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Comparison of BER for Various Digital Modulation Schemes in OFDM System

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***Abstract*— In this paper, an OFDM system model is developed for various digital modulation techniques BPSK, QPSK, 8QAM, 16QAM, 32QAM, 64QAM, 128QAM, 256 QAM and 512QAM using simulation in Matrix laboratory language (MATLAB) on which BER calculations is carried out. The OFDM signal was transmitted over the AWGN channel for various signal-to-noise ratio (SNR) values. To evaluate the performance, for each SNR level, the received signal was demodulated and the received data was compared to the original information. The result of the simulation is shown in the plot of the bit error rate versus E_b /N_o, which provides information about the system's performance. The convolution coding and interleaving is applied to improve BER performance of OFDM system.**

***Index Terms*— BER, convolution coding, digital modulation, OFDM, SNR**

I. Introduction

OFDM is a combination of modulation and multiplexing. In OFDM, multiplexing is applied to the independent signals but these independent signals are a subset of the one main signal. In OFDM the signal itself is first split into independent channels, modulated by data and then multiplexed to create the OFDM carrier. OFDM is a special case of Frequency Division Multiplexing (FDM) [2,3].

II. OFDM System

To implement the OFDM transmission scheme, the whole design is divided into three sections –Transmitter, Channel and Receiver as shown in fig. 1.In the transmitter, binary input data sequence is taken. Forward Error-Correction Coding (FEC) and interleaving is done to provide frequency diversity. The information is typically FEC encoded and interleaved prior to modulation. The sequence is encoded by a convolutional encoder. Then Interleaving is applied to randomize the occurrence of bit errors prior to increase performance. The symbol is modulated onto subcarriers by applying the Inverse Fast Fourier Transform (IFFT). The output is converted to serial and a cyclic extension is added to make the system robust to multipath propagation. In channel, additive white Gaussian noise characteristics are taken. The receiver performs the reverse operations of the transmitter. After removing the cyclic extension, the signal can be applied to a Fast Fourier Transform to recover the modulated values of all subcarriers. The modulated values are then demapped into binary values, and finally deinterleaving and Viterbi decoder decodes the information bits.

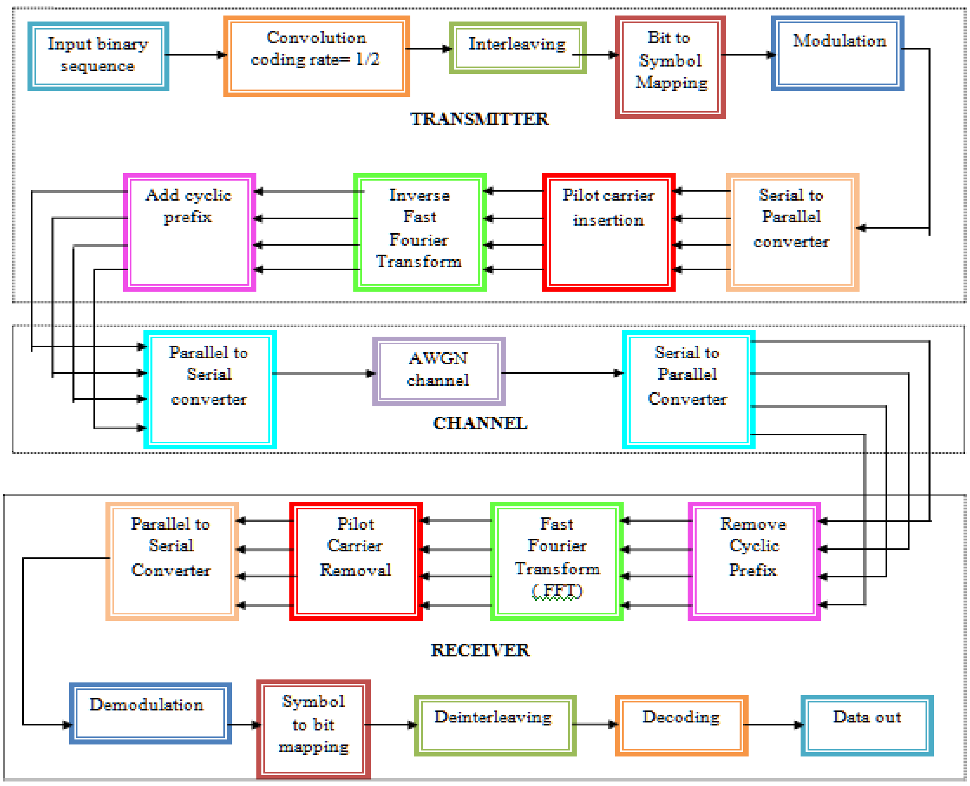

Fig. 1: Block Diagram of OFDM system

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III. Digital Modulation Techniques

Modulation is the process of varying one or more properties of a high frequency periodic waveform, called the carrier signal, with respect to a modulating signal. In digital modulation, an analog carrier signal is modulated by a digital bit stream. Digital modulation methods can be considered as digital-to-analog conversion, and the corresponding demodulation or detection as analog-to-digital conversion.

A Phase Shift Keying (PSK)

The phase shift of a sinusoidal carrier is switched from one value to the other value corresponding to the change over from "0" to "1" or from "1" to "0" in the digital data. The error probability is quite low and noise immunity is high.

1) BPSK

BPSK is the simplest form of phase shift keying (PSK). It uses two phases which are separated by 180° and so can also be termed 2-PSK. 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.

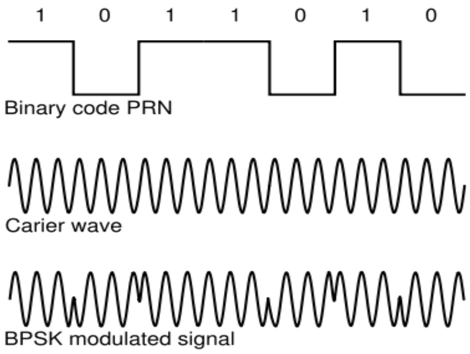

Fig. 2: Phase modulation of binary signal on the carrier wave with BPSK [2]

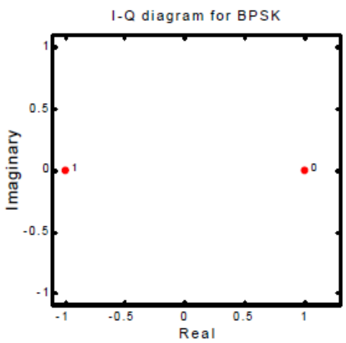

Fig. 3: Constellation diagram of BPSK [3]

2) QPSK

With four phases, QPSK can encode two bits per symbol, shown in the diagram with Gray coding to minimize the BER, twice the rate of BPSK. Analysis shows that this may be used either to double the data rate compared to a BPSK system while maintaining the bandwidth of the signal or to maintain the data-rate of BPSK but halve the bandwidth needed.

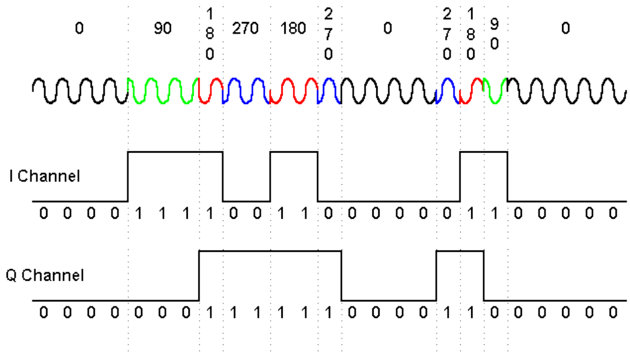

Fig. 4: Phase modulation of binary signal on the carrier wave with QPSK [2]

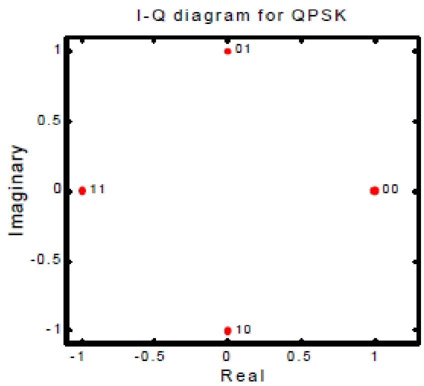

Fig. 5: Constellation diagram of QPSK [3]

B Quadrature Amplitude Modulation

The ability of a receiver to distinguish between one signal vectors from another in presence of noise depends on the distance between the vector end points. So the noise immunity will improve if the signal vectors differ not only in phase, but also in amplitude. Such a system is called as amplitude and phase shift keying system. In this system the direct modulation of carriers in quadrature is involved, therefore this system is called as quadrature amplitude phase shift keying (QASK). It is used in OFDM because of its multilevel nature and high bit rate. QAM is used extensively as a modulation scheme for digital telecommunication systems. QAM is more susceptible to noise because the states are closer together so that a lower level of noise is needed to move the signal to a different decision point. Receivers for use with phase or frequency modulation are both able to use limiting amplifiers that are able to remove any amplitude noise and thereby improve the noise reliance. When a phase or frequency modulated signal is amplified in a transmitter; there is no need to use linear amplifiers, whereas using QAM contains an amplitude component, linearity must be maintained.

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1) 8 QAM

The Table I provide the bit sequences, and the associated amplitude and phase states of 8 QAM. From this it can be seen that a continuous bit stream may be grouped into threes and represented as a sequence of eight permissible states.

Table I: Bit sequences, amplitudes and phases for 8 QAM

Bit sequence	Amplitude	Phase (degrees)
000	1/2	0 (0˚)
000	1	0 (0˚)
010	1/2	pi/2 (90˚)
011	1	pi/2 (90˚)
100	1/2	pi (180˚)
101	1	pi (180˚)
110	1/2	3pi/2 (270˚)
111	1	3pi/2 (270˚)

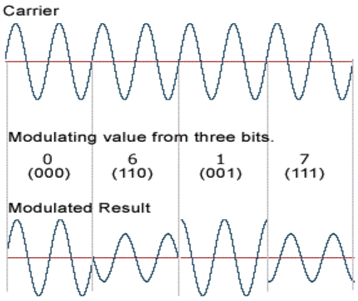

Fig. 6: 8 QAM modulation of binary signal on the carrier wave [2]

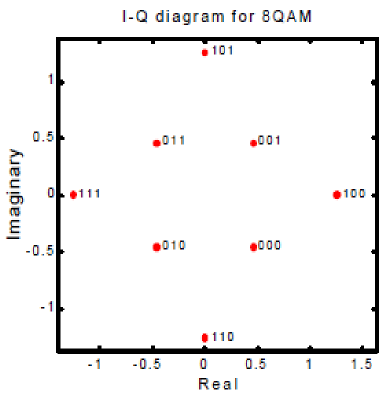

Fig. 7: Constellation diagram of 8 QAM [3]

2) 16 QAM

In 16 QAM, the grouping of 4 bits is done together to form a symbol. 4 different phases and 4 different amplitudes are used for a total of 16 different symbols. This means such a ding is able to transmit 4bps.

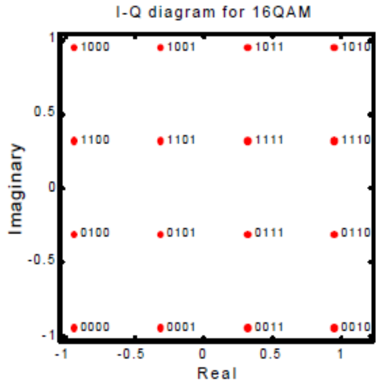

Fig. 8: Constellation diagram of 16 QAM [3]

3) 32 QAM

In 32 QAM, the grouping of 5 bits is done together to form a symbol. Total 32 different symbols are used

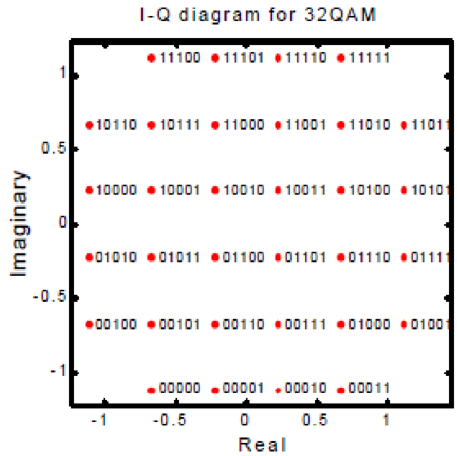

Fig. 9: Constellation diagram of 32 QAM [3]

4) 64 QAM

In 64 QAM, the grouping of 6 bits is done together to form a symbol. Total 64 different symbols are used

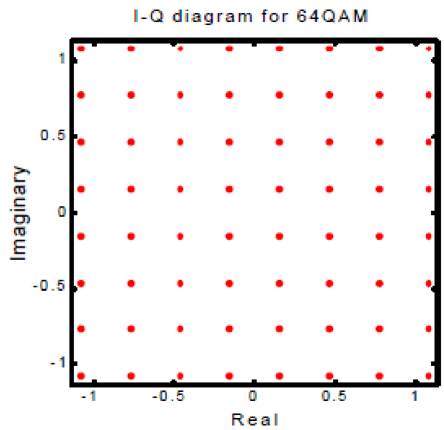

Fig. 10: Constellation diagram of 64 QAM [3]

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5) 128 QAM

In 128 QAM, the grouping of 7 bits is done together to form a symbol. Total 128 different symbols are used.

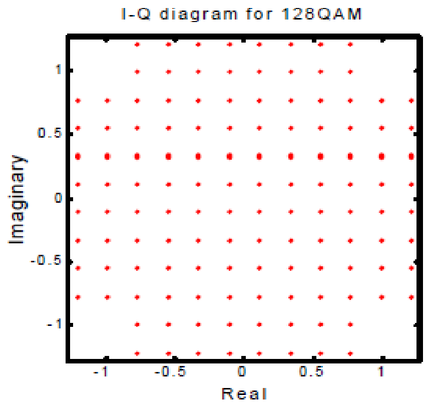

Fig. 11: Constellation diagram of 128 QAM [3]

6) 256 QAM

In 256 QAM, the grouping of 8 bits is done together to form a symbol. Total 256 different symbols are used

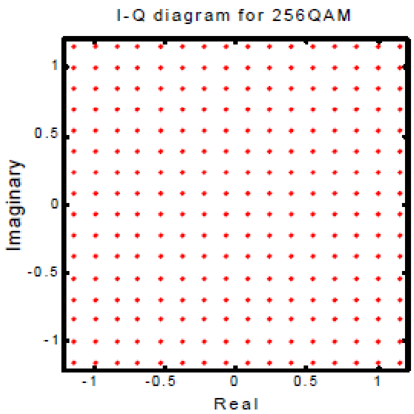

Fig. 12: Constellation diagram of 256 QAM [3]

7) 512 QAM

In 512 QAM, the grouping of 8 bits is done together to form a symbol. Total 512 different symbols are used

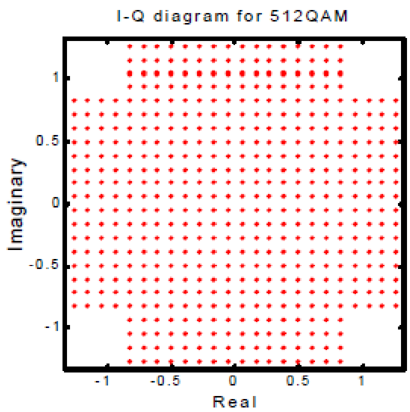

Fig. 13: Constellation diagram of 512 QAM [3]

Table II: Mode and number of bits per symbol of modulation techniques

Modulation Technique	**M** Mode of modulation technique	**K** Number of bits per symbol
BPSK	2	1
QPSK	4	2
8 QAM	8	3
16 QAM	16	4
32 QAM	32	5
64 QAM	64	6
128 QAM	128	7
256 QAM	256	8
512 QAM	512	9

Table III: Theoretical BER of PSK, QAM

Theoretical BER of PSK technique
$\frac{1}{k} * erfc\left[\sqrt{\left(\frac{E_b}{N_0} * k\right)} * \sin(\pi/M)\right]$
Theoretical BER of QAM technique
$\frac{2}{k} * \left[1 - \frac{1}{\sqrt{M}}\right] * erfc\left[\sqrt{\left(3 * \frac{E_b}{N_0} * k * \frac{1}{2 * (M-1)}\right)}\right]$

M = mode of digital modulation technique

k = number of bits per symbol in digital modulation

III. Simulation Results

The simulations are performed on following standardparameters as shown in table IV.

Table IV: Parameters consider in simulation

Parameters	**Values**
Number of OFDM symbols	10000
Total data	260000
Number of bits per OFDM symbol	26
Number of data sub-carriers	26
Number of data sub-carriers after coding	52
Number of FFT points	64
Cyclic prefix	16 (1/4)
OFDM symbol	80 (64 +16)
Modulation scheme	BPSK, QPSK, 8QAM, 16QAM, 32QAM, 64QAM, 128QAM, 256QAM, 512QAM
Coding	Convolutional, code rate ½, constraint length 7, generator polynomial [171, 133]

A Bit error rate curve for BPSK in OFDM

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The Simulated Plots between BER and E_b/N_o for BPSK in OFDM system is shown in Fig.14.From Table V,it is observed that for BPSK, on fixing BER between 10^{-4} and 10^{-5} the simulated E_b/N_o (db) is 1.4 to 2 and theoretical E_b/N_o (db) is 8.4 to 9.6, which indicates the BER for simulated model is better than theoretical model for noisy channel. So the simulated model works better in noisy channel. Simulated model does not allow the BER between 10^{-1} and 10^{-2}, even at worst channel condition i.e. for E_b/N_o (db) of 0 to 2 db.

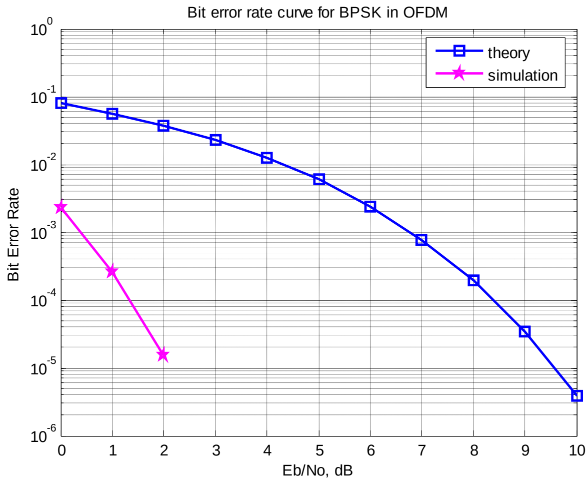

Fig. 14: Demonstrates plot of Bit error rate against E_b/N_o for BPSK

Table V: Comparison of simulated E_b/N_o (db) with theoretical E_b/N_o (db) to maintain BERlevel for BPSK

BER	Simulated E_b/N_o (db)	Theoretical E_b/N_o(db)
10^{-1}-10^{-2}	-----	0-4
10^{-2}-10^{-3}	0-0.4	4-6.8
10^{-3}-10^{-4}	0.4-1.4	6.8-8.4
10^{-4}-10^{-5}	1.4-2	8.4-9.6

B Bit error rate curve for QPSK in OFDM

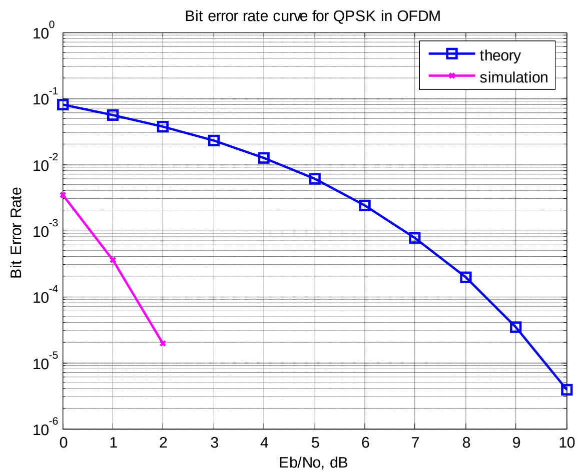

Fig. 15: Demonstrates plot of Bit error rate against E_b/N_o for QPSK

Table VI: Comparison of simulated E_b/N_o (db) with theoretical E_b/N_o (db) to maintain BER level for QPSK

BER	Simulated E_b/N_o (db)	Theoretical E_b/N_o(db)
10^{-1}-10^{-2}	-----	0-4
10^{-2}-10^{-3}	0-0.5	4-6.8
10^{-3}-10^{-4}	0.5-1.5	6.8-8.4
10^{-4}-10^{-5}	1.5-2	8.4-9.6

The Simulated Plots between BER and $E_b/N_o$for QPSK in OFDM system is shown in Fig.15.From Table VI, it is observed that for QPSK, on fixing BER between 10^{-4}&10^{-5} the simulated E_b/N_o(db) is 1.5 to 2 and theoretical E_b/N_o(db) is 8.4 to 9.6, which indicates the BER for simulated model is better than theoretical model for noisy channel. So the simulated model works better in noisy channel. Simulated model does not allow the BER between 10^{-1} and 10^{-2}, even at worst channel condition i.e. for E_b/N_o(db) of 0 to 2 db.

C Bit error rate curve for 8 QAM in OFDM

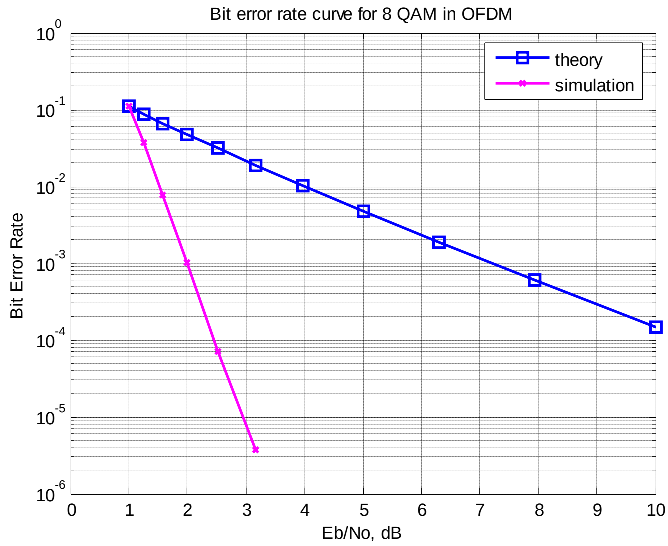

Fig. 16: Demonstrates plot of Bit error rate against E_b/N_o for 8 QAM

Table VII: Comparison of simulated E_b/N_o (db) with theoretical E_b/N_o (db) to maintain BERlevel for 8 QAM

BER	Simulated E_b/N_o (db)	Theoretical E_b/N_o(db)
10^{-1}-10^{-2}	1-1.5	1-4
10^{-2}-10^{-3}	1.5-2	4-7
10^{-3}-10^{-4}	2-2.5	7-10
10^{-4}-10^{-5}	2.5-3	10-14

The Simulated Plots between BER and E_b/N_o for 8 QAM in OFDM system is shown in Fig.16. From Table VII,it is observed that for 8 QAM, on fixing BER between 10^{-4} and 10^{-5} the simulated E_b/N_o (db) is 2.5 to 3 and theoretical E_b/N_o (db) is 10 to14, simulated model is better than theoretical model for noisy channel. So the simulated model works better in noisy channel. Simulated model gives very low BER of $10^{-5.5}$ at E_b/N_o (db) of 3.2

D Bit error rate curve for 16 QAM in OFDM

The Simulated Plots between BER and E_b /N_o for 16 QAM in OFDM system is shown in Fig. 17. From Table VIII, it is observed that for 16 QAM, on fixing BERbetween 10^{-3} and 10^{-4} the simulated E_b /N_o (db) is 2.5 to 3.1 and theoretical E_b /N_o (db) is 11 to 18, which indicates the BER for simulated model is better than theoretical model for noisy channel. So the simulated model works better in noisy channel. The 16 QAM does not allow BER between 10^{-4} and 10^{-5}.

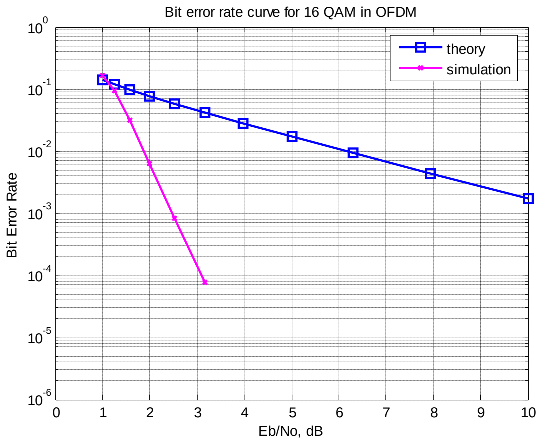

Fig. 17: Demonstrates plot of Bit error rate against E_b /N_o for 16 QAM

Table VIII: Comparison of simulated E_b /N_o (db) with theoretical E_b /N_o (db) to maintain BERlevel for 16 QAM

BER	Simulated E_b/N_o (db)	Theoretical E_b/N_o(db)
10^{-1}-10^{-2}	1.2-1.9	1-6
10^{-2}-10^{-3}	1.9-2.5	6-11
10^{-3}-10^{-4}	2.5-3.1	11-18

E Bit error rate curve for 32 QAM in OFDM

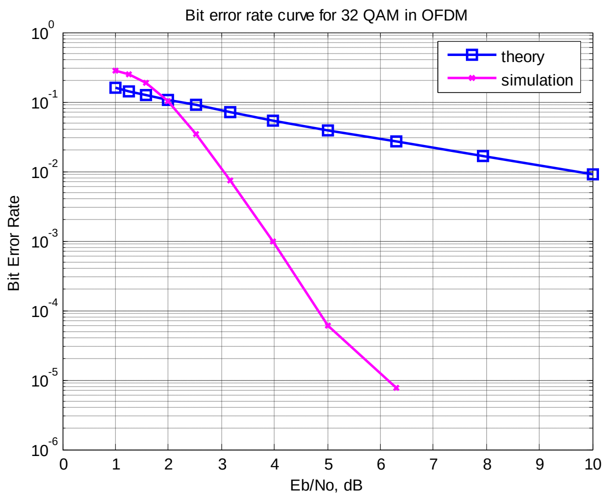

Fig. 18: Demonstrates plot of Bit error rate against E_b /N_o for 32 QAM

Table IX: Comparison of simulated E_b /N_o (db) with theoretical E_b /N_o (db) to maintain BERlevel for 32 QAM

BER	Simulated E_b/N_o (db)	Theoretical E_b/N_o(db)
10^{-1}-10^{-2}	2-3	2-10
10^{-2}-10^{-3}	3-4	10-20
10^{-3}-10^{-4}	4-4.9	20-32
10^{-4}-10^{-5}	4.9-6.1	32-44

The Simulated Plots between BER and E_b /N_o for 32 QAM in OFDM system is shown in Fig. 18. From Table IX, it is observed that for 32 QAM,on fixing BER (Bit Error Rate) between 10^{-4} and 10^{-5} the simulated E_b /N_o (db) is 4.9 to 6.1 and theoretical E_b /N_o (db) is 32 to 44, which indicates the BER for simulated model is better than theoretical model for noisy channel. So the simulated model works better in noisy channel. Simulated model gives very low BER of $10^{-5.5}$ at E_b /N_o (db) of 6.3.

F Bit error rate curve for 64 QAM in OFDM

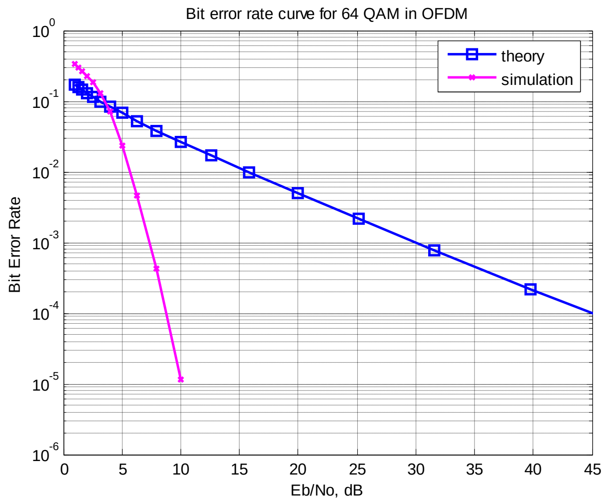

Fig. 19: Demonstrates plot of Bit error rate against E_b /N_o for 64 QAM

Table X: Comparison of simulated E_b /N_o (db) with theoretical E_b /N_o (db) to maintain BER level for 64 QAM

BER	Simulated E_b/N_o (db)	Theoretical E_b/N_o(db)
10^{-2}-10^{-3}	6-7	15-30
10^{-3}-10^{-4}	7-8	30-45
10^{-4}-10^{-5}	8-10	45-60

The Simulated Plots between BER and E_b /N_o for 64 QAM in OFDM system is shown in Fig. 19. From Table X, it is observed that for 64 QAM, on fixing BER (Bit Error Rate) between 10^{-4} and 10^{-5} the simulated E_b/N_o (db) is 8 to 10 and theoretical E_b/N_o (db) is 45 to 60, which indicates the BER for simulated model is better than theoretical model for noisy channel. So the simulated model works better in noisy channel. Simulated model gives very low BER of 10^{-5} at E_b/N_o (db) of 10.

G Bit error rate curve for 128 QAM in OFDM

The Simulated Plots between BER and E_b /N_o for 128 QAM in OFDM system is shown in Fig. 20. From Table XI, it is observed that for 128 QAM, on fixing BER (Bit Error Rate) between 10^{-4} and 10^{-5} the simulated E_b/N_o (db) is 16 to 20 and theoretical E_b/N_o (db) is above 80, which indicates the BER for simulated model is better than theoretical value for noisy channel. So the simulated model works better in noisy channel. Simulated model gives very low BER of 10^{-5} at E_b/N_o (db) of 20.

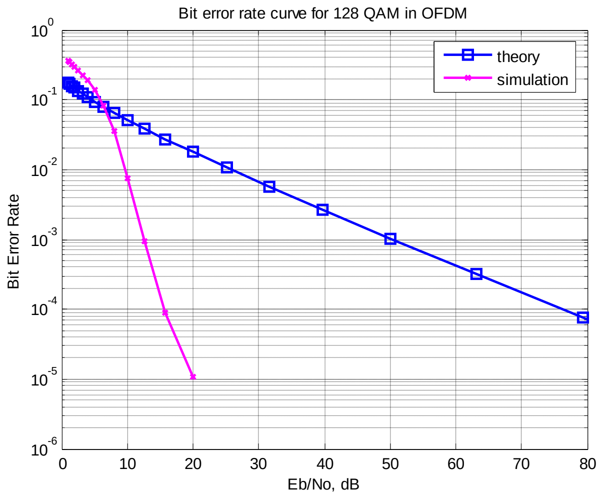

Fig. 20: Demonstrates plot of Bit error rate against E_b /N_o for 128 QAM

Table XI: Comparison of simulated E_b /N_o (db) with theoretical E_b /N_o (db) to maintain BER level for 128 QAM

BER	Simulated E_b/N_o (db)	Theoretical E_b/N_o(db)
10^{-1}-10^{-2}	6-9	4-25
10^{-2}-10^{-3}	9-13	25-50
10^{-3}-10^{-4}	13-16	50-80
10^{-4}-10^{-5}	16-20	----

H Bit error rate curve for 256 QAM in OFDM

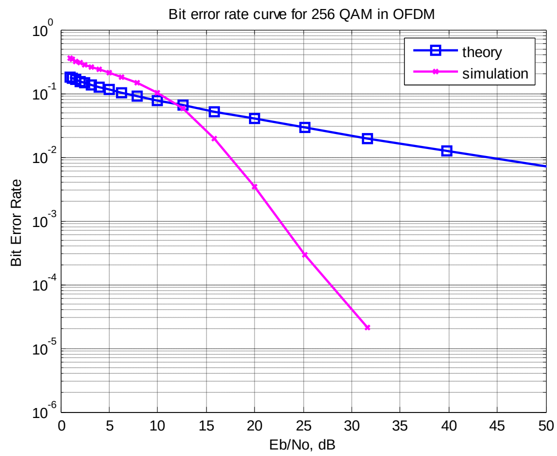

Fig. 21: Demonstrates plot of Bit error rate against E_b /N_o for 256 QAM

Table XII: Comparison of simulated E_b /N_o (db) with theoretical E_b /N_o (db) to maintain BER level for 256 QAM

BER	Simulated E_b/N_o (db)	Theoretical E_b/N_o(db)
10^{-1}-10^{-2}	10-17	5-42
10^{-2}-10^{-3}	17-23	----
10^{-3}-10^{-4}	23-28	----
10^{-4}-10^{-5}	28-32	----

The Simulated Plots between BER and E_b /N_o for 256 QAM in OFDM system is shown in Fig. 21. From Table XII, it is observed that for 256 QAM, on fixing BER (Bit Error Rate) between 10^{-4} and 10^{-5} the simulated E_b/N_o (db) is 28to 32 and theoretical E_b/N_o (db) is not approachable, which indicates the BER for simulated model is better than theoretical value for noisy channel. So the simulated model works better in noisy channel. Simulated model gives very low BER of $10^{-4.5}$ at E_b/N_o (db) of 32.

I Bit error rate curve for 512 QAM in OFDM

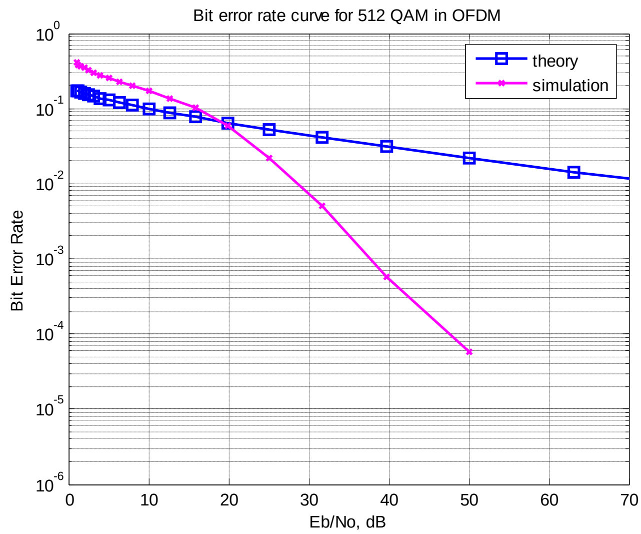

Fig. 22: Demonstrates plot of Bit error rate against E_b /N_o for 512 QAM

Table XIII: Comparison of simulated E_b /N_o (db) with theoretical E_b /N_o (db) to maintain BERlevel for 512 QAM

BER	Simulated E_b/N_o (db)	Theoretical E_b/N_o(db)
10^{-1}-10^{-2}	15-27	6-70
10^{-2}-10^{-3}	27-37	----
10^{-3}-10^{-4}	37-48	----

The Simulated Plots between BER and E_b /N_o for 512 QAM in OFDM system is shown in Fig. 22. From Table XIII, it is observed that for 512 QAM, on fixing BER (Bit Error Rate) between 10^{-3} and 10^{-4} the simulated E_b/N_o (db) is 37 to 48 and theoretical E_b/N_o (db) is not approachable, which indicates the BER for simulated model is better than theoretical value for noisy channel. So the simulated model works better in noisy channel. Simulated model gives very low BER of $10^{-4.5}$ at E_b/N_o (db) of 50.

*J Bit error rate curve for various digital modulation techniques in OFDM*The Simulated Plots between BER and E_b /N_o for various digital modulation techniques in OFDM system is shown in Fig. 23

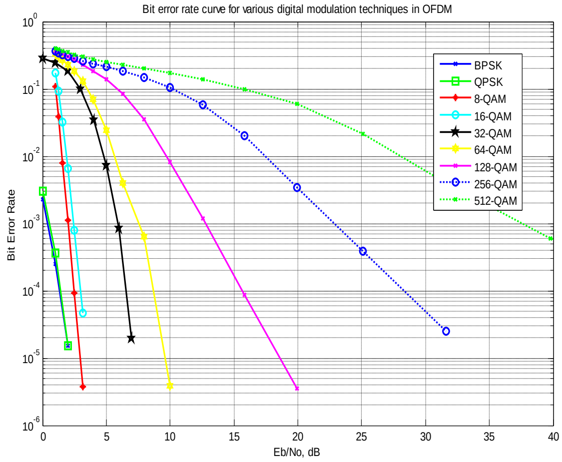

Fig. 23: Demonstrates plot of BER against E_b /N_o for various digital modulation techniques

IV. CONCLUSION

The simulation results of Bit Error Rate (BER) displays that the implementation of BPSK, QPSK modulation technique gives less error at worst channel conditions as compared to QAM modulation techniques. The conclusion is that on fixing BER and under good channel conditions QAM with higher mode value i.e. 16 QAM (4 b/s/Hz), 32 QAM (5 b/s/Hz), 64 QAM (6 b/s/Hz), 128QAM (7 b/s/Hz), 256QAM (8 b/s/Hz) and 512 QAM (9 b/s/Hz) provides better spectral efficiency. But under worst channel conditions, the BPSK or QPSK may be used at the cost of the spectral efficiency (1 - 2 b/s/Hz) to maintain BER low. From these figures, we can conclude that on fixing BER and under good channel conditions QAM with higher mode value gives best spectral efficiency and under worst channel conditions, we can use QPSK, BPSK. Thus, we have to use adaptive modulation depending upon channel conditions.

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