Sirte University Scientific Journal (Applied Sciences) Vol.11(2), Dec 2021

Design, Implementation and Improvement of 16QAM System

Mohammed Elmahdi[1], Algaddafi Alpotte[2], Otman Imrayed[3],El-Sharif A. Omer[4]
m.abusaleem@su.edu.ly

Abstract

In this paper, we will establish a communication model that simulates AWGN and Rayleigh Fading channel using QAM scheme. The first part includes the generation of 16QAM and makes a comparison between the theoretical and simulation results. The second part includes the coding of the QAM signal using the Hamming (15,11,1) system with AWGN and makes a comparison between the theoretical and simulation results. In the third part, we pass the uncoded QAM signal through a fading channel. The fourth part considers the coded 16QAM system with AWGN and Rayleigh fading. Finally, we design an interleaver for the system in order to improve the coding performance.

Key Words: *16QAM System, Hamming code (15,11,1), Rayleigh fading, Interleaver*

1. Introduction

Quadrature amplitude modulation (QAM) is a modulation scheme which conveys data by changing the amplitude of two carrier waves which is a method of combining two amplitude-modulated (AM) signals into a single channel, thereby doubling the effective bandwidth. QAM is used with pulse amplitude modulation (PAM) in digital systems, especially in wireless applications[1].

QAM signal is composed of two carriers, each one has the same frequency but they have phase difference of 90 degrees. This represents a quarter of cycle. The first signal is called I_signal while the second one is called Q_Signal. These carriers are combined at the transmitter side. At the receiver side, the carriers are separated, the data is extracted from each, and then the data is combined into the original modulating information [2]. To detect and correct errors, Hamming code is used. Hamming codes are a family of linear error-correcting codes. They can detect up to two and correct up to one bit errors. Furthermore, they achieve the highest possible rate for codes with their block length. [3].

To improve the overall system performance, we use the interleaver. Interleaving is a method of reading and writing the data out of sequence and a significant part of many digital communication systems involving forward error correction (FEC) coding. Interleaving the encoded symbols provides a form of time diversity to guard against localized corruption or bursts of errors[4].

2. Uncoded 16qam System

Figure 1 below shows the block diagram of designed system. First, we have input bits generator to generate our data. Then, these bits are divided into a matrix of four rows. After that, the output of the mapper goes into a channel where Additive White Gaussian Noise is added to the signal. The signal plus noise are delivered to the detector. Finally the initial input and the output of the detector are fed into the comparator.

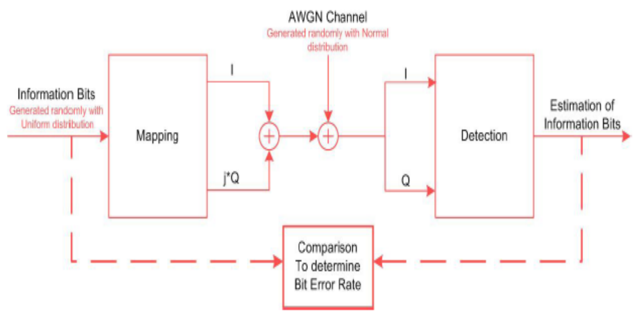

Figure 1-Based band model for uncoded system.

The form of two transmitted modulated signals can be explained by the following equation:

$$s(t) = I(t)\cos(2\pi f_o t) + Q(t)\sin(2\pi f_o t) \qquad (1)$$

Therefore, the probability of bit error, (where M = L^2) is given by:

$$P_B = \frac{2\,(1-L^{-1})}{\log_2 L}\, Q\left(\sqrt{\left(\frac{3\log_2 L}{L^2-1}\right)\frac{2E_b}{N_o}}\right) \qquad (2)$$

Where: L is the length, E_b is the bit energy and N_o is the noise spectral density.

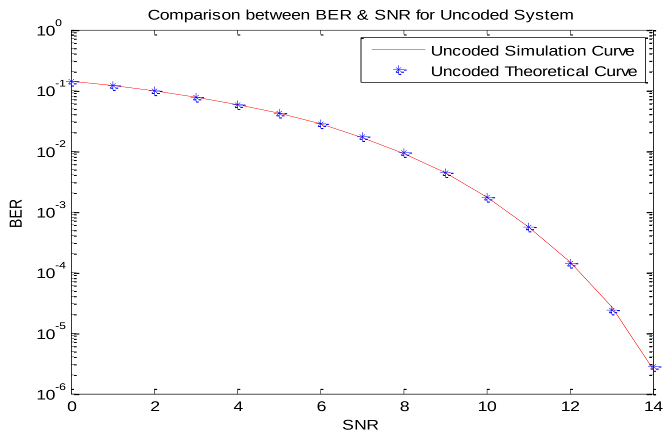

Figure 2-Uncoded 16QAM simulation and theoretical parts.

From Figure 2, the theoretical and simulation curves are almost the same. There is a little difference because the number of bits in the input data is insufficient .this will make difference between the theoretical and simulation results. Therefore, by increasing the input data bits, the simulation results will be close to the theoretical results.

3. Coded 16QAM System

The coded system block diagram is the same as the uncoded system design, but we add two additional blocks which are the Encoder, before the Mapper and the Decoder after the Detector.

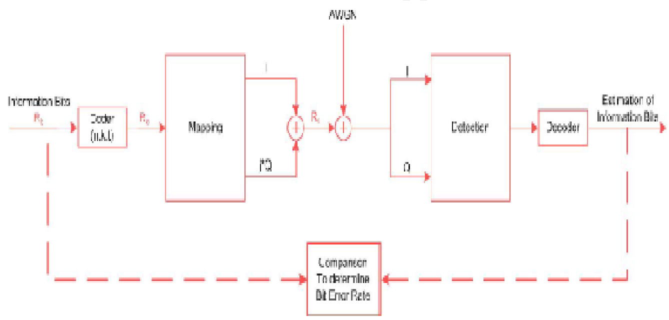

Figure 3- Base band model for coded system.

The hamming code (15,11,1) is used as the coding channel of the system except σ^2 = (n/k)*(N0/2) , where n = 15 and k = 11.
The channel Bit Error Probability of the Uncoded 16QAM system is called here P_c is giving by:

$$P_c = \frac{3}{4}\, Q\left(\sqrt{\frac{4E_b}{5N_o}}\right) \qquad (3)$$

The formula of the Theoretical bit error rate is giving by:

$$P_b = \frac{1}{n}\sum_{j=t+1}^{n} j \binom{n}{j} P_c^{j}\,(1-P_c)^{n-j} \qquad (4)$$

Where, t = 1, n = 15 and k = 11.

In our simulation the input data bits are divided into N/11 messages of 11 bits each. In the encoder, the generator matrix is generated using the parity check Matrix.
We know that:

$$G_{sys} = [P \,\vdots\, I_k] \quad \text{And} \quad H = [I_{n-k} \mid P^T]$$

Thus, the generator matrix can be written as:

$$G_{sys} = \begin{bmatrix} 1&1&1&1&1&0&0&0&0&0&0&0&0&0&0 \\ 0&1&1&1&0&1&0&0&0&0&0&0&0&0&0 \\ 1&0&1&1&0&0&1&0&0&0&0&0&0&0&0 \\ 1&1&0&1&0&0&0&1&0&0&0&0&0&0&0 \\ 1&1&1&0&0&0&0&0&1&0&0&0&0&0&0 \\ 0&0&1&1&0&0&0&0&0&1&0&0&0&0&0 \\ 0&1&0&1&0&0&0&0&0&0&1&0&0&0&0 \\ 0&1&1&0&0&0&0&0&0&0&0&1&0&0&0 \\ 1&0&1&0&0&0&0&0&0&0&0&0&1&0&0 \\ 1&0&0&1&0&0&0&0&0&0&0&0&0&1&0 \\ 1&1&0&0&0&0&0&0&0&0&0&0&0&0&1 \end{bmatrix}$$

The N/11 11-bit messages are encoded to N/11 15-bit codeword's as following:
U = mG, where G is the generator matrix and m is the N/(11*11) message matrix. The output of the Encoder enters to the mapper, the noise and the demapper as in the uncoded design and the output of the demapper enters to a decoder instead of going directly to the comparator.
Second, As explained above Eb/No = SNR, now instead of Eb we have Ec = (k/n)Eb = (11/15)Eb. So, now we have (11/15)Eb/No = SNR, and therefor:
No = 15/(SNR*11) = $(15/11)10^{-SNR/10}$.
After that, in the decoder we will generate the syndrome matrix S, $S = rH^T$, where r is the output of the channel noise and H^T is the transpose matrix of the parity check matrix H.
$2^{n-k} = 2^4 = 16 \geq [1+ C_n^1 + \ldots + C_n^t]$, we end up having t (detection capability) = 1.
The detecting capability t = 1. So, it is possible to generate the matrix error pattern E that maintains the zero error patterns and the 1 bit error pattern, thus we end with error pattern of 16 rows.
Now we can generate the look up table which is equal to EH^T that contains 16 rows of 15-bit error pattern. The corresponding Error vector e is found by searching the lookup table of each syndrome generated previously.
After finding e, we add it to the received signal vector r. as a result we get a matrix of r + e. The received signal is added to its corresponding error vector.
Finally, the output of the decoder is entered to the comparator where it is compared with the 11 bit message inputs. The comparison is done by using the XOR function. Bit error rate is then averaged out and sketched versus Eb/No.

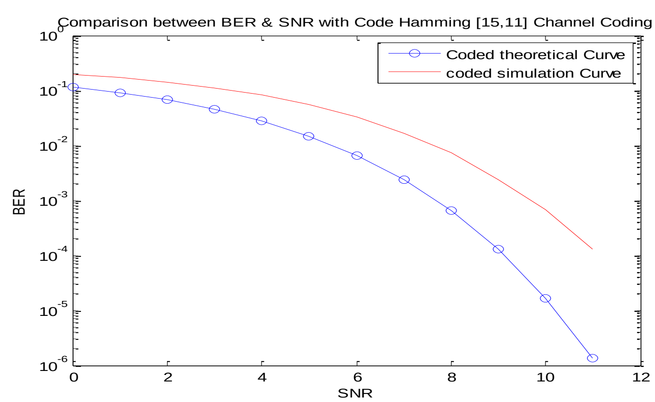

Figure 4-Coded 16QAM simulation and theoretical parts.

From Figure 4, there is a slightly difference between the Theoretical and Simulation curves. The theoretical curve is above the simulation curve. The differences appear because of the number of bits in the input data is insufficient. So, when the number of the bits in the input data is increased, the simulation result will approach to the theoretical results.

4. 16QAM System with Fading

In this section, we will consider the fading channel that is caused by Doppler spread. The type of fading is evaluated by calculating of Tc “Coherence time” and Ts “symbol period” and compares them.

We have T_s =2µs, and to find T_c we need to find f_m “Doppler spread”.

$f_m = (V \times f_c)/C$. Now we have to find T_c by using: $T_c=0.423/f_m$. $T_c = 900$µs.

By comparing T_c and T_s, we find that: $T_s \ll T_c$ which means we have slow fading in the channel and the channel will change after each T_c sec or after each 450 bits ($T_c/T_s = 450$).

The common way to introduce this fading effect is to use Rayleigh distribution.

The probability density function of Rayleigh distribution is given by:

$$P_r(r) = \frac{2r}{\sigma^2} e^{-\frac{r^2}{\sigma^2}}, r \geq 0 \qquad (5)$$

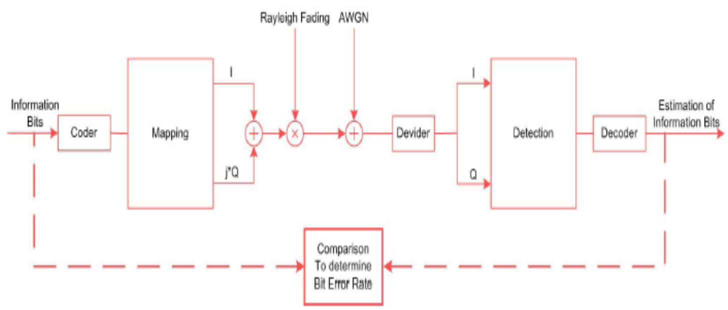

Figure 5- Base band model for fading.

The simulation for both Coded and Uncoded systems with fading was repeated in the same way and we need to simulate large number of bits to get a good result. To make the simulation faster the generation of input and all followed steps are done for blocks of data “each 450 bits is one block”.

In the start we take 450 bits as one block in a way that each bit is formed from real and imaginary part **I**+j**Q**. After that, we generate two Rayleigh random values and represent it by complex number $\mathbf{R_I}$+j$\mathbf{R_Q}$**.** Next we multiply the input signal “**I**+j**Q”** with the Rayleigh complex number “$\mathbf{R_I}$+j$\mathbf{R_Q}$**”**. After that, two random Noises with power density N_o was generated and placed in form of complex number as $\mathbf{N_I}$+j$\mathbf{N_Q}$, to represent the effect of AWGN for each symbol and add them to the output. Then, at the receiver we divide received signal by the same Rayleigh complex number. After that we reinsert each 450 block of bits in a matrix of one row, so we get a matrix of one row after fading is complete. Finally, the output enters to the comparator where it is compared with the inputs. The average of the bit error rate is calculated and sketched versus E_b/N_o.

The simulation for the Uncoded and Coded Systems are given in the following figures:

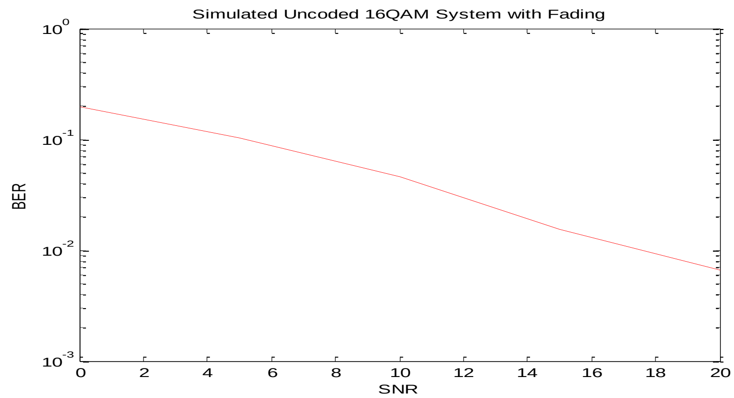

Figure 6-Uncoded 16QAM system with fading.

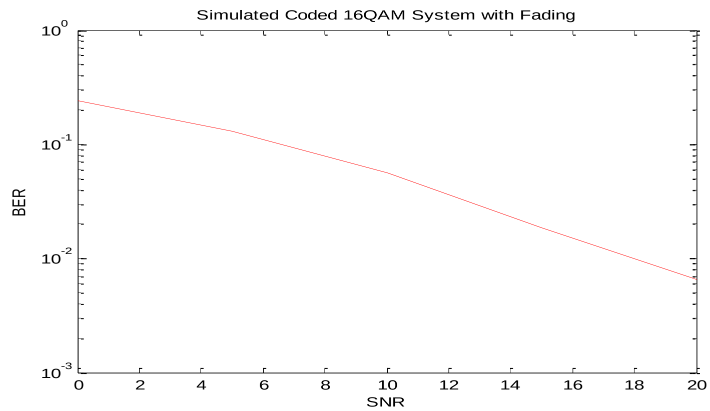

Figure 7-Coded 16QAM system with fading.

From Figure 6 and Figure 7 we observe that the performance of the coded system is worse than uncoded system because, all the bits of one codeword face the same fading coefficient. In the case of the deep fading, all of the codeword are corrupted while (15,11,1) BCH code can correct only 1 bits error in each 15 bits. So, this code would add even more errors and the performance gets worse.

5. 16 QAM Coded System with Interleaver

Interleaving is the rearrangement of data that is to be send so that consecutive bits of data are distributed over a larger sequence of data to decrease the effect of burst errors [5]. The use of interleaving increases the ability of error protection codes to correct for burst errors[6].
If a burst error happens, too many errors can be made in one code word, and that codeword cannot be correctly decoded. To decrease the effect of burst errors, the bits of a number of codewords are

interleaved before being transmitted [7]. In that way, a burst error affects only a correctable number of bits in each codeword, and the decoder can decode the codewords correctly.

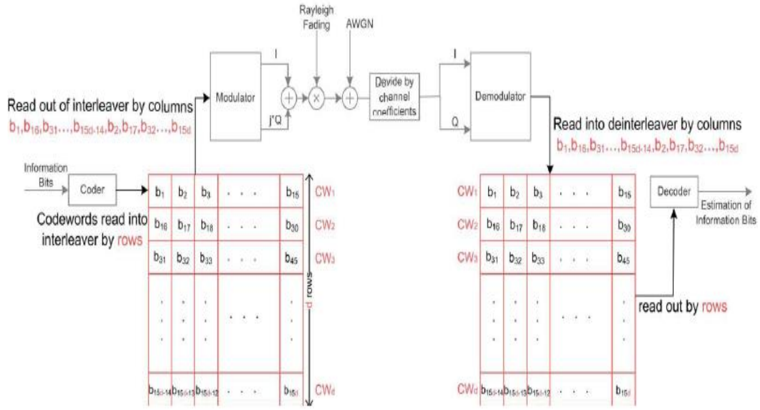

Figure 8-Base band model for interleaver

In this part of the system , the only difference from the part of the coded with fading system is the data which is a matrix of n/11 with 15 bits will be read by columns instead of reading it by rows . After the demodulator, the data will be read by columns and the result will be the same matrix of n/11 rows and 15 columns. The output enters into the comparator where it is compared with the inputs using the XOR function. The average bit error rate is then calculated and sketched versus E_b/N_o.

The simulation of the coded system with fading and interleaving part of the MATLAB code is given by the following figure:

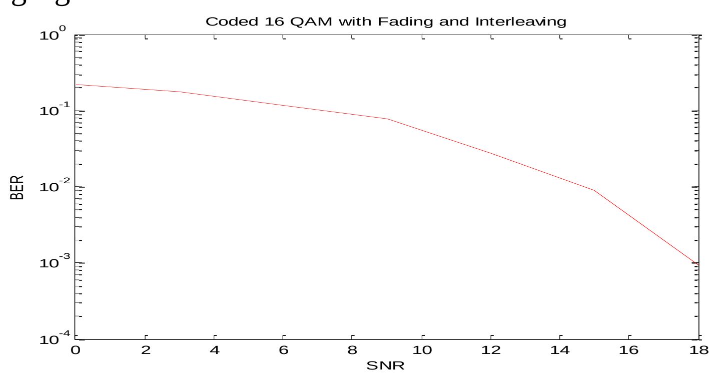

Figure 9-Coded 16QAM system with fading and interleaver.

6. Conclusion

After comparing the Uncoded and the coded systems, we found that, the BER versus E_b/N_0 of the coded system is better than the uncoded system due to two reasons. The first one, BER of the coded system is better than the uncoded one for the same SNR. The second one, by reducing the SNR to improve the reliability of the coding system we get a better result. So, we can conclude that the coding system is better than the uncoded one.
In the case of comparing between the faded and unfaded for both coded and uncoded system we found that, due to slow fading in the channel the signal goes under large distortion. In normal case to achieve probity of specific bit error, we need SNR to be much smaller than the needed SNR in the case of slow fading. But to increase SNR to achieve the required performance is not a practical solution. There are number of methods to solve the fading problem such as using OFDM system, equalization filters and space-time codes.

While comparing the fading in the uncoded and coded system we observe that the performance of the coded system is worse than Uncoded system because, all the bits of one codeword face the same fading coefficient. In the case of the deep fading, all of the codeword are corrupted while (15,11,1) BCH code can correct only 1 bits error in each 15 bits. So, this code would add even more errors and the performance gets worse.
From the simulation part and the theoretical part in both uncoded and code system we observe that, there is slightly difference between the theoretical and simulation curves. The theoretical curve is above the simulation curve. The differences appear because of the number of bits in the input data is insufficient. So, when the number of the bits in the input data is increased, the simulation result will approach to the theoretical results.
Finally, after comparing the entire system with and without interleaver we observe that, the difference between both of them appears because bits in the same codeword experience independently fading due to the greater separation in time compared to the channel coherence time. Also, we observe that if different fading coefficients are applied into different bits within a codeword will give us a good result. By that way there will be more chance that some of them will be degraded less than the others and due to error correcting the codeword can be saved.

7. References

[1] Bernard Sklar, *Digital Communications: Fundamentals and Applications*, 2nd Ed., Prentice Hall, 2001.
[2] Bruce A. Black et al, *Introduction to Wireless Systems*, Prentice Hall, 2008.
[3] S. Haykin, *Communication Systems*, 4th Ed, John Wiley and Sons, 2001
[4] D.M. Motiur Rahaman, “Performance Analysis of Essential Modulation Techniques”, Universal Journal of Communications and Network 1(2): 39-43,2013
[5] M. Trikha, M. Singhal, R. Rajan, N. Sharma and P. Bhardwaj, “BER Performance comparison between QPSK and 4 QA Schemes,” MIT International Journal of Electrical and Instrumentation Engineering, vol. 3, No. 2, pp. 62–66, August 2013.

[6] Islam, Kazi Mohitul, Habib Mohammad Nazir Ahmad, Chowdhury Akram Hossain, and A. K. M. Arifuzzman, "Performance Comparison between Traditional and Gray-mapped 16-QAM Scheme with OFDM in both AWGN and Rayleigh Fading Channel," International Journal (2011).
[7] A K M Arifuzzman, Kazi Mohitul Islam, Chowdhury Akram Hossain, Shaikhul Arefin Khan, Abdul Hasib Siddique, Habib Muhammad Nazir Ahmad, “Performance Comparison Between Traditional and Gray-mapped 16-QAM Scheme in Both AWGN and Rayleigh Fading Channel”, Stamford Journal of Electrical, Electronic and Communication Technology, vol. 1, pp. 75-80, June 2010.