BER PERFORMANCE OF OFDM SYSTEM WITH CYCLIC PREFIX & ZERO PADDING

Prafulla. D. Gawande and Sirddharth. A. Ladhake
Department of Electronics and Telecommunication, Sipna Collage of Engineering and Technology, Sant Gadebaba Amravati University, Amravati, MS, India

ABSTRACT

Multicarrier schemes are supported to high data rate. Orthogonal Frequency Division Multiplexing (OFDM) and Filtered Multi-Tone (FMT) are two techniques of multicarrier schemes. OFDM is an attractive air-interface for next-generation wireless network without complex equalizer. OFDM is an emerging multi-carrier modulation scheme. It has been adopted by several wireless standards such as IEEE 802.11a, IEEE 802.16 and HiperLAN2. OFDM is designed such a way that it sends data over hundreds of parallel carrier which increases data rate. OFDM scheme is suffer by inter-symbol interference (ISI) problem. ISI is distortion in a signal in which one symbol interferes with subsequent symbols, this will degrade performance of OFDM system. There are several methods for reducing the effects of ISI. A guard interval insertion (cyclic prefix and Zero Padding) method is effective method to reduce the effect of ISI. Zero padding (ZP) of multicarrier transmissions has recently been proposed as an appealing alternative to the traditional CP to ensure symbol recovery. In this paper, we are studied the effect of CP and ZP on Bit Error Rate (BER) of OFDM technique with AWGN channel and Rayleigh fading channel. Through simulations, it is shown that the both techniques are effective in mitigating the effects of ISI. For high value of the CP and ZP, performances of both methods are better for Rayleigh fading channel as compared to AWGN channel. Simulation is performed by using MATLAB R2010a.

KEYWORDS: *OFDM, CP, ZP, FMT, FFT, IFFT, QAM, BER.*

I. INTRODUCTION

In single carrier transmission schemes, one Frequency carrier is used to transmit or receive information. Data or information will be transmitted serially on the channel at low data rate. High data rate is creating a problem of ISI in single carrier schemes [2]. In order to support the symbol rate Rs, the minimum required bandwidth is the Nyquist bandwidth (Rs /2 Hz) [4]. It means that wider bandwidth is required to support a higher data rate in a single-carrier transmission. When the signal bandwidth becomes larger than the coherence bandwidth in the wireless channel, the link suffers from multi-path fading, incurring the inter-symbol interference (ISI) [17]. In general, adaptive equalizers are employed to deal with the ISI created by the time-varying multi-path fading channel. Furthermore, the complexity of an equalizer increases with the data rate, modulation order and the number of multi-paths. In conclusion, a high data rate single-carrier transmission may not be practically possible due to too much complexity of the equalizer in the receiver. Simple flat fading channel is used in single carrier transmission schemes therefore guard interval and guard band are not required. Due to drawbacks of single carrier system, multicarrier transmission system is used in Next generation communication system.

Multicarrier transmission or modulation uses multiple subcarrier signals at different frequencies, sending parallel bits on multiple subcarriers. Therefore data rate will be improved in multicarrier schemes. There are two main types of Multicarrier Transmission schemes such as OFDM (Orthogonal Frequency Division Multiplexing) and FMT (Filtered Multi-Tone).

To meet the needs of 4th generation (4G) systems, the 3rd Generation Partnership Project (3GPP) has released the Long Term Evolution (LTE) specification. Amendment released by 3GPP basically made on physical layer and MAC layer of 3rd generation specifically in the modulation and multiple access schemes. In 3rd generation, IEEE 802.16 standard implements the OFDM for uplink and downlink. In next generation, LTE (Long Term Evolution) used Orthogonal Frequency Division Multiplexing (OFDM) for its downlink and Single-Carrier Frequency-Division Multiple Access (SC-FDMA) for its uplink. Therefore in this generation, OFDM becomes a main multicarrier scheme for communication system. OFDM has emerged as a promising air interface technique. In Context of wired environments, OFDM techniques are also known as Discrete Multi Tone (DMT) transmissions and are employed in the American National Standards Institute's (ANSI) ADSL, HDSL and VDSL [5, 10, 11].

In multicarrier transmission schemes, subcarriers are uniformly spaced and the sub channel filters are identical, an efficient digital implementation is possible and is generally referred to as filtered multi tone modulation (FMT). It is based on a fast Fourier transform (FFT) followed by low rate sub channel filtering. Channel frequency selectivity introduces inter carrier (ICI) and inter symbol (ISI) interference at the receiver [7]. The design of the sub channel filters and the choice of the subcarrier spacing in an FMT system aim at subdividing the spectrum into a number of sub channels that do not overlap in the frequency domain such that we can avoid the ICI and get low ISI contributions [13].

One of the most important properties of OFDM transmission is its robustness against multipath delay spread. This is achieved by having a long symbol period (M times longer than an equivalent single carrier transmission), which minimizes the inter-symbol interference. The level of robustness can in fact be increased even more by the addition of a guard period between transmitted symbols as proposed in [15]. The guard period allows time for multipath signals from the previous symbol to decay before the information from the current symbol is gathered. 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. The guard time is chosen to be larger than the expected delay spread, such that multipath components from one symbol cannot interfere with the next symbol [1]. This guard interval is usually chosen as 5 times the delay spread. There are several options for GI. One choice of GI is zero padding. In this scheme no waveform is transmitted in the GI duration. However, the zero-padded waveform would destroy the orthogonality of subcarriers and results in inter carrier interference (ICI).

In this paper, we take a closer look at ZP-OFDM and CP-OFDM and its effects on performance of system. Section II defines the main component of OFDM, basic of CP and ZP and its analysis. Then, a brief description of the BER performance of OFDM by using CP and ZP for AWGN Channel and multipath channel is provided in Section III. Simulation Results are discussed in Section IV with different value of Cyclic Prefix and Zero Padding for AWGN Channel and Multipath channel. Finally, the concluding remarks are given in Section V.

II. OFDM

In this technique, Frequency band is divided into number of subcarriers. These subcarriers are orthogonal to each other. The basic principle of OFDM is to split high-rate data stream into number of lower rate streams that are transmitted simultaneously over a number of subcarriers [4]. Because the symbol duration increases for the lower rate parallel subcarriers, the relative amount of dispersion in time caused by multipath delay spread is decreased. Inter-symbol interference is eliminated by using guard time in OFDM symbol. In OFDM system design, a number of parameters are used such as subcarrier, guard time, symbol duration, subcarrier spacing, modulation type and error correcting code. The choice of parameters depends on bit rate, bandwidth, and delay.

Figure 1 shows complete OFDM trans-receiver, where the upper path is transmitter section and the lower path corresponds to receiver section. The three main component of OFDM system are as follows.

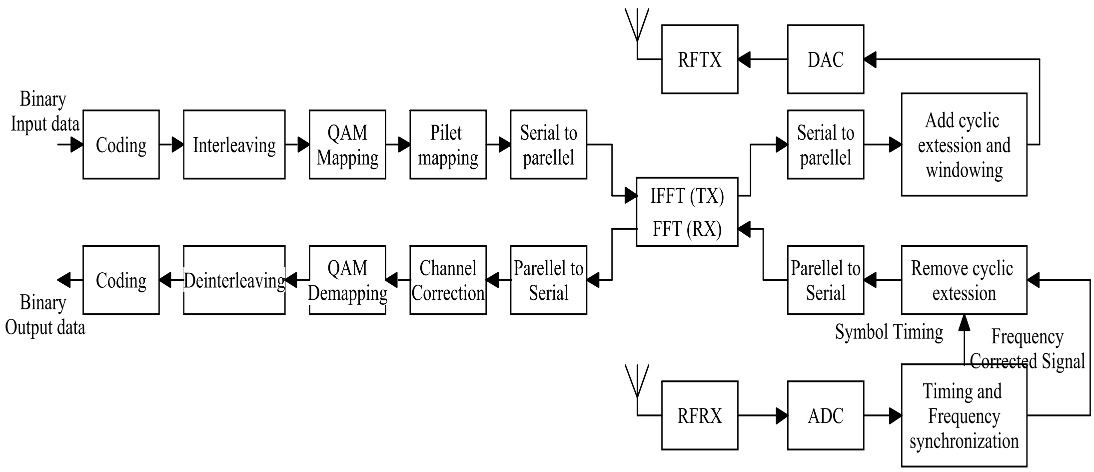


Fig. 1 OFDM Trans-Receiver

1. First main component of OFDM is FFT/ IFFT witch modulates a block of input QAM values onto a number of subcarriers. In the receiver, subcarriers are demodulated by FFT, which perform reverse operation of IFFT. In practice, IFFT can be made by using FFT. Therefore same hardware will be used for the both which reduces the complexity of communication system [14].
2. Second important feature of OFDM system is coding and interleaving. Some successive subcarriers in the OFDM system may suffer from deep fading, in which the received SNR is below the required SNR level. In order to deal with the burst symbol errors, it may be essential to use of FEC (Forward Error Correction) codes. The FEC codes can make error corrections only as far as the errors are within the error-Correcting capability, but they may fail with burst symbol errors. Due to this code average errors convert into random errors, for which interleaving techniques are used. There are two types of interleaving: block interleaving and convolution interleaving. Bit-wise, data symbol-wise, or OFDM symbol-wise interleaving can be used for block interleaving. Interleaving type and size must be determined by the type of FEC code, degree of frequency, time fading and delay due to interleaving.
3. The third key principle is the introduction of a cyclic prefix and zero padding as a Guard Interval to reduce interference between the symbols [8,14].

2.1 Orthogonal Signal and Guard Interval (GI)

All subcarriers have the same phase and amplitude, but in this communication system amplitudes and phases may be modulated differently for each subcarrier. Each Subcarrier has exactly an integer number of cycles in interval T and the number of cycles between adjacent subcarrier differs by exactly one. This property accounts for the orthogonality between the subcarriers. If two carriers are orthogonal then integration of product of subcarriers is zero.[7]

$$\int_0^T \cos(2\pi f_n\, t) * \cos(2\pi f_m\, t)\ = 0$$

Where f_n and f_m are orthogonal frequencies.

Each subcarrier signal is time-limited for each symbol (i.e. not band-limited) [3]. An OFDM signal may incur out-of-band radiation, which causes non-negligible adjacent channel interference (ACI). Therefore, OFDM scheme places a guard band at outer subcarriers called virtual carriers (VCs), around the frequency band to reduce the out-of-band radiation. Orthogonal signals are shown in fig.2.a and fig. 2.b.

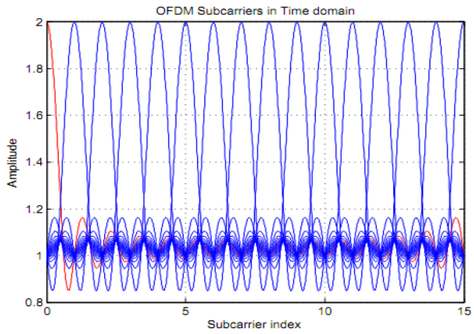


Fig. 2.a 16- Orthogonal Subcarrier

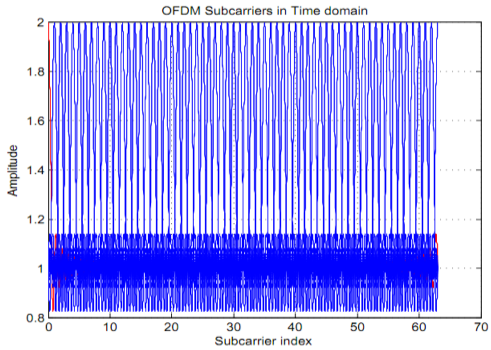


Fig. 2.b 64-Orthogonal Subcarrier

The OFDM scheme also inserts a guard interval which mitigates the inter-symbol interference (ISI) between OFDM symbols. The OFDM guard interval can be inserted at transmitter end in two different ways. One is the zero padding (ZP) that pads the guard interval with zeros and other is the cyclic extension of the OFDM symbol (for some continuity) with cyclic prefix or cyclic suffix). CP or ZP is removing at receiver end [12].

2.2 OFDM symbols with Cyclic Prefix

Cyclic Prefix is to extend the OFDM symbol by copying the last segment of the OFDM symbol into its head side. Let T_G and T_{sym} denote the length of CP in terms of samples and symbol duration without GI respectively. Therefore the extended OFDM symbols now have the duration of $T_{sym(G)} = T_{sym} + T_G$. Fig. 3 shows two consecutive OFDM symbols, each of which has the CP of length T_G. Figure 4 illustrates them jointly in the time and frequency domains. Figure 5 shows the ISI effects of a multipath channel on some subcarriers of the OFDM symbol. It can be seen from this figure that if the length of the guard interval (CP or ZP) is set longer than or equal to the maximum delay of a multipath channel, the ISI effect of an OFDM symbol (plotted in a dotted line) on the next symbol is conned within the guard interval so that it may not affect the FFT of the next OFDM symbol, taken for the duration of $T_{sym(G)}$. Guard interval should be longer than maximum delay of the multipath channel for maintaining the orthogonality among the subcarriers [16]. As the continuity of each delayed subcarrier has been warranted by the CP, its orthogonality with all other subcarriers is maintained over T_{sub} [8].

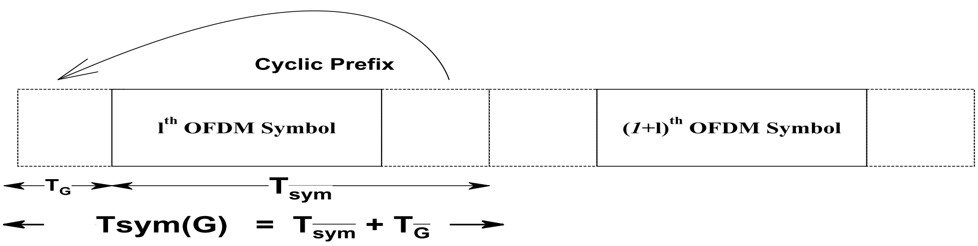
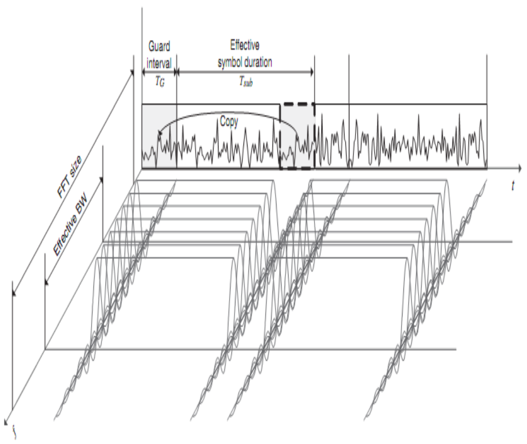


Fig. 3 OFDM Symbol with Cyclic Prefix



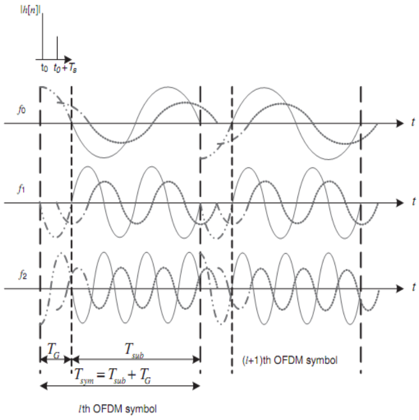


Fig. 4 Time/Frequency domain OFDM Symbol with CP

Fig. 5 ISI effect on OFDM Symbol

2.3 OFDM symbol with Zero Padding

We may insert zero into the guard interval. This particular approach is adopted by multiband-OFDM (MB-OFDM) in an Ultra Wide-band (UWB) system [6]. Fig. 6(a and b) show OFDM symbols with ZP and the ISI effect of a multipath channel on OFDM symbols for each subcarrier respectively. Even with the length of ZP longer than the maximum delay of the multipath channel, a small symbol time offset (STO) causes the OFDM symbol of an effective duration to have a discontinuity within the FFT window [9]. Therefore the guard interval part of the next OFDM symbol is copied and added into the head part of the current symbol to prevent ICI. Since the ZP is filled with zeros, the actual length of an OFDM symbol containing ZP is shorter than that of an OFDM symbol containing CP or CS. Accordingly the length of a rectangular window for transmission is also shorter, so that the corresponding sinc-type spectrum may be wider. This implies that compared with an OFDM symbol containing CP or CS, an OFDM symbol containing ZP has PSD (Power Spectral Density) with the smaller in to band ripple and the larger out-of-band power, allowing more power to be used for transmission with the peak transmission power fixed. Note that the data rate of the OFDM symbol is reduced by $\frac{T_{sym}}{T_{sym(G)}} = \frac{T_{sym}}{(T_{sym}+T_G)}$ times due to the guard interval [8].

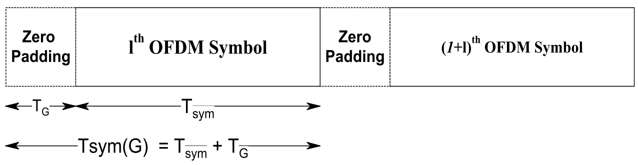


Fig 6.a OFDM symbol with Zero Padding

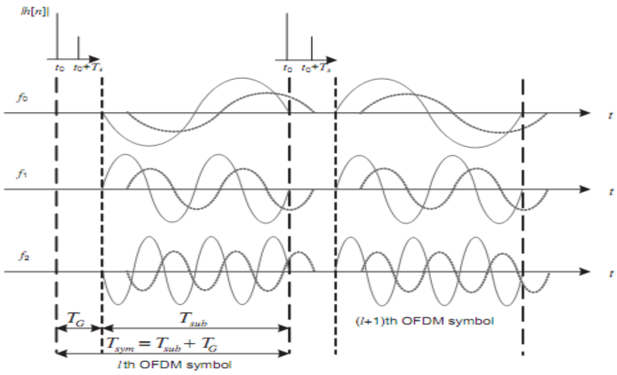


Fig 6.b ISI effect on Multipath OFDM Signal

III. BER OF OFDM SYSTEM

The BER expressions for M-ary QAM signaling for AWGN Channel is as given below [7]

$$P_e = \frac{2(M-1)}{M\log_2 M} Q\left(\sqrt{\frac{6E_b}{N_0}\frac{\log_2 M}{(M^2-1)}}\right) \quad (3.1)$$

For Rayleigh fading channel

$$P_e = \frac{M-1}{M\log_2 M}\left(1 - \sqrt{\frac{3\gamma\log_2 M/(M^2-1)}{3\gamma\log_2 M/(M^2-1)+1}}\right) \quad (3.2)$$

Where $\gamma = E_b/N_0$ and M is the modulation order.

Standard Q- function defined as

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{-t^2/2}\,dt \quad (3.3)$$

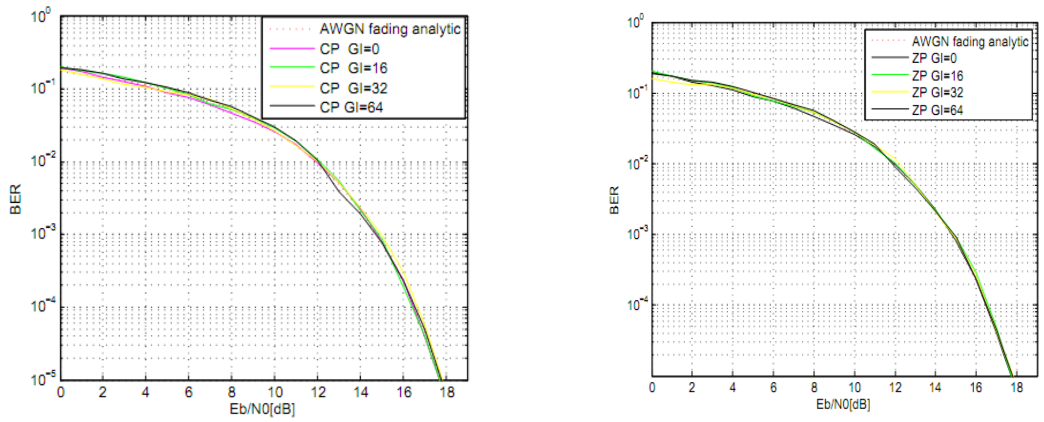
If N_{used} subcarriers out of total N (FFT size) subcarriers are used for carrying data, the time-domain SNR, SNR_t differs from the frequency domain SNR, SNR_f as follows:

$$SNR_t = SNR_f + 10\log\frac{N_{used}}{N}[dB] \quad (3.4)$$

IV. SIMULATION PARAMETER AND RESULT

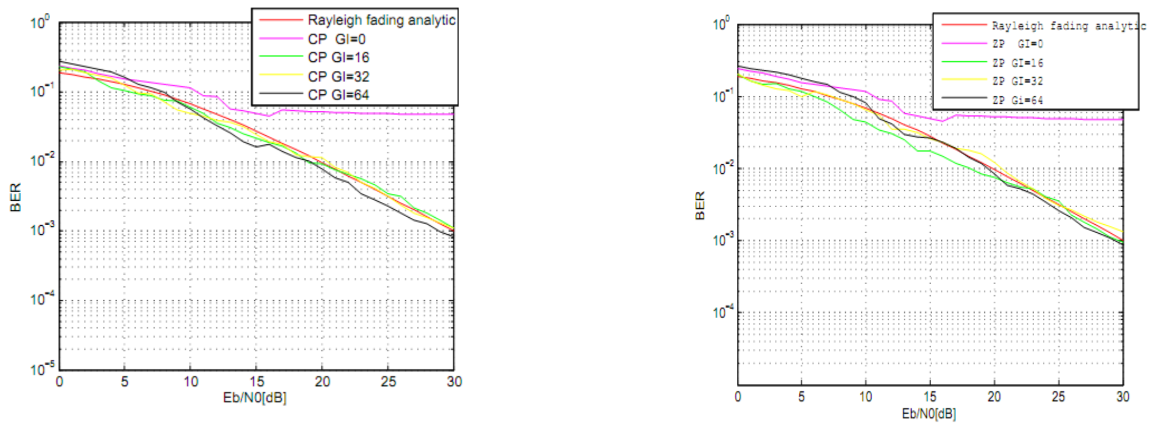
The OFDM trans-receiver was designed and simulated by MATLAB. The BER performances of the proposed scheme are examined by MATLAB simulation. In the simulation we consider an OFDM signal with N = 64 subcarriers, 64-Quadrature Amplitude Modulation (64-QAM) mapping, 16 virtual carrier, 3 symbol per frame and convolution coding. Additive white Gaussian noise (AWGN) channel and Rayleigh fading channel response are consider for simulation result. Effect of Variable length of CP and ZP are analyses on OFDM system with AWGN channel and Rayleigh fading channel.

The Bit error rate performance of OFDM system is depends on many parameters such as modulation scheme, inter-symbol interference, inter-carrier interference, channel noise, bit synchronization problems, attenuation and multipath fading. The BER may be improved by selecting robust modulation scheme, coding schemes, reducing the effect of ISI by inserting guard interval and frequency offset. In this paper, simulated result shown in fig.7 & fig. 8 that indicated BER performance of an OFDM system with varying guard interval (CP or ZP) in the AWGN and a multipath Rayleigh fading channel. The effect of inter symbol interference is simulated as the length of CP or ZP varies. The effect of ISI is negligible in AWGN fading channel because there is no multipath signal and it is significantly varies in Rayleigh fading channel with varying guard interval length.



(a) With Cyclic Prefix (b) With Zero Padding

Fig.7. BER Performance of OFDM System for AWGN Fading Channel



(a)With Cyclic Prefix (b) With Zero Padding

Fig.8.a BER Performance of OFDM System for Rayleigh Fading channel

V. CONCLUSION

In this paper we have discussed issues related to Cyclic Prefix and Zero Padding in OFDM and simulated the effect of CP and ZP on performance of OFDM system in term of BER for AWGN channel and Rayleigh fading channel. OFDM is a block modulation scheme where a block of N information symbols is transmitted in parallel on N sub-carriers. A guard time, usually in the form of CP or ZP, is inserted between OFDM symbols to eliminate the ISI. Transmission of symbol with cyclic prefix or zero padding reduces the ISI and Bit Error Rate (BER).

AWGN channel has only one path between the transmitter and the receiver and only a constant attenuation and noise is considered. Therefore no multipath effect is taken into account. From simulation result it is clear that as Cyclic Prefix and Zero Padding is not affecting on BER performance of AWGN channel. The BER performance in an AWGN channel is in consistence with the analytical results regardless of the length of CP and ZP because there is no multipath delay in the AWGN channel.

Rayleigh fading channel has multipath between transmitter and receiver. Multipath signal produces the distortion. Multipath distortion can also cause inter-symbol interference (ISI) where adjacent symbols overlap with each other. This is prevented in OFDM by the insertion of a cyclic prefix or zero padding between successive OFDM symbols. This cyclic prefix is discarded at the receiver to cancel out ISI. From the simulation Result it is clear that as cyclic prefix duration increases the BER decreases for Rayleigh fading channel. The effect of ISI on the BER performance becomes significant in the multipath Rayleigh fading channel as the length of CP & ZP decreases, which eventually leads to an error. The BER performance in a Rayleigh fading channel is in consistence with the analytical results when Cyclic Prefix or Zero Padding equal 16.

VI. FUTURE SCOPE

CP or ZP plays an important role in combating multipath effects by reducing ICI to maintain orthogonality between subcarriers and eliminating the ISI. It is also the fact that inserting CP or ZP has its own cost, a part of signal energy is lost since CP or ZP carries no information [18]. Length of CP or ZP depends on maximum channel delay. Therefore in future, it may be possible to "measure" the channel maximum delays and insert the CP or ZP according to the measurement. Dynamic length of CP or ZP may be improve the Performance of OFDM system for that we need to develop the technique to select the length of CP or ZP as per maximum channel delay.

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AUTHORS

Prafulla. D. Gawande received the M.Tech degree in Electronics and Telecommunication Engineering from Dr. Babasaheb Technological University,Lonere, Maharastra, India. He is Associate Professor in Department of Electronics and Telecommuniaction, SIPNA Collage of Enginnering and Technology, Amravati.

Sirddharth. A. Ladhake received the Ph.D in Electronic Engineering from Amravati University, Maharastra, India. He is Principal in SHIPNA Collage of Enginnering, Maharastra, Amravati, India.