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BER Evaluation of M-QAM Modulation in Wireless Transmission over AWGN Channel

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ABSTRACT

M-ary Quadrature Amplitude Modulation (M-QAM) is an important technique for modulation of digital signals in wireless communication system. Due to the increasing demands for high rate data outputs in wireless communications, it is essential to investigate methods of achieving high spectral efficiency which would take into account the wireless channel models. The bit error rate (BER) is a parameter which gives an excellent indication of the performance of a data link such as radio or optic fiber system. Understanding the method of evaluating the BER will aid in the design of a more suitable modulation scheme that will best suit the channel quality, thus delivering the optimum and efficient data rate to the downlink terminal. This paper will focus on evaluation of BERs for M-QAM modulation varying from 4 to 64 and for integer values of bit energy-to-noise power spectral density ratio (E_b/N_o) between 0 and 7 using Matlab R2013a simulation tool in AWGN channel.

Keywords: AWGN channel, Bit Error Rate and M-ary Quadrature Amplitude modulation

I. INTRODUCTION

The increasing demand for high data rates in wireless communications has made it necessary to investigate methods of achieving high spectral efficiency which would take into account the wireless channel. M-ary Quadrature Amplitude Modulation (M-QAM) is one such technique of modulation that maps each of the discrete-time symbols belonging to a set of M alphabets into one of the M continuous-time analogue waveforms suitable for transmission over the physical channel. It helps to maximize the data rates transmitted over the wireless channels [1]. Due to its high spectral efficiency, M-QAM is an attractive modulation technique for wireless communications. However, it is very sensitive to channel estimation since it requires an estimation of the amplitude variations (in addition to the phase variations).

Severe amplitude and phase variations, which are inherent to wireless channels, significantly degrade the BER performance of M-QAM. This is because the demodulator must scale the received signal in order to normalize the channel gain so that its decision regions correspond to the transmitted signal constellation. This scaling process is called automatic gain control (AGC). Estimating the channel gain in error will lead to the AGC improperly scaling the received signal, which will lead to incorrect demodulation even in the absence of noise. Therefore, effective communication with M-QAM in fading channels requires accurate fading compensation techniques at the receiver, which can be achieved by using adaptive modulation concept. The adaptive modulation concept maintains a constant performance by varying the transmitted power level, modulation scheme, coding rate or any of the combinations without compromising the BER performance [2]. Other energy efficient modulation schemes such as BiPhase Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK) can also be used when the channel conditions are very poor.

In Second Generation (2G) systems, Gaussian Minimum Shift Keying (GMSK) modulation scheme was widely used in Global System for Mobile (GSM) communication. This modulation scheme can only transmit data rate of 1bit per symbol, which is not suitable for 3G and later communication systems. The implementation of high data rate modulation scheme with good bandwidth efficiency in Wideband Code Division Multiple Access (WCDMA) cellular communication system requires perfect modulators, demodulators, filters and transmission channels, which are practically difficult to achieve in radio environment. This is because modulation schemes which are capable of delivering data of higher bits per symbol are not immune to errors caused by channel noise and interference. Moreover, errors can easily be produced as the number of users increase and the mobile terminal is subjected to mobility [3]. Thus, it has driven many researchers into the application of higher order modulations [4], [5]. Enhanced Data Rate for GSM Evolution (EDGE) was later proposed as transition to 3G as a new Time Division Multiple Access (TDMA) based radio access using 800, 900, 1800 and 1900MHz frequency bands. EDGE enables significantly higher peak rates and triples the spectral efficiency by employing 8-Phase Shift Keying (8PSK) modulation.

In a cellular system, different users have different channel qualities in terms of signal to noise ratio (SNR) due to difference in distance to the base station, fading and interference [6]. Link quality control (LQC) adapts the data protection according to the channel quality so that the optimal bit rate is obtained for all channel qualities. WCDMA adapts the 8PSK and M-QAM to increase the data transmission rate with the link quality control [7], [8]. Additive White Gaussian Noise (AWGN), which is the effect of thermal noise generated by thermal motion of electrons in all dissipative electrical components, i.e. resistors, wires, transistors, etc., is a wireless channel through which signals are transmitted [9], [10]. Mathematically, thermal noise is described by a zero-mean Gaussian random process, where the random received signal is the sum of Gaussian noise random variable and a direct current (DC) signal [11], [12].

$$\mathrm{Z(t)} = \mathrm{a} + \mathrm{n(t)} \qquad (1)$$

Where 'z' is the random received signal, 'a' is the dc signal and n(t) is the Gaussian noise variable. The probability distribution function (PDF) for Gaussian noise can be represented as follows:

$$\mathrm{P(z)} = \frac{\sqrt{2\pi}}{6} e^{-\frac{1}{2}(z-a/\delta)^2} \qquad (2)$$

Where δ^2 is the variance of n(t). The effect of this noise can cause fluctuation in the received signal's amplitude and phase angle at arrival, giving rise to the terminology 'multipath fading'. The complex baseband model of the received signal r(t) is given by:

$$\mathrm{r(t)} = \mathrm{s(t)c(t)} + n(t) \qquad (3)$$

Where s(t) is the transmitted signal and c(t) is the fading distortion. QPSK, 16-QAM and 64-QAM are such examples of M-ary PSK and M-ary QAM modulation techniques (M=4, 16 and 64) where they transmit 2bits, 4bits and 6bits per symbol respectively. The number of bits per symbol (k) transmitted over the channel determines the spectral efficiency of a communication system and is given by:

$$\mathrm{k} = \log_2 M \qquad (4)$$

Where '*M*' is the signal constellation level.

The phase carrier takes on one of the four equally spaced values, such as 0, π/2, π and 3π/2, where each value of the phase corresponds to a unique pair of message bit. The base signal (S_{QPSK}) for QPSK can be expressed as:

$$S_{QPSK} = \sqrt{E_s}\mathrm{Cos}\{\tfrac{\pi}{2}(\mathrm{i}-1)\}\Phi_1(\mathrm{t}) - \sqrt{E_s}\mathrm{Sin}\{\tfrac{\pi}{2}(\mathrm{i}-1)\}\Phi_2(\mathrm{t}) \qquad (5)$$

Where i=1, 2, 3, 4, …..; Φ_1 and Φ_2 are the phase angles, and E_S level is the energy of the signal. Some special advantages of QPSK are that it has identical bit error probability and can send as twice data in the same bandwidth when compared to BPSK. QPSK also provides twice the spectral efficiency with the same energy efficiency as BPSK [13].

M-QAM is a modulation technique where its amplitude is allowed to vary with phase [14]. It is potentially more bandwidth efficient than PSK. Its signalling can be viewed as a combination of Amplitude Shift Keying (ASK) and Phase Shift Keying (PSK). The general form of M- QAM signal can be defined as:

$$S_{MQAM} = \sqrt{\frac{2E_{min}}{T_s}} a_1 \mathrm{Cos}(2\pi ft) + \sqrt{\frac{2E_{min}}{T_s}} b_1 \mathrm{Sin}(2\pi ft) \quad (6)$$

Where T_s is the period of the modulated signal and E_{min} is the energy of the signal with the lowest amplitude integer a_i and b_i chosen according to the location of a particular signal point [15]. The evaluation of BER is one of the fundamental problems in digital communications. In this paper, the focus is on the uncoded BER evaluation in M-varying QAM modulation using two parameters, namely: constellation and labelling (or bits-to-symbol mapping). The constellation is a set of complex symbols (also used for determining the amplitude and the phase of the waveforms), while the labelling is the rule assigning binary codeword (labels) to the symbols in the constellation. The BER depends on the signalling, which defines the probabilities of transmitting the particular symbol or bit. Although, signalling is not strictly related to modulation, it must, however, be considered during the performance evaluation. The exact calculation of BER is required when designing modulation depending on the system level criteria. Mostly, Gray labelling (which minimizes the Hamming distance between the closest constellation points) and uniform signalling (equiprobable symbols in the constellation) are considered when designing QAM and PSK modulation. Gray labelling is also assumed to minimize the probability of error in QAM and PSK modulation [16].

II. METHODS AND MATERIAL

The Wireless System Model

Considering the wireless system model shown in Fig. 1, the user data is assumed to be Bernoulli distributed and is represented by $b_n(t)$. Each user data is multiplied with independent pseudo noise (PN) code produced by a PN generator using XOR logical operator. The multiplied signal of each user is represented as $S_n(t)$ after the signal is modulated by M-QAM modulator. Each signal is added before it is subjected to the channel. At the receiver, the signal $S_k(t)$ is demodulated after passing through the AGC and before the user data is separated from PN code by XOR logical operator. Finally, when the necessary computer simulations are done, tables and graphs of BER as a function of E_b/N_o for various parameters are plotted. The wireless system model used in this paper is the WCDMA system in AWGN and Multipath Rayleigh Fading channel as shown in Fig. 1.

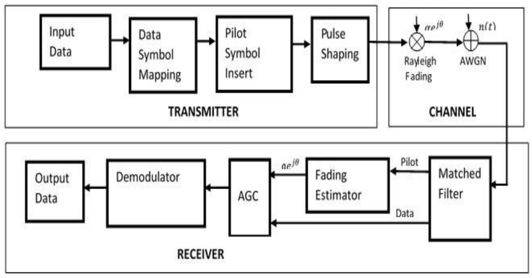

Fig. 1: WCDMA wireless System block diagram

Analysis, observations and results will be scaled on plots based on the simulation results. Rayleigh fading and AWGN noise are selected to symbolize fading effect in the channel. To compensate for the channel fading in the transmission, pilot symbols are periodically inserted into the data symbols at the transmitter so that the channel-induced envelope fluctuation α and phase shift θ can be extracted and interpolated at the channel estimation stage. The received signal goes through the AGC, which compensates for the channel fading by dividing the received signal by the fading estimate $\alpha e^{j\theta}$. The output from the AGC is then fed to the decision device to obtain the demodulated data bits.

In mobile communication systems, the channel is time varying because of the motion of either the transmitter or the receiver, which results in propagation path changes. There are many fading effects that can be categorized as large-scale and small-scale fading. If the channel bandwidth is greater than the signal bandwidth, the signal received will undergo flat fading (deep fades caused by multipath). If there is no line-of-sight (LOS) component in the received signal path, it will result to Rayleigh fading. Rayleigh fading represents the worst case of multipath fading whereas small-scale fading can be due to small changes in position with respect to time that is Doppler Effect. This is to say that, the M-QAM modulation scheme performs poorly in multipath fading channel as the speed of mobile terminal increases. It also performs badly as the number of users increases. On the other hand, AWGN represents the thermal noise generated by electrical instruments. The computer based simulations are the most fitting, powerful and proficient means to stand for the real time scenarios of mobile radio system. Thus, MATLAB R2013a has been used to simulate WCDMA model based on the associated parameters, theories and formulae.

Theoretical BER Evaluation

In digital transmission, the number of bit errors is the number of received bits of data stream over a communication channel that has been altered due to noise interference, distortion or bit synchronization errors. The BER is the ratio of the number of bit errors to the total number of transferred bits during a specified time interval. Thus:

$$\text{BER} = \frac{\text{Number of bit errors}}{\text{Total number of bits}} \qquad (7)$$

When simulating digital modulations in Matlab, it is useful to verify the simulated BER performance against the theoretical BER results. M-QAM being an important modulation scheme that allows for higher data rates and spectral efficiencies needs a carefully calculated BER. This can be done either through Monte Carlo simulations or theoretical approach. As the constellation size of the modulation scheme increases, the BER calculation becomes quite complex. Therefore a theoretical approach is more preferable at higher constellation sizes. Matlab BERtool supports six different types of modulation schemes namely: Phase Shift Keying (PSK), Differential Phase Shift Keying (DPSK), Offset Quatemary Phase Shift Keying (OQPSK), Pulse Amplitude Modulation (PAM), Quadrature Amplitude Modulation (QAM) and Frequency Shift Keying (FSK) over three different channels namely: AWGN Rayleigh and Rician. The theoretical BER calculation for M-QAM modulation is given by:

$$BER = \frac{3}{8} erfc\left(\sqrt{\frac{2}{5}\,snr}\right) - \frac{9}{64} erfc\left(\sqrt{\frac{2}{5}\,snr}\right)^2 \qquad (8)$$

Where *snr* is the signal-to-noise ratio defined as:

$$\text{snr} = \frac{E_b}{N_o} + 10\log_{10} k - 10\log_{10} nsamp \qquad (9)$$

and *erfc* is the complementary error function defined as:

$$erfc(x) = 2\sqrt{\pi}\int_x^{\infty} e^{-t^2}\,dt = 1 - \text{erf}(x) \qquad (10)$$

erf is the error function defined as:

$$\text{erf}(x) = 2\sqrt{\pi}\int_0^{x} e^{-t^2}\,dt \qquad (11)$$

During the theoretical BER evaluation of M-QAM modulation scheme, the following settings shown in table 1 were configured in Matlab BERtool.

TABLE 1: SETTINGS FOR THEORETICAL BER EVALUATION OF M-QAM

S/N	PARAMETERS	SETTINGS
1	Eb/No	0:7dB
2	Channel type	AWGN
3	Modulation type	QAM
4	Demodulation type	Coherent
5	Modulation order	4, 8, 16, 32, 64
6	Channel coding	None
7	Synchronization	Perfect synchronization

The theoretical BER performance plot and tabular results of M-QAM modulation scheme in AWGN channel are shown in Fig. 2 and table 2 respectively.

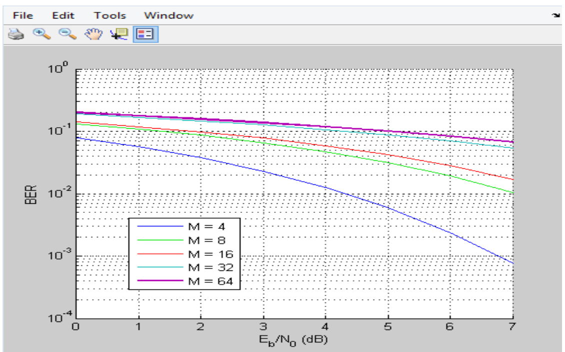

Fig. 2: Plot of theoretical BER evaluation of M-QAM

TABLE2: THEORETICAL BER PERFORMANCE RESULTS OF M-QAM

S/N	Values of M	Number of Mbps	Number of Bits	Values of EbNo	Number of Errors	Deduced BER
1	4	1	30000	0	23580	0.0786
				1	16860	0.0562
				2	11250	0.0375
				3	6840	0.0228
				4	3750	0.0125
				5	1770	0.0059
				6	690	0.0023
				7	240	0.0008
2	8	3	30000	0	39780	0.1326
				1	32760	0.1092
				2	26010	0.0867
				3	19710	0.0657
				4	14100	0.0470
				5	9390	0.0313
				6	5730	0.0191
				7	3120	0.0104
3	16	4	30000	0	42270	0.1409
				1	34470	0.1149
				2	29310	0.0977
				3	23220	0.0774
				4	17580	0.0586
				5	12540	0.0418
				6	8340	0.0278
				7	5070	0.0169
4	32	5		0	56820	0.1894
				1	50160	0.1672
				2	43830	0.1461
				3	37770	0.1259
				4	31980	0.1066
				5	26400	0.0880
				6	21060	0.0702
				7	16080	0.0536
5	64	6		0	59940	0.1998
				1	53370	0.1779
				2	47070	0.1569
				3	41130	0.1371
				4	35550	0.1185
				5	30210	0.1007
				6	25140	0.0838
				7	20250	0.0675

III. RESULTS AND DISCUSSION

SIMULATION OF BER EVALUATION OF M-QAM

This simulation is aimed at evaluating the BER performance of M-QAM parameter-varying modulation in AWGN channel using Matlab R2013a simulation tools. The BERs are computed for varying 'M' of values 4, 8 16, 32 and 64 and for integer values of E_b/N_o between 0 and 7. For each value of 'M', a plot of BER as a function of E_b/N_o using a logarithmic scale for the vertical axis is made. The graphical and tabular results shown in Fig. 3 and table 3 respectively depict the BER performance of M-QAM modulator for M=4, 8, 16, 32 and 64.during the simulation. Both the graphical and tabular simulation results show that when the signal constellation 'M' increases, from 4 to 64 at a specified signal E_b/N_o value, say 0dB, the BER performance decreases. At a higher Signal E_b/N_o value, say 7dB, the Bit Error Rate (BER) performance increases, leading to higher signal performance in the system. It can therefore, be inferred that to achieve optimum signal performance in a wireless multipath fading channel, higher E_b/N_o values should be implemented. Higher level M-QAM modulation performance severely degrades when the channel is subjected to Multipath fading with increasing value of Doppler shift (Hz). The simulation and theoretical results of the BER performance are similar in almost all the features.

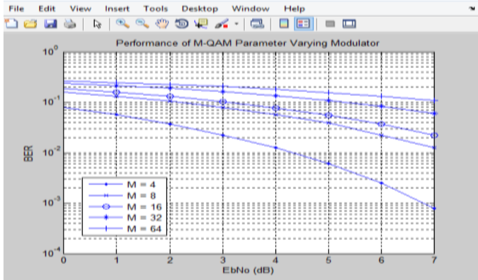

Fig. 3: Plot of BER evaluation of M-QAM modulation

The summary of the simulated BER performance results is shown in table 3.

TABLE 3: SIMULATION RESULTS OF BER EVALUATION OF M-QAM

S/N	Values of M	Number of Mbps	Number of Bits	Values of EbNo	Number of Errors	Deduced BER
1	4	1	30000	0	23520	0.0784
				1	16920	0.0564
				2	11310	0.0377
				3	6840	0.0228
				4	3750	0.0125
				5	1860	0.0062
				6	750	0.0025
				7	240	0.0008
2	8	3	30000	0	47700	0.159
				1	39510	0.1317
				2	31290	0.1043
				3	23580	0.0786
				4	17130	0.0571
				5	11370	0.0379
				6	6780	0.0226
				7	3780	0.0126
3	16	4	30000	0	55560	0.1852
				1	47100	0.157
				2	39300	0.131
				3	31140	0.1038
				4	23340	0.0778
				5	16740	0.0558
				6	11250	0.0375
				7	6960	0.0232
4	32	5		0	71490	0.2383
				1	64560	0.2152
				2	56880	0.1896
				3	48840	0.1628
				4	40620	0.1354
				5	32340	0.1078
				6	24990	0.0833
				7	17700	0.059
5	64	6		0	79380	0.2646
				1	74070	0.2469
				2	67710	0.2257
				3	61410	0.2047
				4	54510	0.1817
				5	46890	0.1563
				6	38910	0.1297
				7	31830	0.1061

IV. CONCLUSION

The major challenge in the field of wireless communication is to convey information as efficiently as possible through a limited bandwidth, though some of the information bits may be lost in most of the cases and the original signal initially sent will face degradation or fading. To minimize the effect of signal fading in wireless channels, the BER should be at a minimal possible level, with the E_b/N_o raised to significantly high level. In this paper, five MQAM modulation schemes (4-QAM, 8-QAM, 16-QAM, 32-QAM and 64-QAM) were analysed at E_b/N_o values between 0 to 7dB in order to evaluate their BER performances in AWGN Channel. The research revealed that 4-QAM modulation has a better BER performance than 64-QAM, but with lower Spectral efficiency (i.e. 2Bits/Symbol). The 64-QAM has a higher Spectral efficiency (i.e. 6Bits/Symbol) than the lower level QAM, but has poor BER performance. This is because the higher order M-QAM modulation schemes are vulnerable to errors despite their high spectral efficiencies. Due to the dependence of the demodulator decision region on the channel fading, the estimation error of the channel severely degrades the performance of the demodulator. However, an efficient channel fading compensation concept such as the adaptive modulation scheme and a more efficient error correction coding like convolution coding or turbo coding can be used to maintain a good BER performance with high spectral efficiency in higher QAM modulation schemes over AWGN channel. The simulation and theoretical results in this analysis are similar in all features. This proves that simulation results can further be verified using theoretical analysis.

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