



RESEARCH ARTICLE

Performance Evaluation and Simulation of M-Ary Quadrature Amplitude Modulation Schemes with VisSim/Comm Software

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ABSTRACT

M-ary modulation schemes are considered one of widely used digital modulation in practice because of its high efficiency in power and bandwidth. Therefore, this necessity the need to study and evaluate the performance of M-ary schemes using simulation techniques. In this paper, the performance of M-ary modulations schemes M-ary quadrature amplitude modulation (QAM) is considered. Because of its efficiency in power and bandwidth, M-ary QAM (M-QAM) is one of the widely used modulation techniques in practice. Therefore, a need for studying and evaluating the performance of QAM modulation schemes is an important task for designers. In this paper, M-QAM modulation schemes for even number of bits per symbol (16, 62, and 256-QAM) and an odd number of bits per symbol (32- and 128-QAM), over Additive White Gaussian Noise channel, are studied. A VisSim/Comm simulation^[1] model for M-QAM is designed. Theoretical and simulation results for bit error ratio (BER) performance of QAM modulation schemes are obtained using VisSim/Comm software. The results are evaluated and compared.

Keywords: Bit error rate, communication system, digital modulation, error probability, M-ary

INTRODUCTION

Quadrature amplitude modulation (QAM) is a type of modulation which is widely used for modulating data signals onto a carrier used for radio communications. The use of QAM basically consists of the combination of two amplitude modulated signals into the same channel. QAM doubles the amount of the bandwidth and hence making it more effective. This combination of analog and digital modulation is very often encountered in digital telecommunication systems.^[2] QAM is used in many radio communications and data delivery applications.^[3,4] In applications of domestic broadcast, 64-QAM and 256-QAM are often encountered in digital cable television and cable modem.^[5,6] 16-QAM and 64-QAM are currently used in the UK for digital terrestrial television using digital video broadcasting.^[7,8] 64-QAM and 256-QAM are used in the US for digital cable as standardized by the Society of Cable Telecommunications Engineers (SCTE) in standard American National Standards Institute/SCTE 07 2000. Moreover, various types of QAM are also used in wireless and cellular technology application.

Most communications systems fall into one of three categories, namely, bandwidth efficient, power efficient, or cost efficient. Bandwidth efficiency describes the ability of a modulation scheme to accommodate data within a limited bandwidth while power efficiency describes the ability of the system to reliably send information at the lowest practical power level. In most communication systems, there is a high priority on bandwidth efficiency. The parameter to be

optimized depends on the demands of the particular system applications.

The highest priority of designers of digital terrestrial microwave radios is good bandwidth efficiency with low bit error rate (BER) because they have plenty of power available and are not concerned with power efficiency. They are not especially concerned with receiver cost or complexity since they do not have to build large numbers of them.

Designers of hand-held cellular phones put a high priority on power efficiency because these phones need to run on a battery. Cost is also a high priority because cellular phones must be low cost to encourage more users. Accordingly, these systems sacrifice some bandwidth efficiency to get power and cost efficiency.

It is noticed that every time one of these efficiency parameters (bandwidth, power or cost) is increased, another one

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decreases, or becomes more complex or does not perform well in a poor environment. Cost is a dominant system priority. Low-cost radios will always be in demand. In the past, it was possible to make a radio low-cost by sacrificing power and bandwidth efficiency. This is no longer possible. The radio spectrum is very valuable and operators who do not use the spectrum efficiently could lose their existing licenses or lose out in the competition for new ones. These are the tradeoffs that must be considered in digital radio frequency communications design.

Much research has done on the comparison of QAM with other modulation techniques. In most cases, the QAM tends to have better performance overall. For instance, multiple papers show that QAM has better noise resistance and is more adaptive for channel change, and more efficient in bandwidth utilization.^[9] While phase-shift keying (PSK) modulation schemes often demonstrate better BER performance than their QAM counterparts, it may be possible to mitigate this issue with more complex hardware.^[9] It is concluded that BER performance of quadrature PSK (QPSK) is better than that of 16-QAM at the expense of large spectral width. Alternatively, 16-QAM can carry more traffic than QPSK at the expense of higher BER.^[9]

BASIC DIGITAL MODULATIONS

In a digital modulation scheme, the digital modulating signal (data bits) alters the amplitude, phase or frequency of a

sinusoidal carrier. Figure 1 illustrates these basic modulations in their binary versions. In the binary amplitude-shift keying modulation, the carrier amplitude is switched between two levels according to the modulating data bits. In the binary PSK modulation, the carrier phase is switched between two values according to the data bits. In the binary frequency shift keying (FSK) modulation, the carrier frequency is switched between two values according to the modulating data bits. These modulations are the digital counterparts of the analog amplitude modulation, phase modulation, and frequency modulation, respectively.

The most popular combined digital modulations is the amplitude-phase keying (APK), in which different symbols may be represented by a carrier signal with different amplitude levels and phases. One of the most important APK modulations is commonly referred to as QAM.

DIGITAL COMMUNICATION SYSTEM MODEL

The system model and the notation that used to represent digital communications over an Additive White Gaussian Noise (AWGN) channel are illustrated in Figure 2. The AWGN channel adds the noise $w(t)$ to the transmitted signal, forming the received signal $x(t)$, which is then correlated with each base-function to form the observed

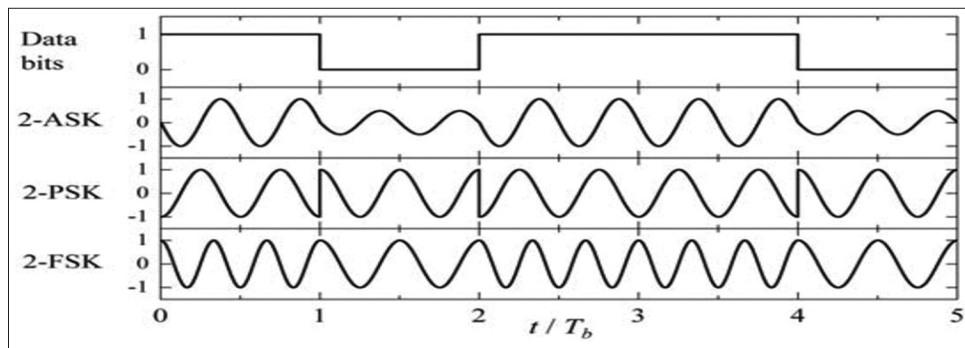


Figure 1: Basic digital modulation schemes

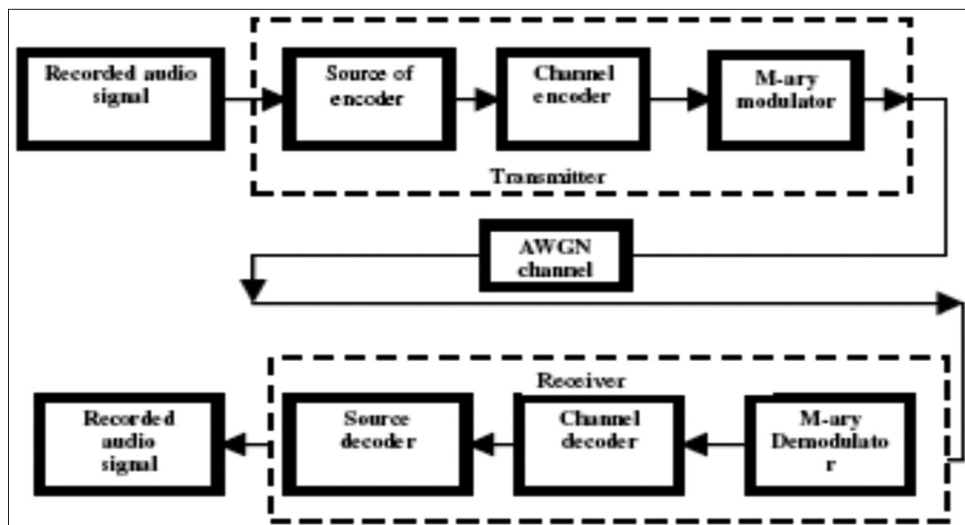


Figure 2: System model for pass-band transmission

vector $x = [x_1 x_2 \dots x_N]^T$. The transmitted symbol is then estimated based on the maximum likelihood criterion and, finally, the estimated symbol is mapped back into the k data bits it represent.

$$\rho = \frac{R_b}{B}, \text{bits/sec/Hz} \tag{1}$$

SPECTRAL EFFICIENCY AND POWER EFFICIENCY IN DIGITAL MODULATIONS

The spectral efficiency of digital modulation is the ratio between the transmitted bit rate R_b and the occupied bandwidth B , that is,

The result shown above, expressed in bits per second per hertz (bit/s/Hz), is, in fact, a measure of the data packing capability of the modulation. Power efficiency is a measure of the E_b/N_0 ratio needed for a specified symbol or bit error probability. For most of the systems, spectral efficiency and power efficiency are conflicting parameters, which means that increasing one will often cause a reduction in the other.

MATHEMATICAL MODEL

The QAM is a type of APK modulation in which symbols are represented by different phases and amplitudes of a sinusoidal carrier. QAM modulations are classified into two types, according to the geometric shape of their constellations. Modulations with an even number of bits per symbol can have square constellations and are called square QAM modulations and modulations with an odd number of bits per symbol cannot have square constellation shapes and are called non-square QAM modulations. Digitally modulated signals can be represented in a multitude of forms using a variety of techniques derived from the three basic forms of frequency, amplitude, and phase keying. In general, a modulated signal can be represented by:

$$s_i(t) = \sqrt{\frac{2E_{min}}{T_s}} a_i \cos(2\pi f_c t) + \sqrt{\frac{2E_{min}}{T_s}} b_i \sin(2\pi f_c t) \tag{2}$$

$$0 \leq t \leq T; i = 1, 2, \dots$$

Where E_{min} is the energy of the signal with the lowest amplitude, and a_i and b_i are a pair of independent integers chosen according to the location of the particular signal point.

M-ary QAM (M-QAM) does not have constant energy per symbol, nor constant distance between possible symbol states, which is why some values of $s(t)$ will be detected with higher probability than others.

CALCULATING THE BER

In this section, we discuss how to obtain the theoretical BER and symbol error rate (SER) for a given QAM constellation

Table 1: M-ary quadrature amplitude modulation bandwidth efficiency

M-ary quadrature amplitude modulation	Bits/symbol (k) (even and odd)	Bandwidth efficiency (Mb/s)
16	4	80
32	5	100
64	6	120
128	7	140
256	8	160

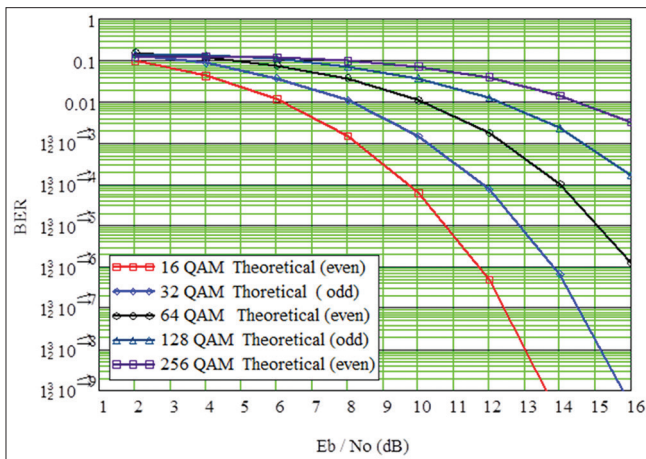


Figure 3: Calculated of BER (from Eqs. (3) to (4)) for different M-ary quadrature amplitude modulation

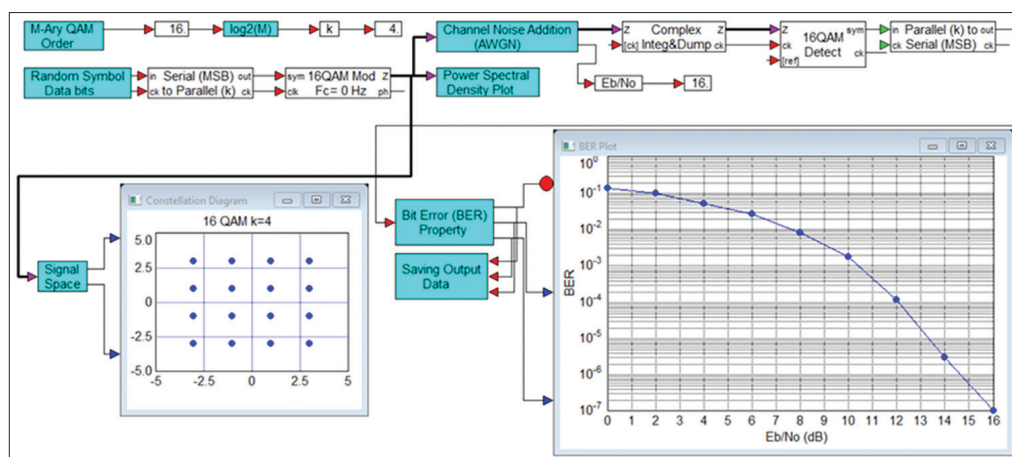


Figure 4: Simulation model of M-ary quadrature amplitude modulation based on VisSim/comm software

using a general equation. The BER and SER are important factors in determining the usefulness of modulation schemes. Here, we discuss how to obtain the theoretical BER for a given QAM constellation using a general equation. The BER is important to factor in determining the usefulness of modulation schemes.

The probability of bit error for M-QAMs is given mathematically in a different manner depending on whether the number of bits per symbol is even or odd. For square

M-QAM, where $k = \log_2(M)$ is even, the P_b can be described as follows:^[10]

$$P_{ev_b} = \frac{2}{\log_2(M)} \left[1 - \frac{1}{\sqrt{M}} \sum_{n=0}^{\frac{\sqrt{M}}{2}-1} \text{erfc} \left[(2n+1) \sqrt{\frac{3 \log_2(M) E_b}{2(M-1) N_0}} \right] \right] \quad (3)$$

$$P_{od_b} = \frac{1}{\log_2(M)} \left[1 - \left[1 - 2 \text{erfc} \left(\sqrt{\frac{3 \log_2(M) E_b N_0}{M-1}} \right) \right]^2 \right] \quad (4)$$

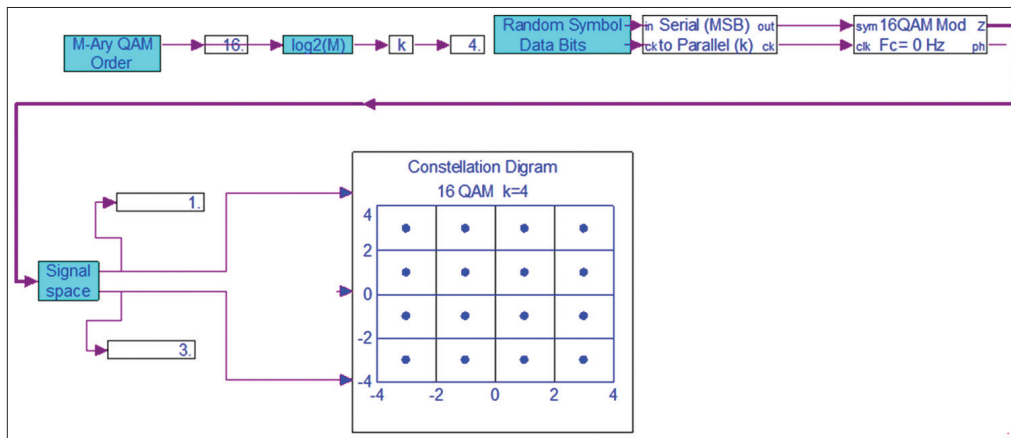


Figure 5: Constellation diagram with VisSim/Comm software (case 8 quadrature amplitude modulation, $k = 4$)

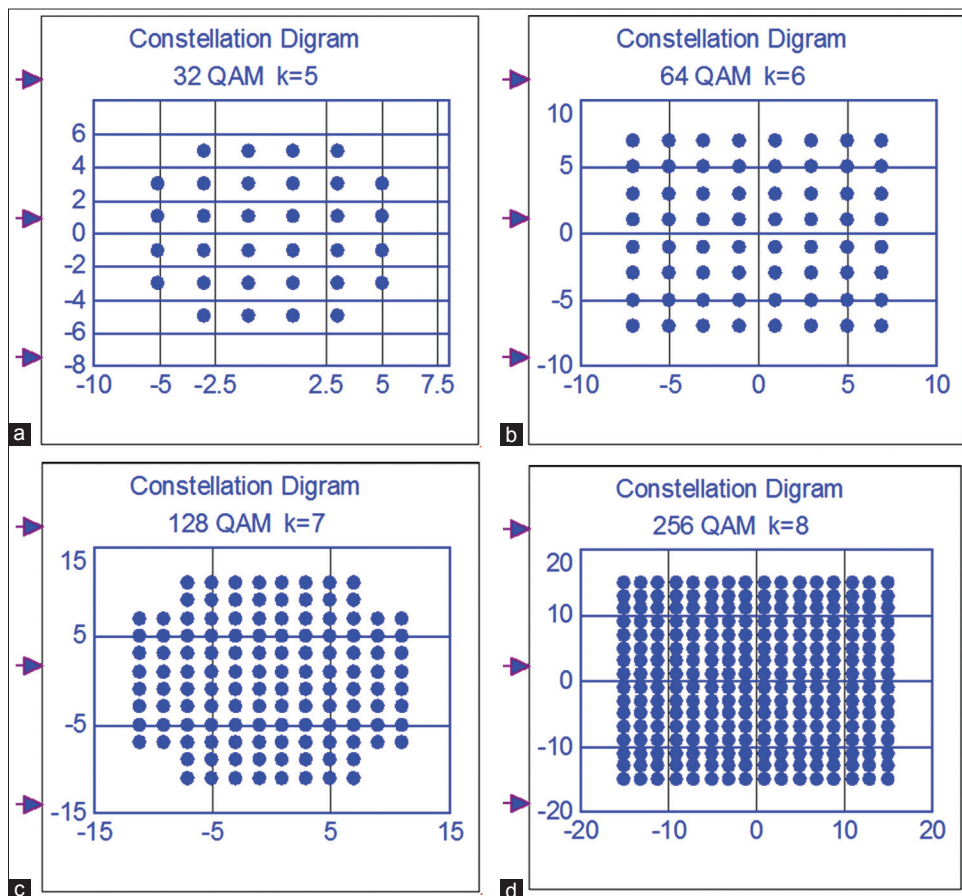


Figure 6: (a-d) Constellation diagrams of different M-ary quadrature amplitude modulation using VisSim/Comm software

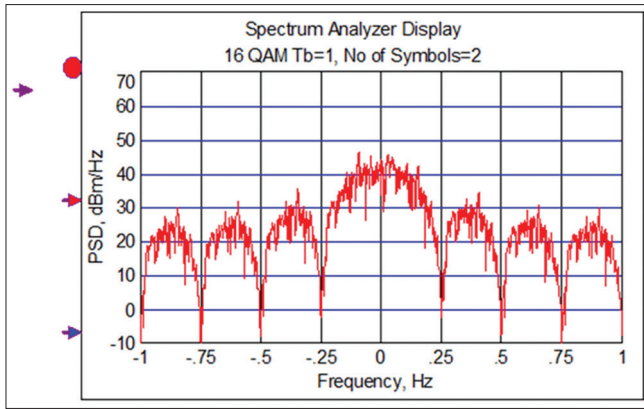


Figure 7: Power spectrum density of 16-quadrature amplitude modulation

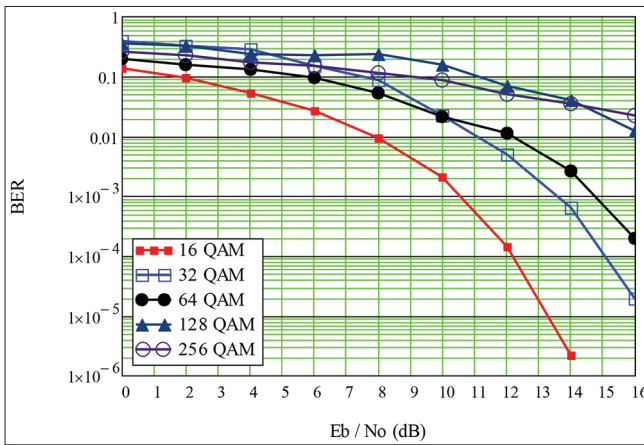


Figure 8: Simulated results of BER using VisSim/comm model

BANDWIDTH EFFICIENCY

In communications, the simple expression $M = 2^k$ is used to relate the symbols to bits. Where M is the number of unique symbols and k is the number of bits transmitter per symbol. Using Shannon’s channel capacity formula, we can calculate the potential capacity of a system using each proposed density of QAM. Shannon’s formula is described as follows:

$$C = B \log_2 \left(1 + \frac{P}{N_0 B} \right) = B \log_2 \left(1 + \frac{S}{N} \right) \text{ [bit/s]} \quad (8)$$

Where C is the channel capacity (bits per seconds).^[2,3] 20 MHz is a commonly allocated bandwidth for channels in 4G cellular communications systems such as long-term evolution-A and WiMAX. Table 1 shows the increase in capacity with respect to each QAM scheme. The Shannon bound can be expressed as bandwidth efficiency,

$$\eta = \log_2 (1 + S/N) \text{ [bit/s/Hz]} \quad (9)$$

The maximum achievable bandwidth efficiency is calculated using Equation (9). The results are shown in Table 1.

M-QAM SIMULATION MODEL

To evaluate the BER performance of M-QAM modulation, a baseband simulation model, using VisSim/Comm software is designed. The model is shown in Figure 4. It allows implementing of comparative BER performance evaluation of M-QAM modulation schemes for different modulation orders (different values of M) over AWGN channel.

M-QAM simulations shown in Figure 3 are capable to plot constellation diagrams as well as the power spectral density of the modulated data, and these are shown in Figures 5-7.

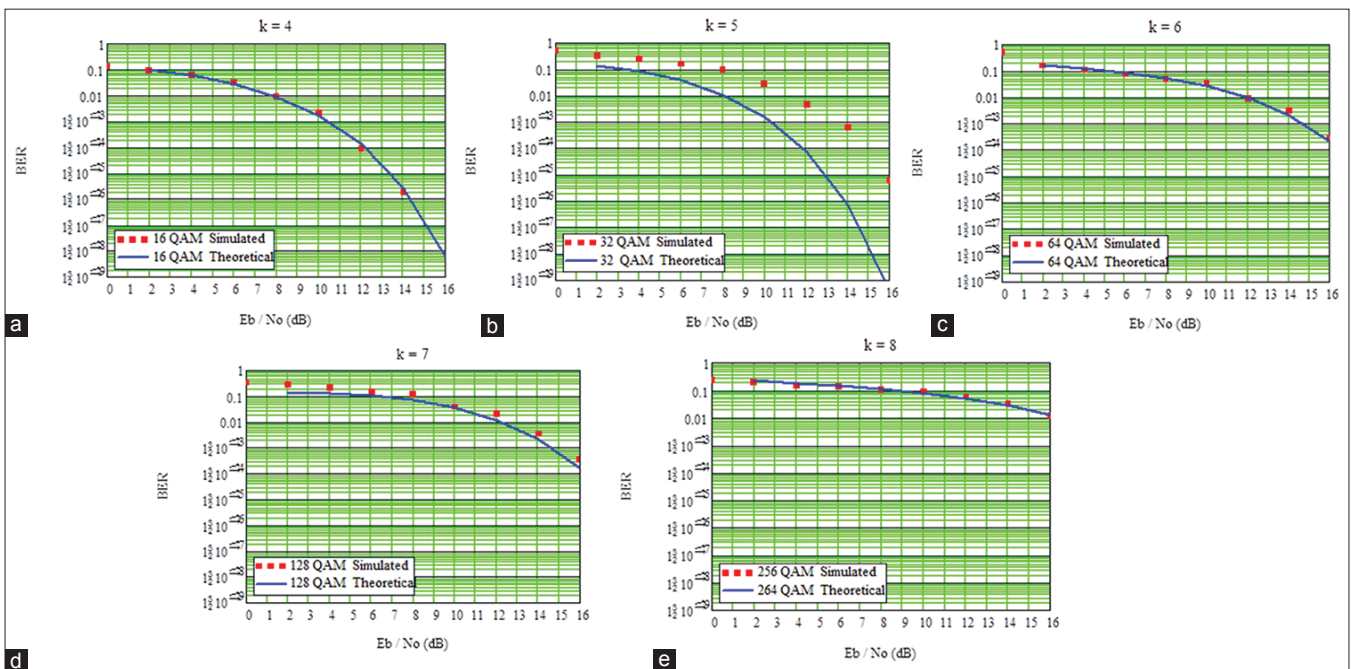


Figure 9: (a-e) Theoretical and simulated M-ary quadrature amplitude modulation for square (even and odd values of k) constellation diagram

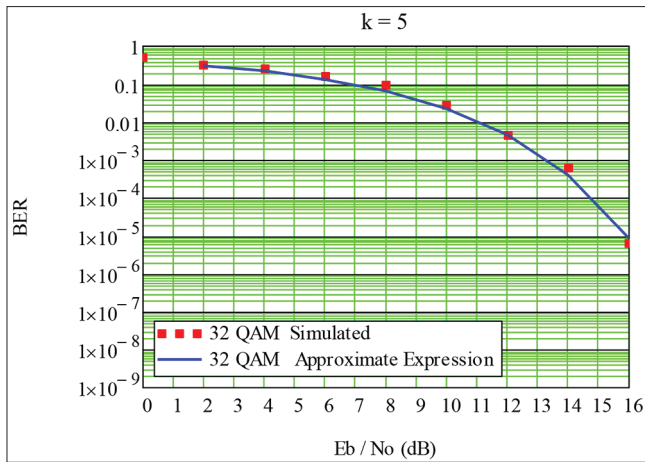


Figure 10: Simulated and approximate expression comparison for 32QAM (odd value of k)

Different M-ary values of QAM are shown in Figure 5.

The simulation of M-QAM is performed for different M orders (16, 32, 64, 128, and 256) using the above VisSim/Comm model. The results of the simulations are shown in Figure 9.

RESULTS AND COMPARATIVE EVALUATION

In this paper, the BER performance of M-QAM ($M = 16, 32, 64, 128, \text{ and } 256$) over AWGN channel is evaluated, applying a theoretical and using VisSim/Comm approach. Figure 9 shows the result of simulation of M-QAM compared with theoretical calculated from Eqs. (3), (4), and (5). Results show very good agreement between simulation and theory except for the case 32 QAM. Fitting method used for the case 32 QAM and this gives an approximate empirical expression shown in Eq. (10). Figure 9 shows a comparison between the simulated and the empirical expression in Eq. (10).

$$P_b = 0.78 \operatorname{erfc} \sqrt{\frac{15}{62} E_b N_0} \quad (10)$$

CONCLUSIONS

In this paper, five M-QAM modulation schemes (16-QAM, 32-QAM, 64-QAM, 128-QAM, and 256-QAM) are studied to find appropriate expressions to calculate and evaluate their BER performances in AWGN channel. A simple simulation model of M-QAM is designed using VisSim/Comm software. This simulation approach is applied to evaluate and compare

the performance of different M-QAM modulation schemes. Theoretical results are compared with the simulation results as well as approximate expression of BER is established for non-square constellation diagram ($M=32$). It is observed that in all cases that the BER decreases when the values of E_b/N_0 are increased. QAM constellations are, in general, sub-optimal in the sense that they do not maximally space the constellation points for a given energy. However, the rectangular QAMs are much easier to modulate and demodulate than other non-rectangular QAMs. However, in terms of energy efficiency, cross QAM is usually the better choice, as it has lesser average and peak energy as compared to rectangular QAM.

Finally, it can be stated that VisSim/Comm software can be successfully used in evaluating the performance not only of M-QAM modulation but also of other digital modulation techniques, such as MPSK, MFSK, MSK, DQPSK, and OQPSK. Evaluate BER data can be helpful for many researchers, in the field of digital modulation techniques, in simplifying the process of passing from simulation to implementation without the necessity of being specialized hardware engineers.

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