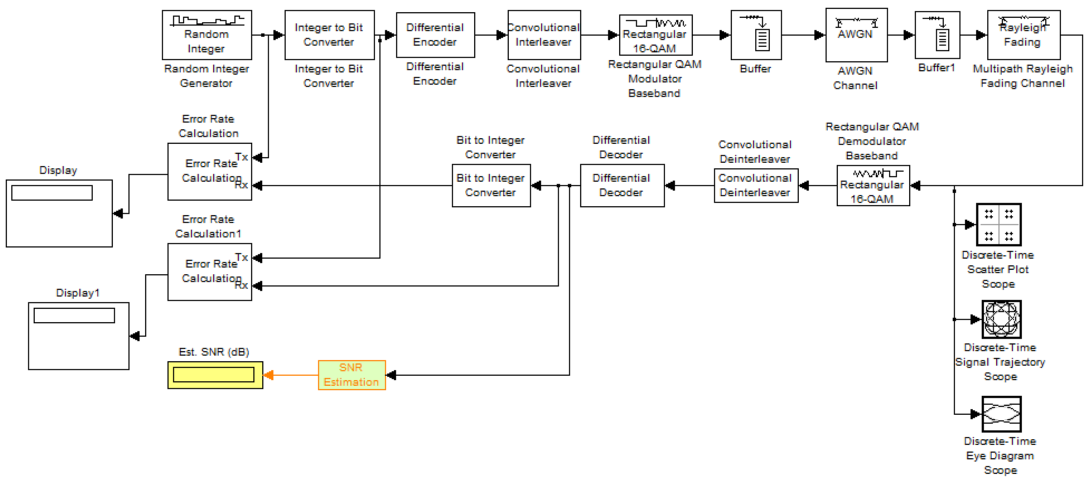

Fig.1.Simulink Environment for performance analysis of Rayleigh fading channels in 16-QAM modulation scheme

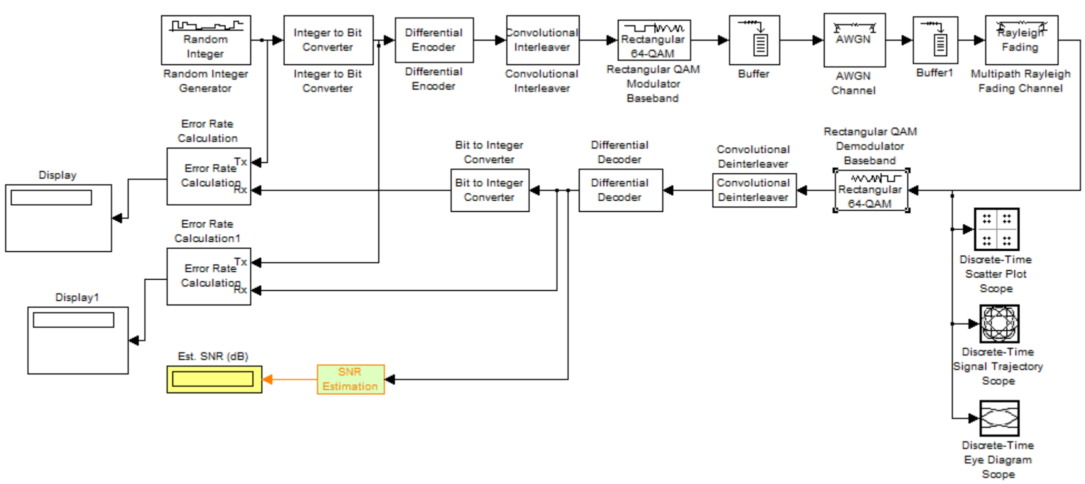

Fig. 2 Simulink Environment for performance analysis of Rayleigh fading channels in 64 QAM modulation scheme

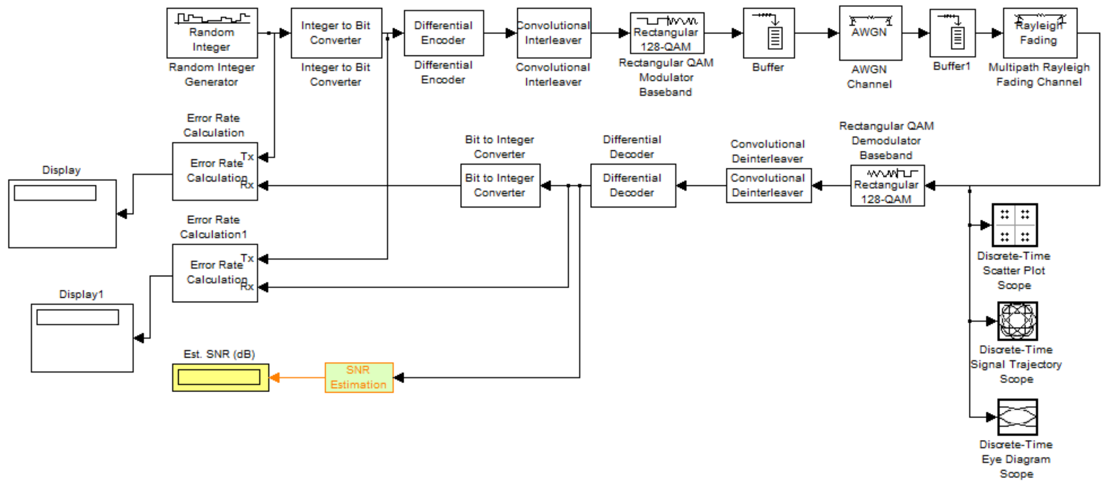

Fig. 3. Simulink Environment for performance analysis of Rayleigh fading channels in 128 QAM modulation scheme

The environment is created as shown in the fig. 1, fig. 2 and fig. 3 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.

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

RECTANGULAR QAM DEMODULATOR BASEBAND: This block demodulates the input signal using the rectangular 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.

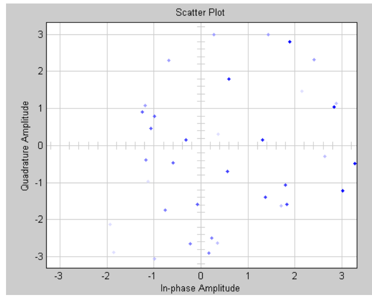

Fig. 4. Scatter plot for the performance analysis of Rayleigh fading Channels in Rectangular QAM schemes

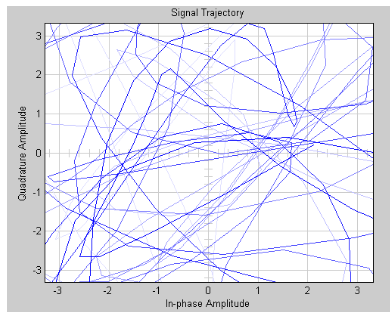

Fig. 5. Signal Trajectory for the performance analysis of Rayleigh fading Channels in Rectangular QAM schemes

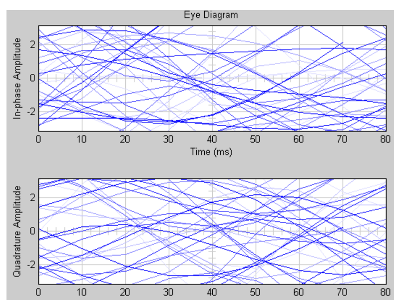

Fig. 6. Eye diagram for the performance analysis of Rayleigh fading Channels in Rectangular QAM schemes

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

DOPPLER SHIFT(Hz)	SNR	BER
10	100	0.1768
8	200	0.1656
6	300	0.1481

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

DOPPLER SHIFT(Hz)	SNR	BER
10	100	0.1469
8	200	0.1222
6	300	0.1119

Table 3. Bit Error Rate Analysis of Rayleigh Fading Channels in Rectangular QAM Modulation Scheme

DOPPLER SHIFT(Hz)	SNR	BER
10	100	0.03696
8	200	0.02697
6	300	0.02413

V. CONCLUSIONS

An introduction to the concept of fading in wireless channels is provided followed by a short review on the properties of Rayleigh fading channels is also provided. It is apparent from table 1, table 2 and table 3 that when the Doppler Shift decreases and when Signal to Noise Ratio increases, the Bit Error Rate decreases gradually. It is also observed from table 1, table 2 and table 3 that for a very high SNR a low bit error rate is achieved. The comparison for Rectangular Quadrature amplitude Modulation schemes like 16 QAM, 64 QAM and 128 QAM is carried out and the results show that when the Doppler shift reduces and when the signal to noise ratio increases, then a very low bit error rate is achieved in 128 QAM scheme rather than the other two modulation schemes. Thus 128 QAM scheme is considered to be a very versatile scheme when compared to 16 QAM and 64 QAM. The eye diagram, scatter plot and signal trajectory diagrams are also provided for the Rectangular QAM scheme in Rayleigh fading channel environment. Future works may include the usage of different modulation schemes for evaluating the bit error rate under different channel conditions.

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