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M-QAM Communication System Over a Multipath Fading Channel with Delay Spread

Md. Shahadat Hossain Akram and Subrata Kumar Aditya

Department of Applied Physics, Electronics and Communication Engineering

Dhaka University, Dhaka-1000, Bangladesh

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Abstract

Multipath performance is an important and practical consideration for communication systems. In this paper the performance of the M-QAM communication system over a six-ray independent multipath fading channel is evaluated by computer simulations. The low-pass equivalent model of the M-QAM system is considered. Based on this model, the effects of system parameters on the bit-error (BER) performance are analyzed. The spread delays, Doppler spread frequency and the attenuation of each ray (path) are the parameters of the simulation. Effect of bit duration on the BER performance of M-QAM system is also analyzed. BER of 10^{-3} was found even at higher Doppler spread frequency and in deep fade scenario and also it is seen that bit-error rate decreases with the increasing data transmission rate.

I. Introduction

In recent years the family of high-throughput quadrature amplitude modulation (QAM) schemes has become predominant in numerous wireless communication [1] standards like cable modems, DSL modems, CDMA, 3G, Wi-Fi (IEEE 802.11) and WiMAX (IEEE 802.16) [2]. Also in Europe Wireless Local Area Network (WLAN) standards such as HiperLAN/2 (very similar to IEEE 802.11a) used punctured convolutional codes and 16-QAM, 64-QAM modulation schemes to explore link adaptation as a means towards increased spectral efficiency [3]. M-QAM is also used in adaptive modulation and coding (AMC) technique since adaptation of different signal constellations according to the channel conditions can be used to send more bits per symbol and thus achieve higher throughputs or better spectral efficiencies [4]. A detailed analysis on M-ary quadrature amplitude modulation (M-QAM) on fading channels is shown in [5] and in [6] a variable-power variable-rate transmission scheme is proposed using M-QAM system for fading channels. The capacity of the fading channels is analyzed in [7] considering the transmit power, data rate, and coding scheme relative to the fade level of the channel.

In this paper an M-ary QAM communication system over six-ray multipath fading channel is represented and analyzed to investigate the bit duration, Doppler spread frequency, the attenuations and the delay spread effects on the channel. Analysis found in [8] proposed optimal strategies to minimize the total energy consumption for AWGN channels with M-QAM modulation. In wireless communications, however, the transmission environment is much more complex than what is covered by the simple AWGN model [9]. The reflecting objects and scatterers in a wireless channel dissipate the signal energy, leading to multiple versions of the transmitted signal arriving at the receiver with different amplitudes, phases, and time delays. These multipath waves combine at the receiver, causing the received signal to vary greatly in amplitude and phase. The attenuation, the interference and the noise are the most significant factors. In addition, the channel parameters are time-varying and they change randomly. Such multipath fading therefore limits the performance in wireless applications. It must be considered that the wireless communication system should operate efficiently in various environments all over the world. This paper analyzed these factors thoroughly for multipath fading channel using M-QAM modulation schemes. Though some performance degradations are shown for multipath effect, and for other parameter variations, considering the practical implications the system performs effectively.

II. System Model

M-QAM System

The QAM system model is shown in Fig. 1 in which the multipath fading channel model used in this study is a six-ray fading channel. For realistic and fast simulations, the baseband (low-pass) equivalent model of the M-QAM system is considered. The encoded data from the signal source are first applied to the flow splitter that produces two continuous-time analog pulse signals, $p_I(t)$ and $p_Q(t)$, called the in-phase and the quadrature signals, respectively. The signals are sent to the carrier-wave modulator which produces an information-bearing waveform signal

$$y(t) = p_I(t)\cos(2\pi ft) - p_Q(t)\sin(2\pi ft) \tag{1}$$

where f is called the carrier frequency. The information-bearing waveform *y(t)* is transmitted which is affected in the channel due to multipath fading, delay spread. Before reaching the receiver, the transmitted signal is also corrupted by AWGN $\xi(t)$. This faded noisy signal is represented by $s(t)$ in Fig. 1. The receiver simply performs the inverse process of the transmitter. Multiplying by a cosine (or a sine) and by a low-pass filter it is possible to extract the component in phase (or in quadrature). At the receiver, these two modulating signals is demodulated using a coherent demodulator. Such a receiver multiplies the received signal separately with both a cosine and sine signal to produce the received estimates of $p_I(t)$ and $p_Q(t)$ respectively. Because of the orthogonality property of the carrier signals, it is possible to detect the modulating signals independently.

In the ideal case $p_I(t)$ is demodulated by multiplying the transmitted signal with a cosine signal:

$$r_i(t) = s(t)\cos(2\pi ft) \tag{2}$$

Low-pass filtering $r_i(t)$ removes the high frequency terms leaving only the $p_I(t)$ term. Similarly, multiplying $s(t)$ by a sine wave and then using low-pass filter it is possible to extract $p_Q(t)$.The hard decision algorithm is used at the QAM demodulator.

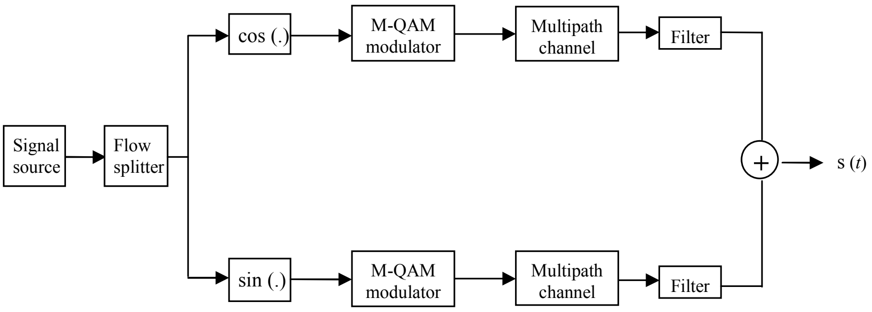

Fig. 1. The M-QAM system

Multipath Fading Channel Model

In wireless communication systems, the channel is more complex and the transmitted signal suffers from fading and multipath delay spread in addition to the effect of noise. The multipath fading model used in practice consists of 12 rays [10]. These models are defined for three various environments including urban, hilly and rural. Each model is determined by a set of propagation delays and attenuations associated with corresponding paths. A simplified 6-ray model as shown in Fig. 2 is considered in this paper. The received composite signal for such model can be written as

$$s(t) = a_o y(t) + \sum a_n R_n y(t - \tau_n) + \xi(t) \tag{3}$$

where, R_n, n = 1, 2,…, 5, determines five independent Rayleigh random variables representing the attenuation of the five Rayleigh paths, and τ_n, n = 1, 2,…, 5, determines the relative delays between the Rayleigh components, and a_n, n = 0, 1, 2,…, 5, determines the relative power level P_n, n = 0, 1, 2,…, 5, of the six multipath components. a_n is also a function of Rician factors and Doppler spread frequency. Also, $\xi(t)$ is the AWGN with mean equal to zero and power spectral density $N_o/2$. Some simplifications are considered. The line-of-sight component is unfaded and the instantaneous phase is not affected. It is known that Rayleigh fading (typical in indoor or urban environments) occurs when multiple indirect (NLOS) paths between the transmitter and receiver exist with no distinct dominant (LOS) path. The Rician factor is therefore $K_{Rice} = 0 = -\infty$ dB . The Rayleigh A-PDF (amplitude PDF) is therefore given by [11]:

$$p(r|\sigma^2) = \frac{r}{\sigma^2}\exp(-\frac{r^2}{2\sigma^2}) \quad \text{if } (0 \le \text{r} < \infty) \tag{4}$$

$$= 0 \qquad \text{if r} < 0$$

where σ^2 is the average power of the received signal before envelope detection and the phase PDF is given by [12]:

$$p(\phi) = \frac{1}{2\pi} \qquad \text{for } (-\pi \le \phi \le \pi) \tag{5}$$

assuming an input signal with constant phase.

III. Simulation Results

BER Performance for Different Fading Parameters

The example system is designed according to the guidelines described on QAM system and multipath fading channel in previous section. The BER performance is simulated and the figures 4, 5 are showing the dependency of BER on E_b/N_o for the three different parameter variations such as attenuation of each path, Doppler spread frequency, respectively. At first it is shown in Fig. 3 that the performance degrades due to multipath effect from that of the AWGN channel which is performed for 4-QAM modulation. Fig. 4 illustrates the performance of the 16-QAM system for two different sets of pathgains of the 6-ray multipath fading channel. For the shallow fade case the set of pathgains considered for the six different rays is {50 dB, 40 dB, 30 dB, 20 dB, 10 dB, 0 dB} and for deep fade case the set considered is {0.5 dB, 0.4 dB, 0.3 dB, 0.2 dB, 0.1 dB, 0 dB }. The time delay parameter set considered for both the cases is {0 1e-10s 2e-9s 4e-8s 3e-8s 1e-8s}. Also, the Doppler spread frequency considered is 33 Hz which corresponds to the mobility of 40 km/h. It is seen from the figure that the system performs nearly same under both the conditions. After BER of 10^{-3} a slight performance degradation of 0.5 dB - 1 dB is observed for deep fade case.

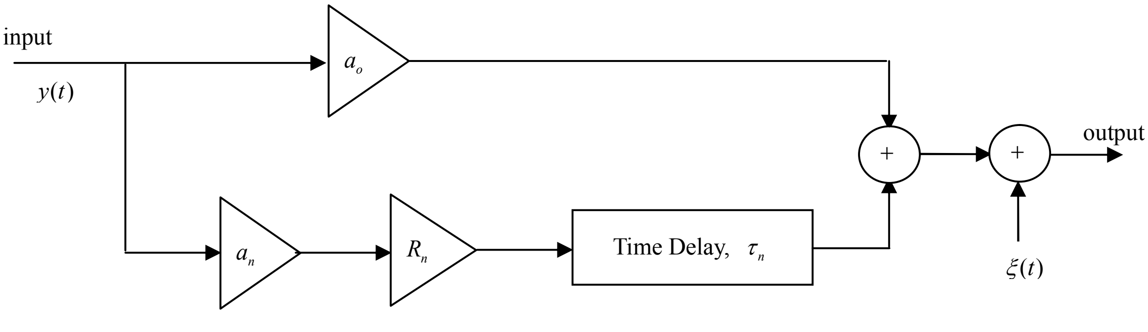

Fig. 2. Multipath Fading channel model

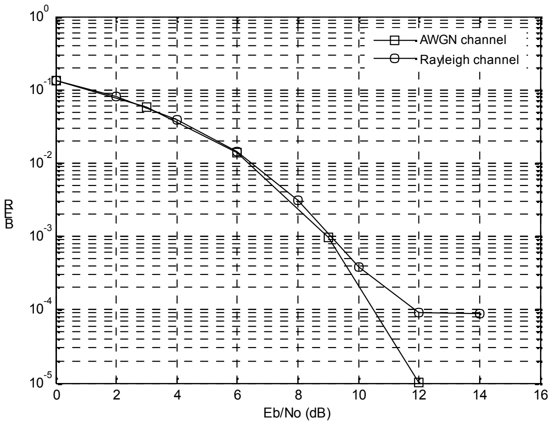

Fig. 3. Comparison of AWGN and multipath fading channel performance.

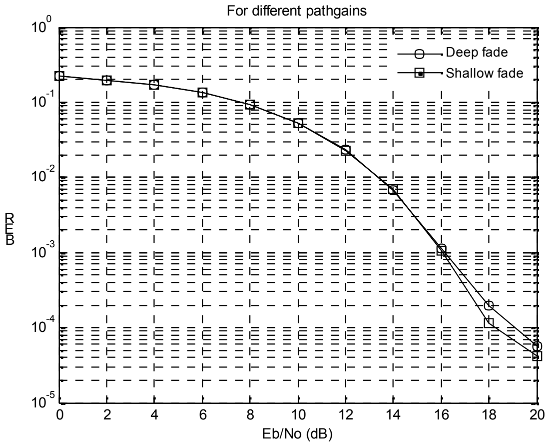

Fig. 4. BER performance for two set of path gains.

The BER performance for different Doppler spread frequency is shown in Fig. 5. In this case the fading amplitudes are considered following the deep fade case of this study. From this figure it is observed that as the frequency increases BER performance decreases gradually though BER of above 10^{-3} is found up to 100 Hz which is considered to be the real world frequency spread.

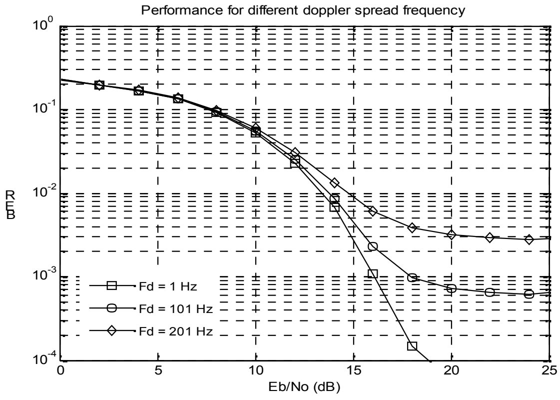

Fig. 5. Performance for different Doppler spread frequency.

Bit Duration Effect

The effect of bit duration on the system performance is shown in Fig. 6. Again the deep fade case is considered and, the time delay parameter and Doppler spread frequency are considered following the first experiment on pathgains. This figure plots the curves of BER versus E_b/N_o, with $T_s = 20$, 50 μs. In Fig. 7, 8 the effects of T_s on the BER performance are shown for Rayleigh and Rician distribution respectively with E_b/N_o fixed to 15 dB. In this case the Rician K-factor value is set as 6 dB. It is clear from the figures that reducing the bit duration, the BER performance can be improved. The similar result has been got in the single-path [13] and two-path environments [14]. Another merit of reducing the bit duration is that the data rate can be increased. However, when the bit duration decreases, the system will be sensitive to timing recovery errors. Thus, in practice, a trade-off of these two factors should be considered. Fig. 9 compares these two channel performance revealing a slight better BER performance of Rician channel than the Rayleigh fading channel due to the line-of-sight (LOS) component in each discrete path of the Rician channel.

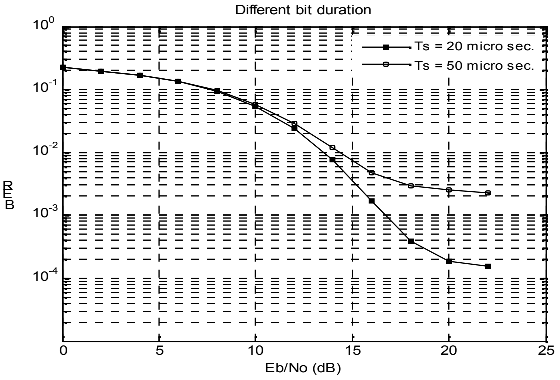

Fig. 6. BER performance with $T_s = 20$, 50 μs.

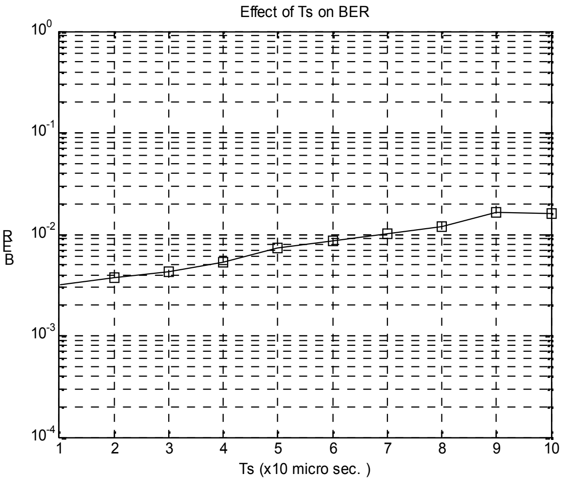

Fig. 7. BER versus T_s, for Rayleigh multipath distribution, with $E_b/N_o = 15$ dB.

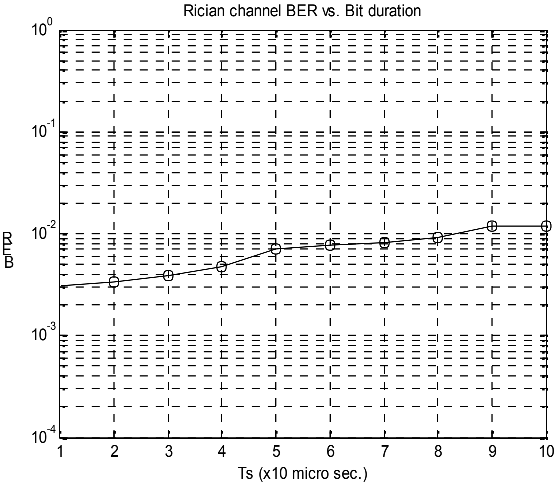

Fig. 8. BER versus T_s, for Rician distribution, with $E_b/N_o = 15$ dB.

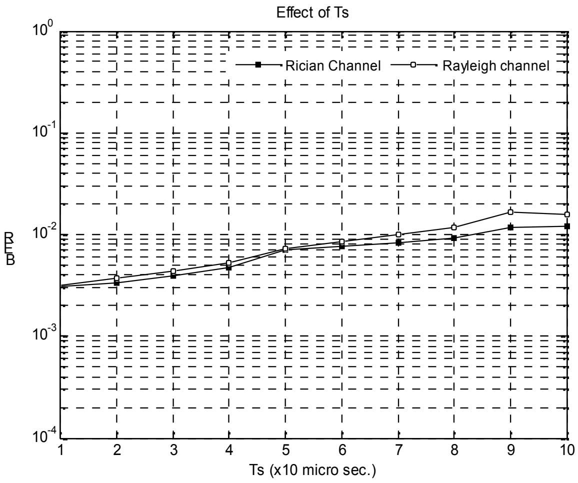

Fig. 9. BER versus T_s curves for Rayleigh and Rician fading channel.

IV. Conclusions

In this paper the performance of the M-QAM system over a six-ray multipath fading channel is evaluated by computer simulations. The results show the degradation of the system bit-error performance due to the channel fading and Doppler spread frequency. But the performance (BER) results found in deep fade and at higher Doppler frequencies prove that the designed M-QAM system can work properly at adverse fading environment. This paper also reveals the effects of bit duration on the bit-error performance. It is shown that increasing the data rate also improves the BER performance of the simulated system.

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