

## Simulink-based Simulation of Quadrature Amplitude Modulation (QAM) System

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### Abstract

Adaptive modulation system is one of the key techniques in building a broadband mobile communication network because of increasing shortage of wireless communication channels. Quadrature amplitude modulation (QAM) has been widely used in adaptive modulation because of its efficiency in power and bandwidth. To better understand the QAM system, a Simulink-based simulation system is designed. In the paper, the theory of M-ary QAM and the details of the simulation model are provided. In the simulation model, the parameter settings for random generator, QAM modulation and demodulation, AWGN wireless channel are provided. Error rates of QAM system versus the signal-to-noise ratio (SNR) are used to evaluate the QAM system for adaptive modulation. The model can be used not only for the criteria for adaptive modulation but also for a platform to design other modulation systems.

### Introduction

With the fast development of modern communication techniques, the demand for reliable high data rate transmission is increased significantly, which stimulate much interest in modulation techniques. Different modulation techniques allow you to send different bits per symbol and thus achieve different throughputs or efficiencies. QAM is one of widely used modulation techniques because of its efficiency in power and bandwidth. In QAM system, two amplitude-modulated (AM) signals are combined into a single channel, thereby doubling the effective bandwidth. However, it must also be noted that when using a modulation technique such as 64-QAM, better signal-to-noise ratios (SNRs) are needed to overcome any interference and maintain a certain bit error ratio (BER).

The use of adaptive modulation can increase the transmission rate considerable by matching modulation schemes to time varying channel conditions, which justifies its popularity for future high-rate wireless applications. Crucial to adaptive modulation is the requirement of channel state information at the transmitter. In figure 1, a general estimate of the channel state information for different modulation techniques is provided. As you increase your range, you step down to lower modulations (in other words, QPSK), but as you are closer you can utilize higher order modulations like QAM for increased throughput. In addition, adaptive modulation allows the system to overcome fading and other interference.

Both QAM and QPSK are modulation techniques used in IEEE 802.11 (Wi-Fi), IEEE 802.16

(WiMAX), and 3G (WCDMA/HSDPA) wireless technologies. The modulated signals are then demodulated at the receiver where the original digital message can be recovered. The use of adaptive modulation allows wireless technologies to optimize throughput, yielding higher throughputs while also covering long distances.

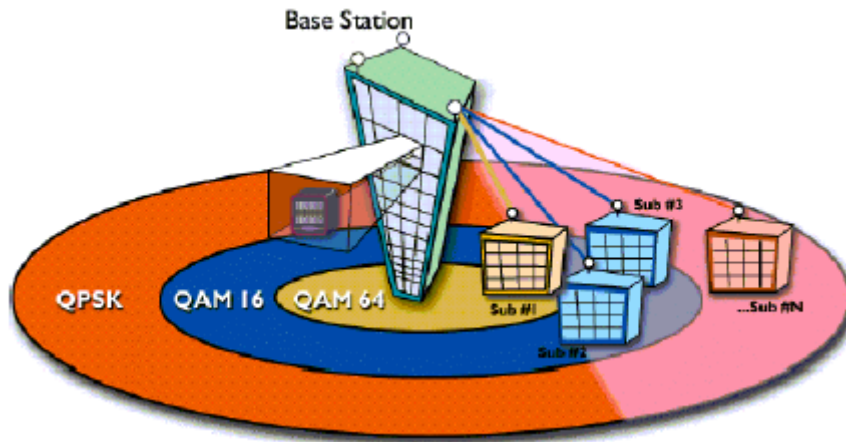


Figure 1: Adaptive Modulation and Coding [1]

To better understand the QAM system, a MATLAB/Simulink-based simulation system is designed in this paper. In the simulation model, the parameter settings for random generator, QAM modulation and demodulation, AWGN wireless channel are provided. Error rates of QAM systems versus the SNR are used to evaluate the QAM system for adaptive modulation. The model can be used not only for the criteria of adaptive modulation but also for a platform to simulate other modulation techniques.

### M-ary QAM

Modern modulation techniques exploit the fact that digital baseband data may be sent by varying both envelope and phase/frequency of a carrier wave. Because the envelope and phase offer two degrees of freedom, such modulation techniques map baseband data into four or more possible carrier signals. Such modulation techniques are called M-ary modulation, since they can represent more signals than if just the amplitude or phase were varied alone.

In an M-ary signaling scheme, two or more bits are grouped together to form symbols and one of  $M$  possible signals is transmitted during each symbol period. Usually, the number of possible signals is  $M = 2^n$ , where  $n$  is an integer. Depending on whether the amplitude, phase, or frequency is varied, the modulation technique is called M-ary ASK, M-ary PSK, or M-ary FSK. Modulation which alters both amplitude and phase is M-ary QAM.

As with many digital modulation techniques, the constellation diagram is a useful representation. It provides a graphical representation of the complex envelop of each possible symbol state. The constellation diagram of 16-QAM is shown in Figure 2. The constellation

consists of a square lattice of signal points. The general form of an M-ary signal can be defined as [2]

$$S_i(t) = \sqrt{\frac{2E_{\min}}{T_s}} a_i \cos(2\pi f_0 t) + \sqrt{\frac{2E_{\min}}{T_s}} b_i \sin(2\pi f_0 t) \quad 0 \leq t \leq T_s \quad i = 1, 2, \dots, M, \quad (2)$$

Where  $E_{\min}$  is the energy of the signal with the lowest amplitude,  $a_i$  and  $b_i$  are a pair of independent integers chosen according to the location of the particular signal point;  $f_0$  is the carrier frequency;  $T_s$  is the symbol period.

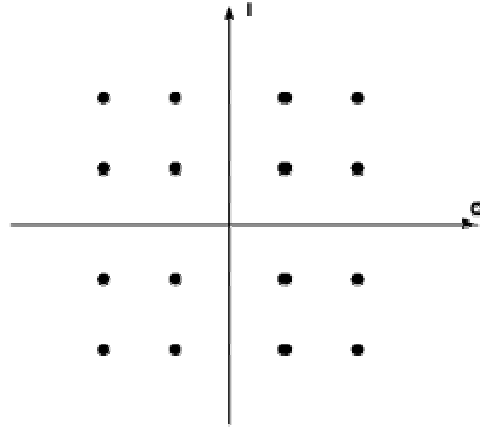


Figure 2: 16-QAM Constellation Diagram

If rectangular pulse shapes are assumed, the signal  $S_i(t)$  may be expanded in terms of a pair of basis functions defines as

$$\phi_1(t) = \sqrt{\frac{2}{T_s}} \cos(2\pi f_0 t) \quad 0 \leq t \leq T_s. \quad (3)$$

$$\phi_2(t) = \sqrt{\frac{2}{T_s}} \sin(2\pi f_0 t) \quad 0 \leq t \leq T_s. \quad (4)$$

The coordinates of the  $i$ th message points are  $a_i \sqrt{E_{\min}}$  and  $b_i \sqrt{E_{\min}}$  where  $(a_i, b_i)$  is an element of the  $L$  by  $L$  matrix given by

$$[(a_i, b_i)] = \begin{bmatrix} (-L+1, L-1) & (-L+3, L-1) & \cdots & (L-1, L-1) \\ (-L+1, L-3) & (-L+3, L-3) & \cdots & (L-1, L-3) \\ \vdots & \vdots & \vdots & \vdots \\ (-L+1, -L+1) & (-L+3, -L+1) & \cdots & (L-1, -L+1) \end{bmatrix}, \quad (5)$$

Where  $L = \sqrt{M}$

It can be shown that the average probability of error in an AWGN channel for M-ary QAM, using coherent detection, can be approximated by [3]

$$P_e \cong 4 \left(1 - \frac{1}{M}\right) Q \left( \sqrt{\frac{3E_{av}}{(M-1)N_0}} \right), \quad (6)$$

Where  $E_{av} / N_0$  is the average signal to noise ratio.

### M-ary QAM Simulation Model

Simulink, developed by The MathWorks, is an environment for multidomain simulation and Model-Based Design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that let you design, simulate, implement, and test a variety of time-varying systems, including communications, controls, signal processing, video processing, and image processing.

With Simulink, you build models by dragging and dropping blocks from the library browser onto the graphical editor and connecting them with lines that establish mathematical relationships between blocks. You can set up simulation parameters by double clicking the blocks.

The modulation library in Communication Blockset of Simulink contains four sublibraries: digital baseband modulation, analog baseband modulation, digital passband modulation, and analog passband modulation. For a given modulation technique, two ways to simulate modulation techniques are called baseband and passband. Passband simulation requires higher sample rate since it contains the carrier wave. Baseband simulation, also known as the lowpass equivalent method, requires less computation. Because baseband simulation is more prevalent, this paper focuses on baseband simulation.

The baseband simulation model of M-ary QAM is given in Figure 3. The parameter settings for each block are given in tables 1 to 4.

Table 1: Parameter Setting for General QAM Modulator/Demodulator

Parameter	Value
Signal constellation	Coordinates of signal points in constellation diagram (row by row)
Samples per symbol	1

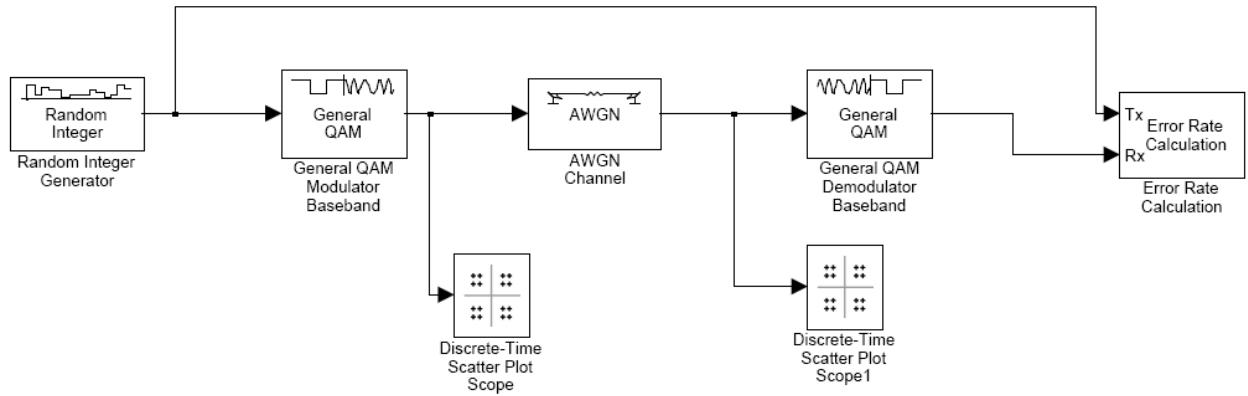


Figure 3: QAM Simulation Model

Table 2: Parameter Setting for Random Integer

Parameter	Value
M-ary number	$M = 2^n$ , $n$ is an integer
Initial seed	Any positive integer
Sample time	1/symbol rate
Frame-based output	Unchecked
Interpret Vector parameters as 1-D	Unchecked

Table 3: Parameter Setting for AWGN Channel

Parameter	Value
Initial see	Any positive integer
Mode	SNR
$E_s / N_0$ (dB)	Constant or variable
Input signal power (watts)	1
Symbol period	1/symbol rate

Table 4: Parameter Setting for Error Rate Calculation

Parameter	Value
Receive delay	0
Computation delay	0
Computation mode	Entire frame
Output data	Workspace
Variable name	Name of a variable

Given different signal constellation in table 1, this simulation model can be used to simulate different order of M-ary QAM system. In order to compare the performance of different modulation techniques, SNR (dB) in table 3 is set as a variable. Write a .m file to get the error probability versus SNR for each order of QAM technique.

### Simulation Results

4-QAM, 16-QAM, and 64-QAM techniques are simulated in this paper. The symbol rate is 10 baud/second. According to Equation 5, the constellation diagram is given by  $[-3+3*i - 1+3*i \ 1+3*i \ 3+3*i \ -3+1*i \ -1+1*i \ 1+1*i \ 3+1*i \ -3-1*i \ -1-1*i \ 1-1*i \ 3-1*i \ -3-3*i \ -1-3*i \ 1-3*i \ 3-3*i]$ . Connect the blocks as in the Figure 3. Before you run the simulation, you need to choose the Simulation parameters: set Stop time to 2000.

In order to get the performance of QAM techniques under different channel conditions, a .m file is needed. The simulation results are shown in Figure 4.

```
M = 16;
X = 0:0.5:10;
Err_vec = [];

for i=1:length(X);
    SNR = X(i);
    Sim('QAM_16');
    err_vec(i) = Error_QAM16(1);
end
```

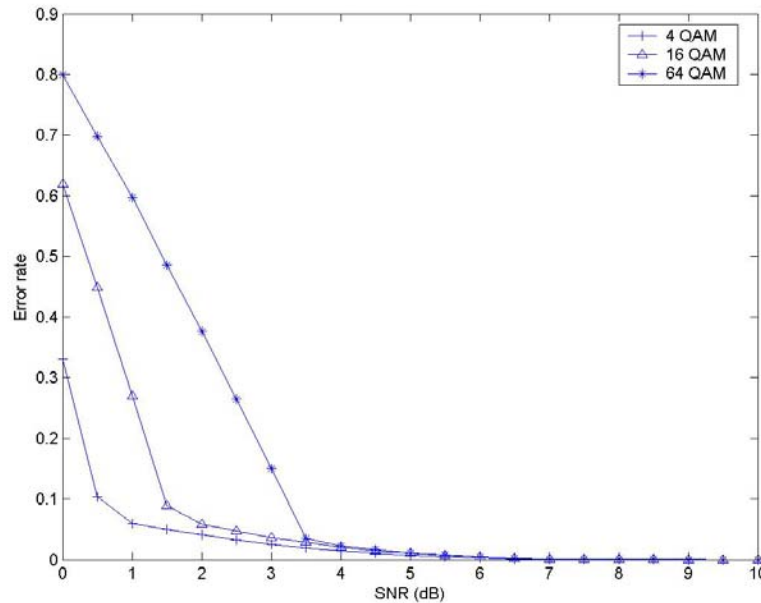


Figure 4: QAM Error Rate versus SNR (dB)

From the simulation results in Figure 4, we can find that the error rates are increased with the order of QAM techniques. This is because the symbol points get closer as the order of QAM increase if the transmission power is constant. However, higher order of QAM technique can increase the transmission rate. This is the tradeoff between reliability and efficiency in the communication system.

The simulation model can not only be used for QAM system, it can also be used for other digital modulation techniques, such as M-PSK, DQPSK, etc. The MPSK simulation model is shown in the Figure 5.

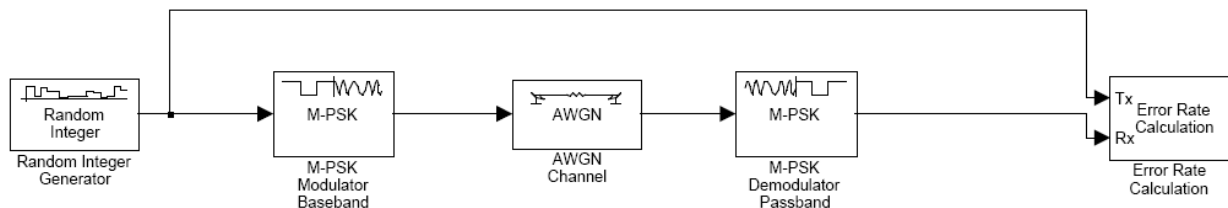


Figure 5: MPSK Simulation Model

## Conclusions

MATLAB/Simulink is a very powerful tool that can be used for simulation in communication, control, DSP, etc. This paper builds a simple simulation model to illustrate the QAM techniques and how the Communication Blockset of the Simulink allow you to implement it. The simulation model verified the theory of QAM and can be used not only for the criteria for adaptive modulation but also for a platform to design other modulation systems.

## References

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## Biography

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