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# OFDM: A System Based Comparison with Cyclic Prefix

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**Abstract:** The objective of paper is to develop and compare a model of an OFDM system using different values of cyclic prefixes in Matrix laboratory language (MATLAB) on which BER calculations is carried out for various digital modulation schemes like BPSK, 16 QAM, and 64 QAM. 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 convolution coding and interleaving is applied to improve BER performance of OFDM system.

**Keywords:** OFDM, Convolution coding, Cyclic Prefix, Additive White Gaussian Noise, Bit error rate.

## I. INTRODUCTION

Beyond 3G, OFDM is used instead of CDMA. In IEEE802.11 series, the low date rate uses CDMA (IEEE 802.11b) and high date rate uses OFDM (IEEE 802.11g and IEEE 802.11a). WiMAX (IEEE 802.16) is also using OFDM. OFDM is currently being used in several new radio broadcast systems including high definition digital television (HDTV) and digital audio broadcasting (DAB). A research has been done into the use of OFDM as a transmission method for mobile telecommunications systems. A promising candidate that eliminates a need for the complex equalizers is the Orthogonal Frequency Division Multiplexing (OFDM), a multiple carrier modulation technique. OFDM is robust in adverse channel conditions and allows a high level of spectral efficiency. It effectively mitigates performance degradations due to multipath and is capable of combating deep fades in part of the spectrum. Orthogonal Frequency Division Multiplexing (OFDM) is an emerging multi-carrier modulation scheme, which has been adopted for several wireless standards such as IEEE 802.11a and HiperLAN2.The OFDM system is analysed for different cyclic prefixes (1/4, 1/8, 1/16 and1/32) and compared for various digital modulation techniques (BPSK, 16 QAM, and 64 QAM).

## II. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

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).
Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission technique, which divides the available spectrum into many carriers, each one being modulated by a low rate data stream. OFDM is similar to FDMA in which the multiple user access is achieved by subdividing the available bandwidth into multiple channels that are then allocated to users. OFDM uses the spectrum more efficiently by spacing the channels closer together. This is achieved by making all the carriers orthogonal to one another, preventing interference between the closely spaced carriers. [3,4]
Coded Orthogonal Frequency Division Multiplexing (COFDM) is the same as OFDM except that forward error correction is applied to the signal before transmission. This is to overcome errors in the transmission due to lost carriers from frequency selective fading, channel noise and other propagation effects
The attraction of OFDM is mainly because of its way of handling the multipath interference at the receiver. Multipath phenomenon generates two effects one is frequency selective fading and other is Inter symbol interference (ISI). The "flatness" perceived by a narrowband channel overcomes the frequency selective fading. On the other hand, modulating symbols at a very low rate makes the symbols much longer than channel impulse response and hence reduces the ISI. Use of suitable error correcting codes provides more robustness against frequency selective fading. The insertion of an extra guard interval between consecutive OFDM symbols can reduce the effects of ISI even more. [2]

Suppose the symbol length is $T_U$ sinusoidal signals differing in frequency by $1/T_U$will be orthogonal over the period $T_U$

$$\int_{t_s}^{t_s+T_u}\left[e^{j2\pi f_0 t}\right]\left[e^{-j2\pi\left(f_0+\frac{1}{T_u}\right)t}\right]dt = 0 \tag{1}$$

In OFDM the carriers are orthogonal and overlap without interfering with one another. The symbols in a single-carrier system overlap in the time domain, but don't interfere with one another because of the symbol (T) spacing of the zero crossings. For OFDM, the carriers have spectral null at all other carrier frequencies.

$$\int_0^{T_{FFT}} \cos(2\pi mt/T_{FFT})\cos(2\pi mt/T_{FFT})dt = \begin{cases} \frac{T_{FFT}}{2} & m = n \\ 0 & m \neq n \end{cases} \tag{2}$$

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Due to change in phase shift in either carrier, the result has no effect. So orthogonally is still maintained.[2]

$$\int_0^{T_{FFT}} \cos(2\pi mt/T_{FFT} + \emptyset)\cos(2\pi nt/\ T_{FFT})dt = 0\ \neq n \qquad (3)$$

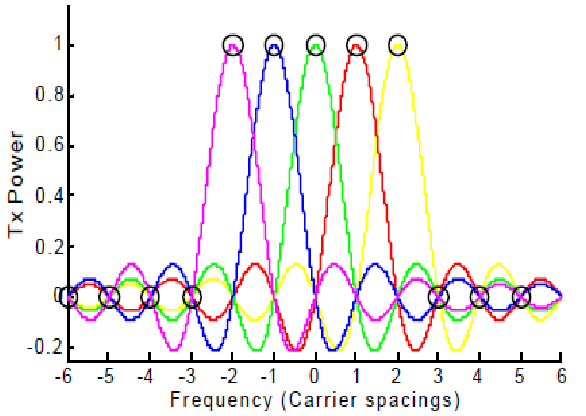


Fig.1. Frequency response of the subcarriers in 5 tone OFDM signal.

The IEEE 802.11 specification is a wireless LAN (WLAN) standard that defines a set of requirements for the physical layer (PHY) and a medium access control (MAC) layer. For high data rates, the standard provides two PHYs - IEEE 802.11b for 2.4-GHz operation and IEEE 802.11a for 5-GHz operation. The IEEE 802.11a standard is designed to serve applications that require data rates higher than 11 Mbps in the 5-GHz frequency band. [2,6]

TABLE I PHYSICAL LAYER PARAMETERS OF IEEE 802.11A [2]

| **Parameters** | **Values** |
|---|---|
| Sampling rate | 20MHz |
| Number of FFT points | 64 |
| Total number of sub-carriers available | 52 |
| Number of data sub-carriers | 48 |
| Number of pilot sub-carriers | 4 |
| Subcarrier frequency spacing | 0.3125 MHz |
| FFT symbol period | 3.2μs |
| Cyclic prefix | 0.8μs (1/4) |
| OFDM symbol period | 4μs |

## III. CYCLIC PREFIX INSERTION

Adjacent-channel interference or ACI is interference caused by extraneous power from a signal in an adjacent channel. ACI may be caused by inadequate filtering, such as incomplete filtering of unwanted modulation products in frequency modulation (FM) systems, improper tuning, or poor frequency control, in either the reference channel or the interfering channel, or both. ACI is distinguished from crosstalk.
Adjacent symbol interference (ASI) is a form of distortion of a signal in which one symbol interferes with subsequent symbols. This is an unwanted phenomenon as the previous symbols have similar effect as noise, thus making the communication less reliable. ISI is usually caused by multipath propagation or the inherent non-linear frequency response of a channel causing successive symbols to "blur" together. [3]The adjacent channel interference and adjacent symbol interference degrades the performance of communication system. Fig. 2. shows the adjacent symbol interference due to channel transfer function. To suppress ASI Guard Interval inserted between adjacent symbols as shown in fig. 3 but ACI still exists. Cyclic Prefix inserted in Guard Interval to suppress Adjacent Channel Interference (ACI) as shown in fig. 4. [3]

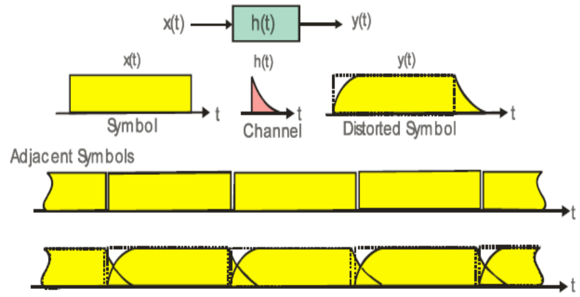


Fig.2. Adjacent Symbol Interference (ASI) [3]

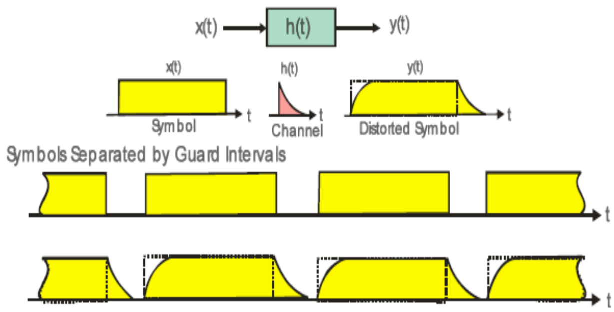


Fig.3. Guard Interval Inserted Between Adjacent Symbols [3]

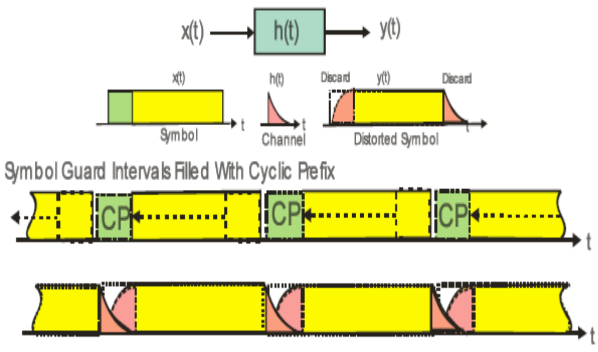


Fig4. Cyclic Prefix Inserted in Guard Interval [3]

The most effective guard period to use is a cyclic extension of the symbol. If a mirror in time, of the end of the symbol waveform is put at the start of the symbol as the guard period, this effectively extends the length of the symbol, while maintaining the orthogonality of the waveform. Using this cyclic extended symbol the samples required for performing the FFT, can be taken anywhere over the length of the symbol. The guard interval needs to be larger than the delay spread, but not so long that throughput is lost. In the 802.11A standard, the guard

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interval is fixed at 1/4. [6]The cyclic prefix can be varied from 1/4, 1/8, 1/16 and 1/32. To provide cyclic prefix of 1/4, 1/8, 1/16 and 1/32 of 64 FFT points i.e sub carriers, 4, 8, 16and 32 cyclic prefix subcarriers are added respectively.
Cyclic prefix duration is determined by the expected duration of the multipath channel in the operating environment. The condition is only that cyclic prefix duration should be more than delay spread. For example, for the indoor wireless multipath channel, the typically expected multipath channel is of around 0.8 µ sec duration, hence determining the cyclic prefix chosen per the IEEE 802.11a specification. This provides multipath immunity as well as symbol time synchronization tolerance. [6]

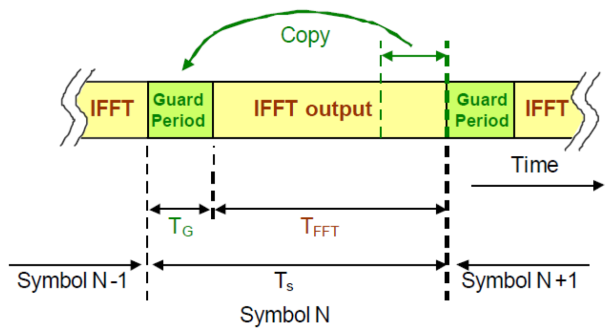


Fig. 5: Addition of a guard period to an OFDM signal [4]

The total length of the symbol is $T_s = T_G + T_{FFT}$, where $T_s$ is the total length of the symbol in samples, $T_G$ is the length of the guard period in samples, and $T_{FFT}$is the size of the IFFT used to generate the OFDM signal.
The advantages of cyclic prefix are they are very helpful in combating adjacent symbol interference and adjacent channel interference efficiently. Cyclic prefix transforms a linear convolution channel to a cyclic convolution channel

$$\mathrm{DFT}\{h(k) * s(k)\} \neq \mathrm{DFT}\{h(k)\} * \mathrm{DFT}\{s(k)\} \quad (4)$$

The cyclic extension allows applying the circular convolution.

$$\mathrm{DFT}\{h(k) * s(k)\} = \mathrm{DFT}\{h(k)\} * \mathrm{DFT}\{s(k)\} \quad (5)$$

The disadvantage of cyclic prefix is that it introduces a loss in signal to noise ratio of received signal to mitigate interference.

## IV. CONVOLUTIONAL CODING

The main aim of a digital communication system is to transmit information reliably over a channel. The channel is subject to various types of noise, distortion, and interference. There is need some form of error control encoding to recover the information reliably. Convolutional codes are extensively used for real time error correction. Convolutional codes are used extensively in numerous applications in order to achieve reliable data transfer, including digital video, radio, mobile communication, and satellite communication.
Convolutional code is a type of error-correcting code in which each m-bit information symbol (each m-bit string) to be encoded is transformed into an n-bit symbol, where m/n is the code rate (n ≥ m) and the transformation is a function of the last k information symbols, where k is the constraint length of the code. [16]

The terms to be used here to describe a convolutional code are as follows:

- **Input frame** (m) - the number of bits taken into the encoder at once.
- **Output frame** (n) - the number of bits and output from the encoder at once.
- **Memory order** (s) - the maximum number of shift register stages in the path to any output bit.
- **Memory constraint length** (u) **-** the total number of shift register stages in the Encoder.
- **Input constraint length** (k) **-** the total number of bits involved in the encoding operation, equal to sum of no. of shift registers and no. of inputs. The constraint lengths of the encoder form a vector whose length is the number of inputs in the encoder diagram. The elements of this vector indicate the number of bits stored in each shift register, including the current input bits.
- **Generator polynomial -** The way in which the encoder works is that the input bit is modulo-2 added to stored values of previous input bits which are buffered ready for transmission. The input bit is then moved into the shift registers and all the other bits shift to the left (the leftmost, i.e. oldest, stored bit being lost).

$$G_1 = x[n] + x[n-1] \quad (6)$$

$$G_2 = x[n] + x[n-1] + x[n-2] \quad (7)$$

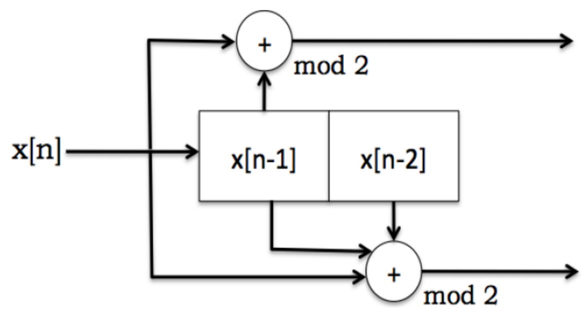


Fig6. Block diagram of convolutional code with k = 3 and rate ½ [2]

From the fig. 6, the encoding operation is described by two polynomials, representing the generation of each output bit from the input bit. Build a binary number representation by placing a 1 in each spot where a connection line from the shift register feeds into the adder, and a 0 elsewhere. The leftmost spot in the binary number represents the current input, while the rightmost spot represents the oldest input that still remains in the shift register. Convert this binary representation into an octal representation by considering consecutive triplets of bits, starting from the rightmost bit. The rightmost bit in each triplet is the least significant. If the number of bits is not a multiple of three, then place zero bits at the left end as necessary.

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The binary numbers corresponding to the upper and lower adders in the fig 3.1 are 110 and 111, respectively. These binary numbers are equivalent to the octal numbers 6 and 7, respectively. $G_1$ = 6 and $G_2$ = 7 of rate R = 1/2. Thus generator polynomial matrix is [6 7].

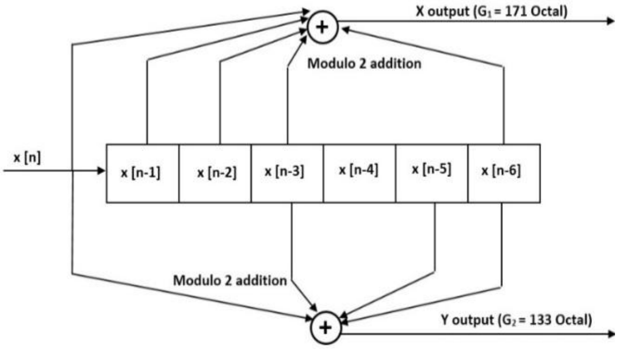


Fig7. Block diagram of convolutional code with k = 7 and rate 1/2 [2]

This convolutional encoder uses the industry-standard generator polynomials, $G_1$ = 171 and $G_2$ = 133 of rate R = ½ having 64 states. Thus the generator polynomial matrix is [171 133].

## V. OFDM SYSTEM

To implement the OFDM transmission scheme, the whole design is divided into three sections –Transmitter, Channel and Receiver.

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. After interleaving, the binary values are converted to symbol values, on which digital modulation scheme is applied. Previously, multi-carrier systems were implemented through the use of separate local oscillator. This was both inefficient and costly. With the advent of cheap powerful processors, the sub-carriers can now is implemented by the FFT which keep tones to orthogonal with each other.

The FFT is used to calculate the spectral content of the signal. It moves a signal from the time domain where it is expressed as a series of time events to the frequency domain where it is expressed as the amplitude and phase of a particular frequency. 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.

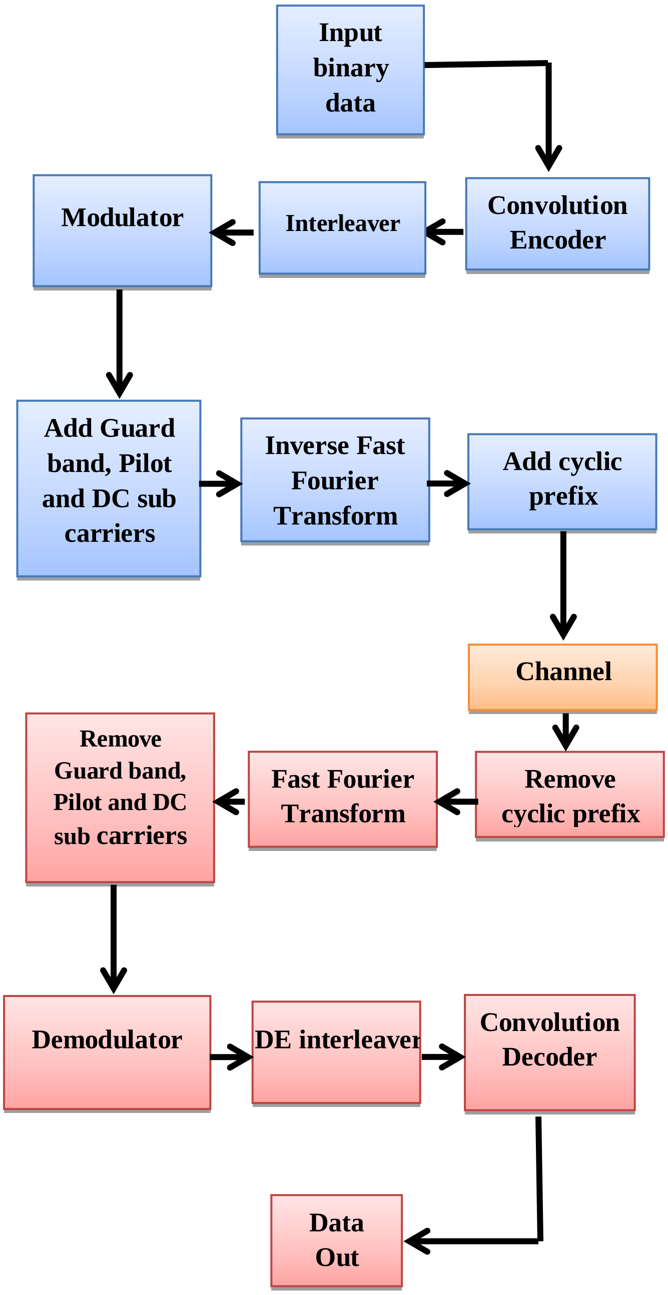


Fig.8. Block diagram of OFDM system

The system design parameters are derived according to the system IEEE 802.16 requirements. The design parameters or WiMAX system are shown in Table II.

TABLE II 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 |

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| | |
|---|---|
| Number of FFT points | 64 |
| Cyclic prefix | 4 (1/4),<br>8 (1/8),<br>16 (1/16)<br>32 (1/32) |
| OFDM symbol | 68 (64 +4)<br>72 (64 +8)<br>80 (64 +16)<br>96 (64 +32) |
| Modulation scheme | BPSK 16QAM<br>64QAM |
| Coding | Convolutional, code rate ½, constraint length 7, generator polynomial [171, 133] |

## VI. SIMULATION RESULTS

The Bit error rate curve for BPSK digital modulation technique with different cyclic prefixes i.e. 1/32,1/16, 1/8 and 1/4 in OFDM system is shown in the fig. 9.

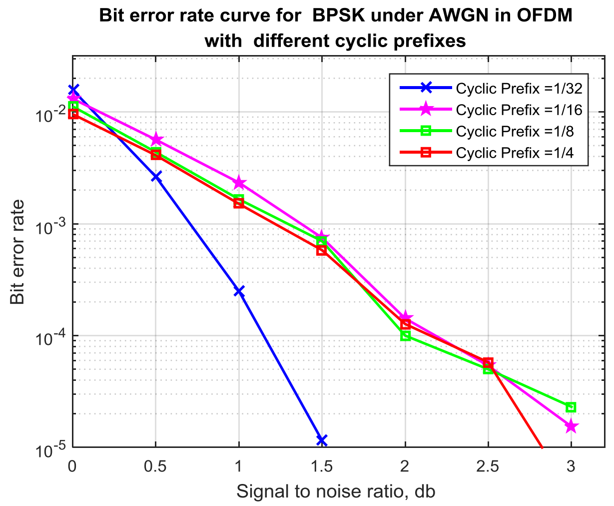


Fig.9. Demonstrates plot of BER against SNR for BPSK under AWGN with different cyclic prefixes

The above figure indicates the BER for system having 1/32 cyclic prefix is better than other cyclic prefixes variants. The remaining cyclic prefix variants are almost shows similar result. On fixing BER between $10^{-3}$ and $10^{-4}$,1/32 cyclic prefix SNR value is 0.7 to 1.2 and remaining cyclic prefix variants are almost SNR value is 1.3 to 2, which indicates the BER of BPSK OFDM system for 1/32 cyclic prefix model is better than other cyclic prefix models for noisy channel.

The Bit error rate curve for 16 QAM digital modulation technique with different cyclic prefixes i.e. 1/32, 1/16, 1/8 and 1/4 in OFDM system is shown in the fig. 10. The above figure indicates the BER for system having 1/16 cyclic prefix is quite better than other cyclic prefixes variants. The remaining cyclic prefix variants are almost shows similar result.

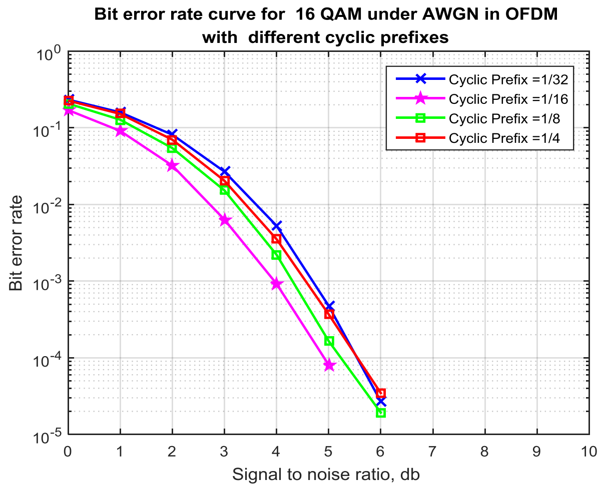


Fig.10. Demonstrates plot of BER against SNR for 16 QAM under AWGN with different cyclic prefixes

On fixing BER between $10^{-3}$ and $10^{-4}$,1/16 cyclic prefix SNR value is 4 to 5 and remaining cyclic prefix variants are almost SNR value is 4.8 to 5.5, which indicates the BER of 16 QAM OFDM system for 1/16 cyclic prefix model is better than other cyclic prefix models for noisy channel. Here 1/32 plays worse than other cyclic prefix models.

The Bit error rate curve for 64 QAM digital modulation technique with different cyclic prefixes i.e. 1/32, 1/16, 1/8 and 1/4 in OFDM system is shown in the fig. 11.The below figure indicates the BER for system having 1/16 cyclic prefix is quite better than other cyclic prefixes variants. The remaining cyclic prefix variants are almost shows similar result. On fixing BER between $10^{-3}$ and $10^{-4}$,1/16 cyclic prefix SNR value is 8.5 to 9.5 and remaining cyclic prefix variants are almost SNR value is far away as compared to 1/16 model.Here 1/32 model plays worse than other cyclic prefix models whose range comes under the 9.9 to 11.4 on fixing BER between $10^{-3}$ and $10^{-4}$, which indicates the BER of 16 QAM OFDM system for 1/16 cyclic prefix model is better than other cyclic prefix models for noisy channel.

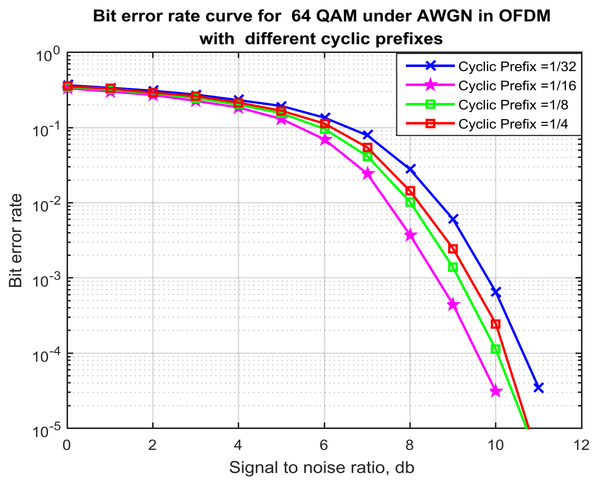


Fig.11. Demonstrates plot of BER against SNR for 64 QAM under AWGN with different cyclic prefixes

## VII. CONCLUSION

The simulation results of Bit Error Rate (BER) displays that the implementation of 1/32 cyclic prefix for BPSK and 1/16 cyclic prefix for 16 QAM and 64 QAM modulation technique gives less error as compared to other cyclic prefixes models. The conclusion is that on fixing BER and under good channel conditions QAM with higher mode value i.e. 16 QAM, 64 QAM with cyclic prefix 1/16 provides better spectral efficiency. But under worst channel conditions, the BPSK with cyclic prefix 1/32 may be used at the cost of the spectral efficiency to maintain BER low.

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