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Performance Evaluation of OFDM using BPSK,QPSK and 16-QAM modulation Techniques

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ABSTRACT— Wireless communication is one of the most popular areas in the communication field today. Development of next generation wireless networks depends on suitable wireless and access techniques. These techniques needs to provide high data rates and should maintain a certain level of robustness against errors. There are numerous challenges to implement these systems. These problems include propagation effects in particular multipath propagation, capacity limits due to spectral availability, the need for asynchronous access, Intersymbol Interference (ISI). Orthogonal Frequency-Division Multiplexing (OFDM) effectively mitigates intersymbol interference caused by the delay spread of wireless channels. Therefore, it has been used in many wireless systems and adopted by various standards. The flexibility of OFDM provides opportunities to use advanced techniques, such as adaptive loading, transmit diversity, and receiver diversity to improve transmission efficiency. This paper investigates the performance of OFDM using different digital modulation techniques which are used for wireless communications over AWGN (Additive White Gaussian noise) and Rayleigh fading Channels. The performance of the different digital modulation techniques is evaluated using Bit Error Rate (BER) versus Signal to Noise Ratio (SNR).

Keywords— Orthogonal Frequency Division Multiplexing (OFDM), Bit Error Rate (BER), Additive White Gaussian Noise (AWGN), Rayleigh Channel, Signal to Noise Ratio (SNR).

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I. INTRODUCTION

Orthogonal Frequency-Division Multiplexing (OFDM) is a special form of multicarrier (MC) that dates back to 1960s. The concept of MC transmission was first explicitly proposed by Chang [1] in 1966. It has seen application in recent years as an approach to the problem of transmitting data over channels which are severely distorted and may suffer from additive or impulsive noise, distorting crosstalk, or multipath fading [2].

The demand for data communications over mobile radio channels has increased steadily over the last few years and will likely continued to grow [3]. Wireless communications has become an emerging and vastly growing field in our modern life and creates enormous impact on nearly every feature of our daily life. A tremendous technological transformation during the previous two decades has provided a potential growth in the field of digital communication and lot of latest applications and technologies are coming up every day due to these valid reasons [9]. The evolution objective of wireless cellular technology from 1G to 4G is capable of delivering high data rate signal so that it can transmit high bit rate multimedia content in cellular mobile communication. Thus, it has driven many researches into the application of higher order modulations

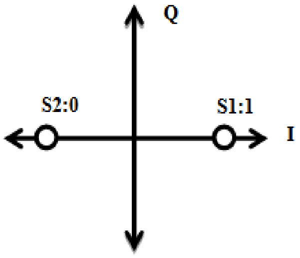
In this paper we investigates the performance of OFDM using different digital modulation techniques which are used for wireless communications over AWGN (Additive White Gaussian noise) and Rayleigh fading Channels. We start with the basic digital modulation techniques in Section II. Then, we address the OFDM techniques in Section III. Next, section IV presents the results and discussions. Finally, we present our conclusions in Section V.

II. DIGITAL MODULATION TECHNIQUES

Wireless communications has become an emerging and vastly growing field in our modern life and creates enormous impact on nearly every feature of our daily life. A tremendous technological transformation during the previous two decades has provided a potential growth in the field of digital communication and lot of latest applications and technologies are coming up every day due to these valid reasons. The evolution objective of wireless cellular technology from 1G to 4G is capable of delivering high data rate signal so that it can transmit high bit rate multimedia content in cellular mobile communication. Thus, it has driven many researches into the application of higher order modulations

A. Binary Phase-Shift Keying (BPSK)

BPSK is the simplest form of phase shift keying. It uses two phases which are separated by 180°. It does not particularly matter exactly where the constellation points are positioned, as in this figure they are shown on the real axis, at 0° and 180°. This modulation is the most robust of all the PSKs since it takes the highest level of noise or distortion to make the demodulator reach an incorrect decision. It is, however, only able to modulate at 1 bit/symbol and so is unsuitable for high data rate applications when bandwidth is limited.



Symbol	Phase in degree
S1	0
S2	90

Fig. 2.1: Constellation diagram for BPSK

The two phases which are separated by 180^0 and can also be termed as 2-PSK. In BPSK, a single carrier is modulated by controlling its polarity according to the binary data signal to be transmitted. The magnitude of the modulated BPSK signal is kept constant, thus increasing the maximum power to be delivered.

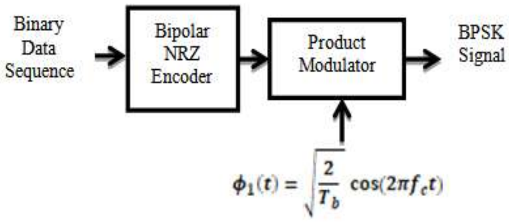
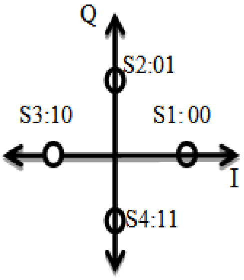


Fig. 2.2: BPSK Modulator

To produce a BPSK signal, the binary sequence in polar form with symbol 1 and 0 are represented by fixed magnitude levels of $+\sqrt{E_b}$ and $-\sqrt{E_b}$respectively. The resulting binary wave in polar form and a sinusoidal carrier $\phi_1(t)$, whose frequency is given by $f_c = \frac{n_c}{T_b}$ for some fixed integer $n_c$are applied to the product modulator. The carrier and timing pulses used to obtain the binary wave are generally extracted from a common master clock. At the output of modulator the desired PSK waveform can be obtained.

B. Quadrature Phase-Shift Keying (QPSK)

QPSK is one example of M-ary PSK modulation technique (M = 4) where it transmits 2 bits per symbol. The phase carrier takes on one of four equally spaced values, such as 0, π/2, π and 3π/2, where each value of phase corresponds to a unique pair of message bits as it is shown in figure 2.3.



Symbol	Phase in degree
S1	0
S2	90
S3	180
S4	270

Fig. 2.3: Constellation diagram for QPSK

Although QPSK can be viewed as a quaternary modulation, it is easier to see it as two independently modulated quadrature carriers. With this interpretation, the even (or odd) bits are used to modulate the in-phase component of the carrier, while the odd (or even) bits are used to modulate the quadrature-phase component of the carrier. BPSK is used on both carriers and they can be independently demodulated. As a result, the probability of bit-error for QPSK is the same as for BPSK:

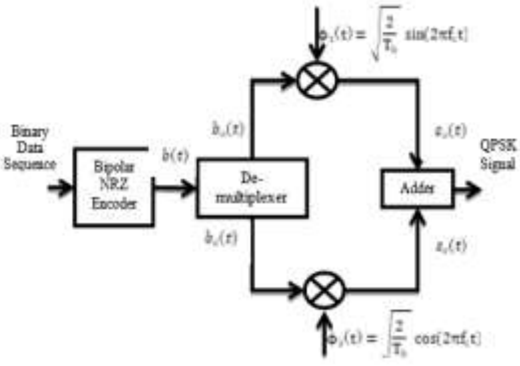


Fig. 2.4: QPSK Modulator

The input binary data sequence is first converted into a bipolar NRZ signal, b(t). The value of b(t)= +1V for a logic 1 input and b(t) = -1V when the binary input is equal to 0. The demultiplexer will divide $b(t)$ into two separate bit streams named $b_o(t)$ and $b_e(t)$. The bit stream $b_e(t)$ consists of only even numbers 2, 4, 6 …and so on whereas the

$b_o(t)$ bit stream consists of only odd numbered bits. Each bit in even and odd bit stream will be held for a period of $2T_b$seconds. This duration is called as symbol duration T_s. This is because every symbol contains two bits. The bit streams $b_e(t)$ is superimposed on a carrier $\phi_2(t)$ and the bit streams $b_o(t)$ is superimposed on a carrier $\phi_1(t)$by means of using two multipliers to generate two signals $s_e(t)$ and $s_o(t)$ respectively. These two signals are basically BPSK signals. The multipliers output is then added together to generate QPSK signal.

C. Quadrature Amplitude Modulation (QAM)

The QAM is a modulation scheme where its amplitude is allowed to vary with phase. This technique can be viewed as a combination of ASK as well as PSK. QAM is widely used in many digital data communication applications , where data rates beyond 8-PSK are needed by a radio communication system then QAM modulation scheme is extensively used because QAM achieves a greater distance between adjacent points in the I-Q plane by distributing the points are more distinct and data errors are reduced. The QAM modulation is more useful and efficient than the others and is almost applicable for all the progressive modems.

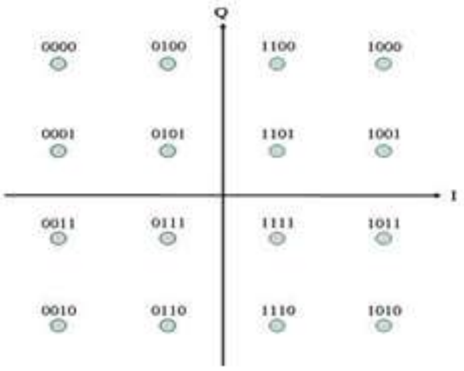


Fig. 3.8: Constellation Diagram For 16-QAM

Theoretically, higher order of M-ary QAM enables data to be transmitted in a much smaller spectrum. However, the symbols are easily subjected to errors due to noise and interference because the symbols are located very closed together in the constellation diagram. Thus such signal has to transmit extra power so that the symbol can be spread out more and this reduces power efficiency as compared to simpler modulation scheme. Also the radio equipment is more complex. However, there is a trade off in employing bandwidth efficient M-QAM modulation scheme. The complexity of the receiver increases linearly with M (number of orthogonal sequences) and exponentially with the number of bits per symbol. The achievable bandwidth efficiency of the system is limited by the maximum possible number of orthogonal sequences and by acceptable complexity of the receiver.

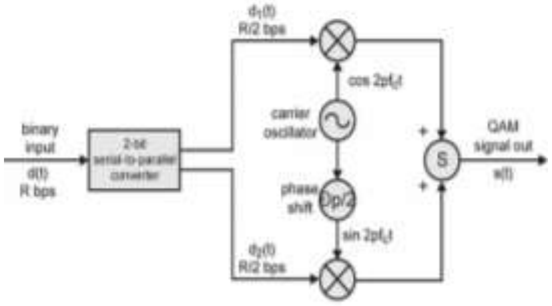


Fig. 2.5: **QAM Modulator**

At QAM transmitter the input signal is first split into two equal parts using ASK. One of them is multiplied with the Cosine function to give the In phase component and other signal is multiplied with Sine function to give the Quadrature component. These two signals are then added to give the final signal as QAM signal.

III. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

High data rate transmission over mobile or wireless channels is required by many applications. However, the symbol duration reduces with the increase of the data rate, and dispersive fading of the wireless channels will cause more severe Intersymbol Interference (ISI) if single-carrier modulation, such as in Time Division Multiple Access (TDMA) or Global System for Mobile Communications (GSM), is still used. To reduce the effect of ISI, the symbol duration must be much larger than the delay spread of wireless channels. In orthogonal frequency-division multiplexing (OFDM), the entire channel is divided into many narrow-band subchannels, which are transmitted in parallel to maintain high-data rate transmission and, at the same time, to increase the symbol duration to combat ISI.

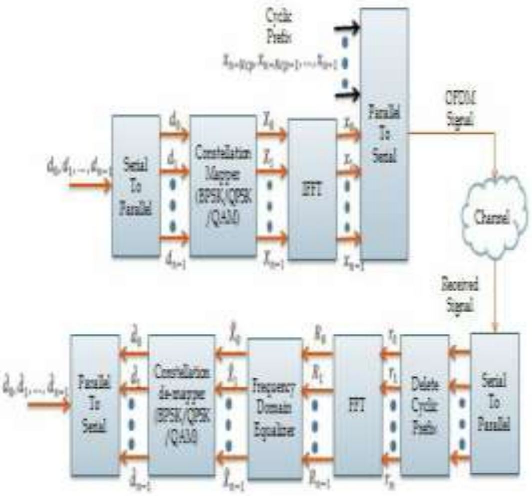


Fig. 3.1: OFDM system

In the fig. 3.1, symbols represented by small case letters are assumed to be in time domain, whereas the symbols represented by uppercase letters are assumed to be in frequency domain. Consider data bits D = {d0, d1, d2,…). Select number of subcarriers required to send the given data. As a generic case, assume N subcarriers. The data (D) is first converted from serial stream to parallel stream depending on the number of sub-carriers (N). Decide digital modulation techniques such as BPSK/ QAM. Apply IFFT algorithm on generated symbols and add cyclic prefix bits. Finally, the resultant output from the N parallel arms are summed up together to produce the OFDM signal. The channel in this case is modeled as a simple AWGN channel. Since the channel is considered to be an AWGN channel, there is no need for the frequency domain equalizer in the OFDM receiver as shown in Fig. 3.1. Reverse the process at the receiver side. Compare the transmitted and received bits to compute bit error rate.

A. Mathematical Expression for OFDM

Let $\{S_{n,k}\}_{k=0}^{N-1}$ with $E|S_{n,k}|^2 = \sigma_s^2$ be the complex symbols to be transmitted at the n^{th} OFDM block, then the OFDM modulated signal can be represented by

$$S_n(t) = \sum_{k=0}^{N-1} S_{n,k}\, e^{j2\pi k\Delta ft}, \quad 0 \le t \le T_s ----(3.1)$$

where Ts, Δf, and N are the symbol duration, the subchannel space, and the number of subchannels of OFDM signals, respectively. For the receiver to demodulate the OFDM signal, the symbol duration should be long enough such that TsΔf =1, which is also called the orthogonal condition since it makes $e^{-j2\pi k\Delta ft}$ orthogonal to each other for different k. With the orthogonal condition, the transmitted symbols $S_{n,k}$ can be detected at the receiver by

$$S_{n,k} = \frac{1}{T_s}\int_0^{T_s} S_n(t)\, e^{-j2\pi k\Delta ft} dt, \quad ----(3.2)$$

if there is no channel distortion. The sampled version of the baseband OFDM signal $S(t)$ in (1) can be expressed as

$$S_n\left(m\frac{T_s}{N}\right) = \sum_{k=0}^{N-1} S_{n,k}\, e^{j2\pi k\Delta fm\frac{T_s}{N}} = \sum_{k=0}^{N-1} S_{n,k}\, e^{j\frac{2\pi mk}{N}} --(3.3)$$

which is actually the Inverse Discrete Fourier Transform (IDFT) of the transmitted symbols $\{S_{n,k}\}_{k=0}^{N-1}$ and can efficiently be calculated by Fast Fourier Transform (FFT). It can easily be seen that demodulation at the receiver can be performed using DFT instead of the integral in (3.2).

A cyclic prefix (CP) or guard interval is critical for OFDM to avoid inter block interference (IBI) caused by the delay spread of wireless channels. They are usually inserted between adjacent OFDM blocks. Fig. 1 shows the function of the CP. Without the CP, the length of the OFDM symbol is Ts. With the CP, the transmitted signal is extended to T = Tg + Ts and can be expressed as

$$\tilde{S}_n(t) = \sum_{k=0}^{N-1} S_{n,k}\, e^{j2\pi k\Delta ft}, \quad -T_g \le t \le T_s \quad ----(3.4)$$

It is obvious that $\tilde{S}_n(t) = S_n(t + T_s) for - T_g \le t \le 0$ which is why it is called the CP. The impulse response of a wireless channel can be expressed by

$$h(t) = \sum_i \gamma_i \delta(t - \tau_i) ----- (3.5)$$

where τ_i and γ_i are the delay and the complex amplitude of the i^{th} path, respectively. Then, the received signal can be expressed as

$$x_n(t) = \sum_i \gamma_i \tilde{S}_n(t - \tau_i) + n(t) ----- (3.6)$$

where $n(t)$ represents the Additive White Gaussian Noise (AWGN) at the receiver. As demonstrated in Fig. 1, $x_n(t)$ consists of only the signal component from the n^{th} OFDM block when $\tau_l \le t \le \tau_u$, where $\tau_l = -Tg + \tau_M$, τ_u = Ts + τ_m, $\tau_m = min_i\{\tau_i\}$, and $\tau_M = max_i\{\tau_i\}$, otherwise, the received signal consists of signals from different OFDM blocks. If $\tau_l \le 0$ and $\tau_u \ge T_s$ then

$$x_{n,k} = \frac{1}{T_s}\int_0^{T_s} x_n(t)\, e^{-j2\pi f_k t} dt = \frac{1}{T_s}\int_0^{T_s}\left(\sum_i \gamma_i \tilde{S}_n(t - \tau_i) + n(t)\right) e^{-j2\pi f_k t} dt = H_k S_{n,k} + n_k --(3.7)$$

for $0 \le k \le N-1$, and all n, where H_k denotes the frequency response of the wireless channel at the k^{th} subchannel and is defined as

$$H_k = \sum_i \gamma_i e^{-j2\pi k\Delta f \tau_i} ------ (3.8)$$

and n_k is the impact of AWGN and is defined as

$$n_k = \frac{1}{T_S}\int_0^{T_S} n(t)\, e^{-j2\pi f_k t} dt ------ (3.9)$$

It can be proved that n_k are independent identically distributed complex circular Gaussian with zero mean and variance σ_n^2 with H_k, transmitted symbols can be estimated. For single carrier systems, the received signal is the convolution of the transmitted sequences or symbols and the impulse response of wireless channels in addition to AWGN, whereas the impact of the channel is only a multiplicative distortion at each subchannel for OFDM systems, which makes signal detection in OFDM systems very simple and is also one of the reasons why OFDM is very popular now a days.

IV. RESULTS AND DISCUSSION

This chapter presents simulation results along with the Bit Error Rate (BER) analysis for AWGN and Rayleigh fading channel. All simulations are performed in MATLAB (R2016a) tool to generate the noise sequence, data sequence, both data and noise sequence and add them together, recover signal from noisy received data and calculate BER and then plot them with different SNR values. Finally the conclusion is presented from simulation results.

Results are simulated for a basic communication system in which the signal is first modulated using BPSK, QPSK and M-QAM modulation techniques respectively. The modulated signal is then passed through AWGN and Rayleigh fading channel respectively prior to being demodulated. Lastly, the BER verses SNR results are estimated and plotted.

A. BER performance for BPSK system in AWGN & Rayleigh fading channel.

Table 4.1: BPSK Simulation Parameters

Parameter	Value
Modulation order	2
Bits per symbol	1
Eb/No values (dB)	-3 to 35
Number of BPSK symbols per frame	1000000

Table 4.1 shows the simulation parameters for BPSK system. It conveys 1 bit per symbol and number of BPSK symbols per frame transmitted are 1000000 with modulation order (M) set as 2

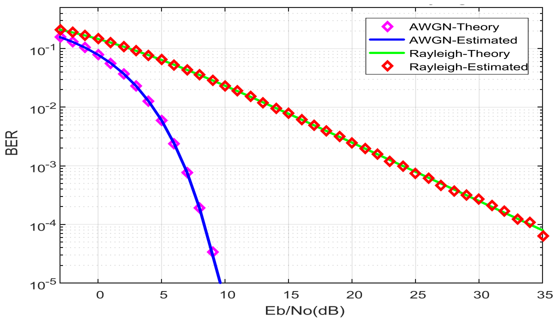


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Fig.4.1: BER performance for BPSK modulation in AWGN & Rayleigh fading channel

Fig.4.1 shows the BER performance analysis for BPSK system over AWGN & Rayleigh fading channels. BPSK has lower BER in AWGN channel compared to Rayleigh fading channel. For example at SNR=5 dB, BER in BPSK for AWGN channel is 0.0059 while for Rayleigh channel is 0.064. It is evident from fig. 4.1 that both theoretical and estimated BER are in good agreement with each other for BPSK over AWGN and Rayleigh fading channels. Also BER of BPSK system in AWGN channel gives good performance as compared to Rayleigh fading Channel.

B. BER performance for QPSK system in AWGN & Rayleigh fading channel

Table 4.2: QPSK Simulation Parameters

Parameter	Value
Modulation order	4
Bits per symbol	2
Eb/No values (dB)	-3 to 35
Number of QPSK symbols per frame	1000000

Table 4.2 shows the simulation parameters for QPSK system. BPSK system conveys 1 bit per symbol while on the other hand QPSK conveys 2 bits per symbol. Thus the number of bits per symbol carried by QPSK system is twice more than that carried by BPSK system.

Fig. 4.2 shows the BER vs SNR performance analysis for QPSK system over AWGN & Rayleigh fading channels. It reveals that BER for AWGN channel needs less signal power than that of Rayleigh fading channel. Fig. 4.2 also shows that both theoretical and estimated BER for AWGN and Rayleigh channels are in good agreement with each other.

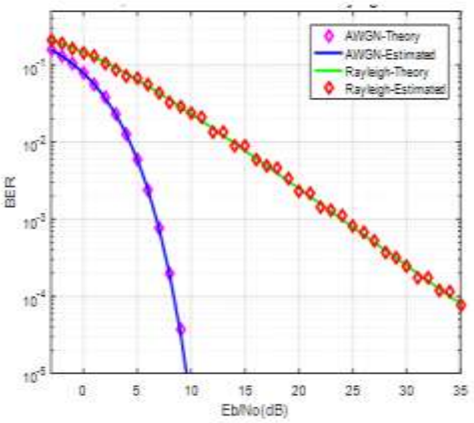

Fig.4.2: BER performance for QPSK modulation in AWGN & Rayleigh fading channel

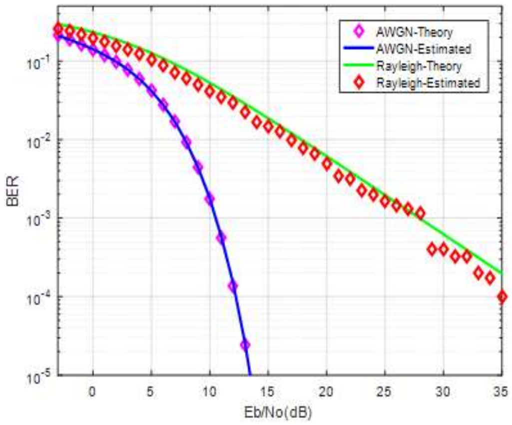

Fig**.4.3:** BER performance for 16-QAM modulation in AWGN & Rayleigh fading channel

C. BER performance for 16-QAM system in AWGN & Rayleigh fading channel

Table 4.3: QAM Simulation Parameters

Parameter	Value
Modulation order	16
Bits per symbol	4
Eb/No values (dB)	-3 to 35
Number of BPSK symbols per frame	1000000

Table 4.3 shows the simulation parameters for 16-QAM system. QPSK system conveys 2 bits per symbol while on the other hand 16-QAM conveys 4 bits per symbol. Thus the number of bits per symbol carried by 16-QAM system is twice more than that carried by QPSK system.

Fig.4.3 shows the BER performance analysis for 16-QAM system over AWGN & Rayleigh fading channels. It shows that as the SNR increases the BER decreases. Also the 16-QAM has lower BER in AWGN channel as compared to BER of Rayleigh fading channel. For example at SNR=10 dB, BER for AWGN channel is 0.0017 while for Rayleigh channel is 0.041.

D. BER performance for BPSK, QPSK and 16-QAM system in AWGN channel

Fig.4.4 shows BER vs. SNR performance analysis of BPSK, QPSK and 16-QAM modulation technique over Additive White Gaussian Noise channels. It is evident from fig 4.4 that for 16-QAM modulation in AWGN channel, estimated BER needs an additional transmitted signal power of 4.5 dB compared to estimated BER of BPSK and QPSK modulation to achieve a BER of 10-4. It is also evident from fig.4.4 that as SNR increases, BER decreases.

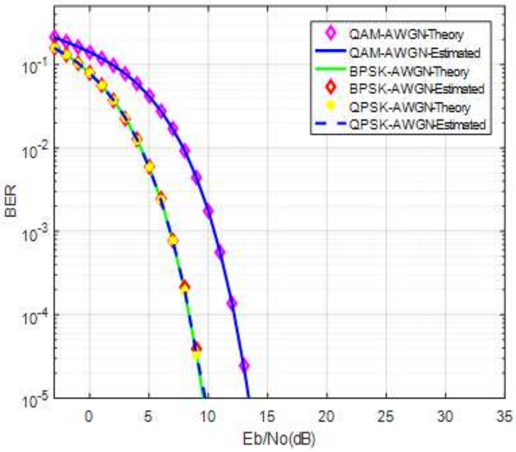

Fig.4.4: BER performance for BPSK, QPSK and 16-QAM modulation in AWGN channel

E. BER performance for BPSK, QPSK and 16-QAM modulation in Rayleigh fading channel

Fig.4.5 shows BER performance analysis of BPSK, QPSK and 16-QAM modulation technique over Rayleigh fading channel. From fig 4.5, it is clear that BPSK and QPSK modulation gives better performance as compared to 16-QAM modulation. Also, both theoretical and estimated BER for BPSK, QPSK and 16-QAM modulation are in good agreement with each other.

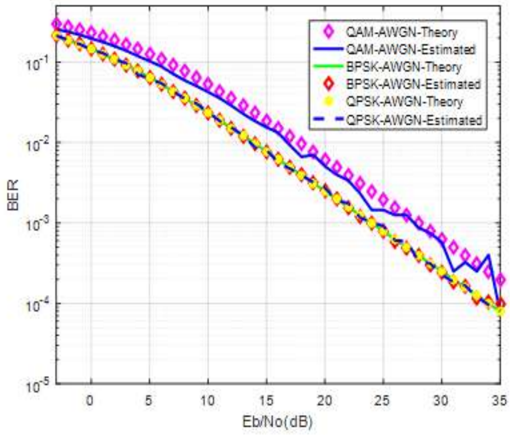

Fig.4.5: BER performance for BPSK, QPSK and 16-QAM modulation in Rayleigh fading channel

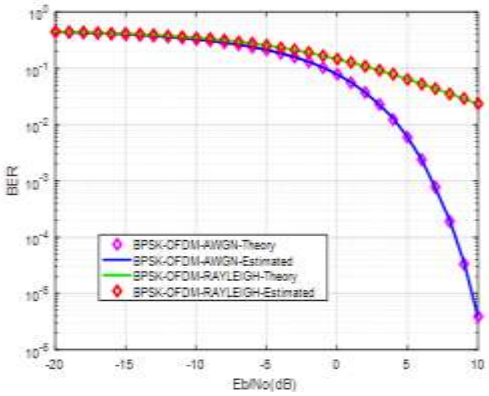

Fig.4.6: BER performance of OFDM using BPSK modulation in AWGN & Rayleigh fading channel

F. BER performance of OFDM system using BPSK modulation in AWGN & Rayleigh fading channel

Table 4.4: OFDM Simulation Parameters

Parameter	Value
FFT size	64
Number of data subcarriers	48
Number of pilot subcarriers	4
Number of OFDM Symbols	10000
OFDM Bandwidth	20MHz
EbNo in dB	-20 to 10
Cyclic prefix length	32

OFDM system is simulated with 10000 OFDM symbols, M modulation level is set to 2, FFT length is set as 64, bandwidth set as 20MHz and cyclic prefix length is set to 32.

Fig.4.6 shows the BER vs SNR performance analysis of OFDM using BPSK modulation in AWGN & Rayleigh fading channel. At SNR = 5 dB, BER for AWGN using BPSK is -2.22 whereas for Rayleigh channel is 0.064. It is clear from fig.4.6 that the BER performance of OFDM system using BPSK modulation in AWGN channel is better than Rayleigh fading channel. Also from graph it is evident that as the SNR increases the BER decreases for both the channels.

G. BER performance of OFDM system using QPSK modulation in AWGN & Rayleigh fading channel

Fig.4.7 shows the BER vs SNR performance analysis of OFDM using QPSK modulation over AWGN & Rayleigh fading channels. QPSK has lower BER in AWGN channel as compared to BER of Rayleigh fading channel. For example at SNR=5 dB, BER for AWGN channel is 0.0059 while for Rayleigh channel is 0.1913. It is clear from fig. 4.7 that both theoretical and estimated

BER for AWGN & Rayleigh fading channels are in good agreement with each other.

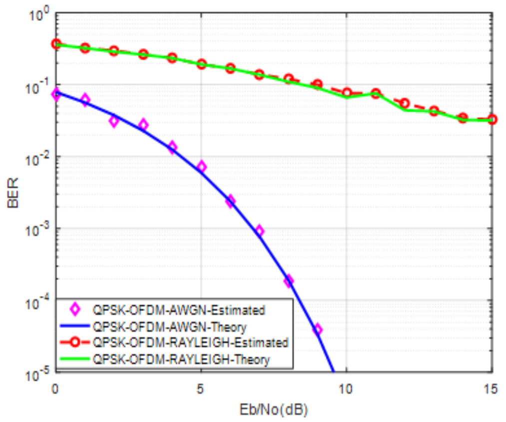

Fig. 4.7: BER performance of OFDM using QPSK modulation in AWGN & Rayleigh fading channel

H. BER performance of OFDM system using 16-QAM modulation in AWGN & Rayleigh fading channel

Fig.4.8 shows the BER vs SNR performance analysis of OFDM using 16-QAM modulation over AWGN & Rayleigh fading channels. 16-QAM has lower BER in AWGN channel as compared to BER of Rayleigh fading channel. For example at SNR=10 dB, BER for AWGN channel is 0.0017 while for Rayleigh channel is 0.062. It is clear from fig. 4.8 that both theoretical and estimated BER for AWGN & Rayleigh fading channels are in good agreement with each other for the channels. Also for both the channels as the SNR increases the BER decreases.

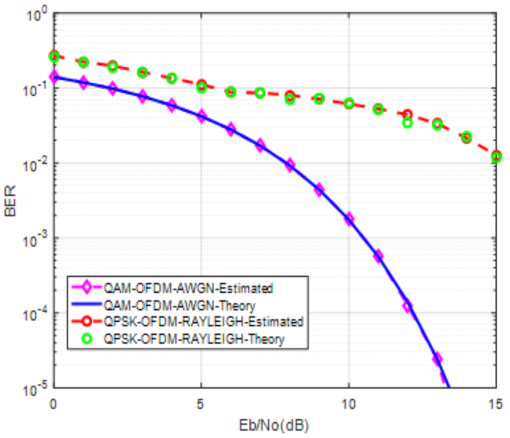

Fig. 4.8: BER performance of OFDM using 16-QAM modulation in AWGN & Rayleigh fading channel

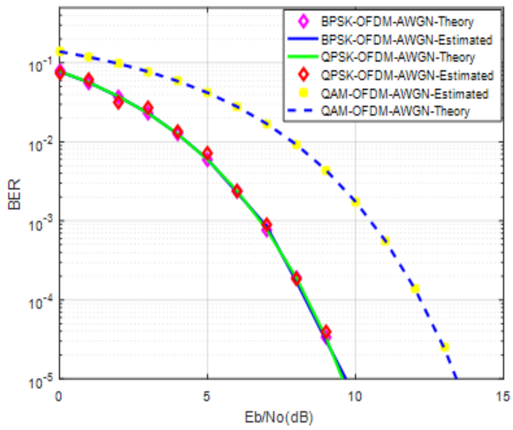

Fig.4.9: BER performance of OFDM using BPSK, QPSK and 16-QAM modulation in AWGN channel

I. BER performance of OFDM system using BPSK, QPSK and 16-QAM modulation in AWGN channel

Fig.4.9 shows that for 16-QAM modulation in AWGN channel, estimated BER needs an additional transmitted signal power of 4.5 dB compared to estimated BER of BPSK and QPSK modulation to achieve a BER of 10-4. It is also evident from fig.4.9 that as SNR increases, BER decreases.

J. BER performance of OFDM system using BPSK, QPSK and 16-QAM modulation in Rayleigh Fading channel

Fig.4.10 shows the BER vs SNR performance analysis of OFDM using BPSK, QPSK and 16-QAM modulation over Rayleigh Fading channel. BER performance of BPSK is better as compared to QPSK and 16-QAM. It is also evident from fig. 4.10 that as SNR increases BER decreases for BPSK, QPSK and 16-QAM modulations over Rayleigh fading channel.

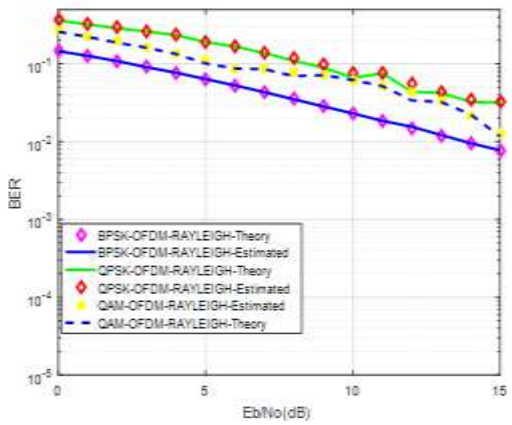

Fig. 4.10: BER performance of OFDM using BPSK, QPSK and 16-QAM modulation in Rayleigh Fading channel

V. CONCLUSIONS

The wireless channel is susceptible to a variety of transmission obstacles such as noise, fading, path loss, interference, and blockage. These factors restrict the range and the reliability of the wireless transmission.

In this paper we have studied and compared the performance of BPSK, QPSK, QAM and OFDM using BPSK, QPSK and QAM modulation techniques under AWGN and Rayleigh fading channels. To compare different modulation techniques efficiencies it is important to calculate BER at different SNR.

Our results showed that the choice of modulation techniques plays a critical role in system performance. An examination of the three modulation techniques quickly reveals the added complexity each new method introduces.

From the outcome of the simulation results, conclusions are as follows:

1. It is clear from the simulation results obtained in fig. 4.1 to 4.10 that the performance of BPSK and QPSK is better than 16-QAM because the BER values with respect to SNR (in dB) in case of BPSK and QPSK are lower than the values obtained in the case of 16-QAM for AWGN and Rayleigh fading channels..
2. The spectral width of 16-QAM is more than that of BPSK and QPSK. Therefore 16-QAM can carry more traffic as compared to BPSK and QPSK but at the expense of poor performance in BER over AWGN and Rayleigh fading channels.
3. For BPSK, QPSK, 16-QAM systems and OFDM using BPSK, QPSK and 16-QAM modulation techniques over AWGN and Rayleigh fading channels it is evident from the fig. 4.1 to 4.10 that as the value of SNR increases the value BER decreases. So, we can reduce errors by increasing SNR.
4. For OFDM system, from fig.4.9 and fig. 4.10 we conclude that the BER performance of OFDM using BPSK and QPSK modulation techniques is better than that of 16-QAM modulation over AWGN and Rayleigh fading channels.
5. We observed from the results that we can choose best modulation schemes to obtain optimum performance of the system based on needs, to obtain greater data rate we can choose higher modulation schemes and to have very less loss of data we can use lower modulation schemes.
6. The BPSK has an overall better performance as compared to QPSK & 16-QAM techniques. That means lower order of modulation techniques is better to use in communication system if spectral efficiency is not taken in an account.
7. Finally, it is evident from fig.4.1 to 4.10 that theoretical and estimated values of BER are in good agreement with each other.

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