ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 8, August 2014

Improvement of BER for OFDM using Equalization and Windowing for AWGN and Rayleigh Fading Channels

Nikhil Bhardwaj[1], Ankush Kansal[2]

M.E. Student, Electronics and Communication Engineering Department, Thapar University, Patiala, India[1]

Assistant Professor, Electronics and Communication Engineering Department, Thapar University, Patiala, India[2]

Abstract: The orthogonal relation between the carriers among different users is well known in OFDM. The overlap of spectrums of various users can be achieved thereby enhancing the spectrum efficiency of the communication system. OFDM is a popular multicarrier modulation technique which is currently being explored for use in the IEEE 802.11e (WiMax) standard. In OFDM, the orthogonality between the closely spaced sub-carriers is important for overcoming the phenomenon of inter-carrier interference (ICI) leading to a reduction in the Bit Error Rate (BER) performance of the system. A technique for shaping the time portion of our measured data so as to minimize the effects of the edges thus reducing the leakage that arises out of the spectrum of FFT is called windowing. The Raised Cosine (RC) window is a period of raised value of cosine function so the negative peaks of the window just touch the nil mark, hence giving its name. In order to protect the transmitted signals against the effect of multipath channels i.e. the inter-symbol interference (ISI), a cyclic prefix is added with the duration which is greater than the delay of multipaths. The phase and amplitude of the received signal also suffers due these effects. As a solution to this, some sub-carriers are sent as a reference in order to determine the role of the multipath channel. Having this estimation, the equalization technique is employed which results in the compensation for the detrimental signal effects created as a result of the multipath channels. Here, a linear equalizer namely Zero Forcing (ZF) Equalization is used in conjunction with Raised Cosine (RC) Windowing approach on traditional Orthogonal Frequency Division Multiplexing (OFDM) system using the modulation technique of 16-QAM modulation at $\mathbf{10^{-2.9}}$ Bit Error Rate (BER). The result is that a 5 dB improvement is achieved in the Signal-to-Noise Ratio (SNR) value for Additive White Gaussian Noise (AWGN) Channel as compared to traditional OFDM used in the same channel model. And a 15 dB improvement is achieved in the Signal-to-Noise Ratio (SNR) value for Rayleigh Channel as compared to traditional OFDM for the same channel model at $\mathbf{10^{-2.9}}$ Bit Error Rate (BER).

Keywords: OFDM, AWGN, Rayleigh, RC Windowing, Equalization.

I. INTRODUCTION

Radio technology facilitated instant communication between great distances. The methods for wireless communications have been evolving since the days of Nikola Tesla [1]. The need of humans to constantly be connected, anytime and anytime has been the prime motivation for this evolution and development in the wireless field. In fact, the rapid pace of development for the wireless communications field has shrunk the world into a globalinformation village. Wireless communications present various problems when it comes to developing a system which would present us with the advantages of high mobility, ever increasing capacity requirements and range of communications. Fresh challenges such as limited available bandwidth of the communication spectrum, a need for high efficiency of the communication equipment so as to facilitate mobility and a need to maintain a connection in all kinds of environments; has fuelled growth in this direction. Research has been conducted and various methods have been suggested that address these issues thoroughly. Spectrum efficiency is of utmost importance as the need to send ever increasing amounts of data within the limited spectrum that is available to us addresses the issue of capacity. Now, the need to be connected anywhere and anytime has exposed us to the environment which is modelled by frequency selective and time-varying fading channels. Not all the modulation schemes can operate in such environments and keep up with the ever increasing demands on mobility, capacity and range from the desired communication systems. It has been firmly established that the multicarrier data transmission methods such as OFDM are best suited for providing reliable communications in such environments [2].

II. PRINCIPLE OF OFDM SYSTEMS

A. *OFDM Technique*

OFDM (Orthogonal Frequency Division Multiplexing) is a special scheme to achieve parallel transmission of data. It is a modulation as well as a multiplexing technique.

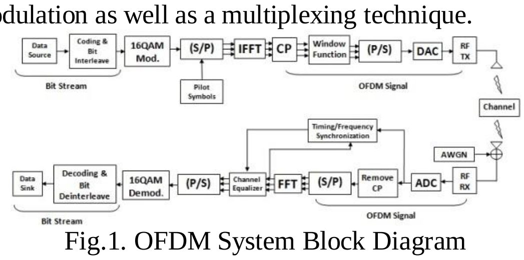

Fig.1. OFDM System Block Diagram

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 8, August 2014

It can be seen as Frequency Division Multiplexing (FDM) technique which is used as multicarrier digital modulation of multiple sub-carriers that are so selected that they are orthogonal to each other. The high data rate OFDM is split up into lower data rate sub-carriers which need lesser bandwidth and experience a type of fading that is flat, thus simplifying the equalization process. Orthogonal sub-carriers also allow an efficient use of the limited spectrum resources as the orthogonal property of the sub-carriers allows them to overlap each other [3]. The OFDM system block diagram is shown as figure 1.

The data that is to be sent is coded and mapped using 16-QAM modulation technique. Then it is converted to parallel while simultaneously adding pilot symbols. The module that accomplishes IFFT as shown in the block diagram is the system for multi-carrier modulation which hugely reduces the complexity in the system. Thereafter, following the addition of cyclic prefix, RC (Raised Cosine) Window function is used on the OFDM signal. This windowed function is then converted to serial form and then converted to analog form by the DAC and transmitted through the RF block. The receiving section is just the opposite of the sending section. The received signal after being processed through the RF section and the ADC, is removed of the cyclic prefix. The system then converts the signal into a parallel data stream to input to the FFT block. The equalization block comes next. Thereafter, the Demapper block demodulates the signal. The signal is further de-interleaved and decoded to get the original bit stream as was sent at the transmitter.

B. Mathematical Model for OFDM Systems

Considering an Orthogonal Frequency Division Multiplexing system containing 'J' sub-carriers, the sequence $\{k_0, k_1, k_2 \ldots k_{n-1}\}$ is mapped onto these J-subcarriers in parallel; the transfer rate for said sequence being 1/T, thereby achieving a reduction in the transmission rate for the signal to,

$$\frac{1}{T_s} = \frac{1}{JT} \quad (1)$$

We may say that the 'J' parallel information symbols K_n (n = 1,2,3…J) as the Orthogonal Frequency Division Multiplexing signal; the cycle for the symbol being T_s, so writing the expression for the Orthogonal Frequency Division Multiplexing signal in its complex envelope form is:

$$a(t) = \frac{1}{\sqrt{J}} \sum_{n=1}^{J} X_n \, rect\left[\frac{t}{T_s} - \frac{1}{2}\right] e^{j2\pi f_n t} \quad (2)$$

$1/\sqrt{J}$ is the factor of power normalization.

$$f_n = \frac{n-1}{T_s} \quad ; \quad n = 1, 2, 3, \ldots \ldots . J \quad (3)$$

Sampling the complex envelope for the Orthogonal Frequency Division Multiplexed signal a(t) for the time instant, $t = (v-1)T_s/N$

$$a_v = \frac{1}{\sqrt{J}} \sum_{n=1}^{J} K_n \, e^{j2\pi(n-1)(v-1)/J} \quad (4)$$

Consider the channel to be $c(\tau, T)$ and AWGN, the signal is:

$$b(t) = \int_0^{\tau_{max}} a(t-\tau)c(t,\tau)d\tau + n(t) \quad (5)$$

Now, considering the received signal and performing an FFT transform on it, the following multicarrier sequence of modulation is achieved, $\{R_n\}$; for {n = 1,2,3….,J}

$$R_n = \frac{1}{\sqrt{J}} \sum_{n=1}^{J} b_v \, e^{-j2\pi(n-1)(v-1)/J} \quad (6)$$

Now, selecting the sub-carrier number that is necessary i.e., J; the response of the channel would become flat and thus the problem of ICI would be eliminated.

III. WINDOWING

A. Raised Cosine (RC) Windowing

The signal that is transmitted as the Orthogonal Frequency Division Multiplexed signal has a composition involving IFFTs that are joined together. Thus considering the boundary of each of the symbol period there occurs a certain discontinuity with regards to the differences between the end and the beginning of period i.e. very large side lobes are generated and the spectrum falls off rather slowly. If we were to increase the sub-carrier number, the roll-off for the spectrum would be sharp in the beginning, but would get worse further from the 3db cut-off frequency. The effect of these discontinuities which would appear as the transitions considering the time waveforms that are very fast is that a certain high frequency spectral noise is generated [4]. Therefore, to avoid this high frequency spectral noise, a window function namely Raised Cosine (RC) window function is used on individual symbol periods. The Raised Cosine (RC) function will accomplish the attenuation of the said waveform beginning and ending at each period, leading to smaller discontinuity thereby reducing the generated (high frequency) noise component. Care has to be taken that the attenuation thus generated does not distort the desired frequency content [5]. The RC (Raised Cosine) window is given by,

$$w(t) = \begin{cases} 0.5 + 0.5\cos\left(\pi + \frac{\pi t}{\beta T_r}\right), 0 \le t \le \beta T_r \\ 1.0, \quad \beta T_s \le t \le T_r \\ 0.5 + 0.5\cos\left((t - T_r) + \frac{\pi t}{\beta T_r}\right), T_s \le t \le (1+\beta)T_r \end{cases} \quad (7)$$

Here, T_r is the interval of the symbol. It is so chosen that this interval is of shorter duration than the duration of the Orthogonal Frequency Division Multiplexing symbol, as a partial overlap for the symbols is also allowed in the region of roll-off for the RC Window. Applying the Window function, the representation of the Orthogonal Frequency Division Multiplexing symbol is represented by the following equation,

$$R(t) = 2\,Re\left\{w(t)\sum_{n=0}^{N-1} d_n e^{j2\pi nt/T}\right\}, for\ 0 \le t \le T \quad (8)$$

B. Mathematical Analysis

Suppose that the normalized duration of the window is (1+β), now this value represents the normalized duration of RC Window, the roll-off factor for which is 'β'. That's to say that a window length extension is observed by 'β' when a comparison is done with the traditional rectangle window function ensuring a faster roll-off. The function thus used is split up into a series of cosine functions of period (1+β) i.e.,

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 8, August 2014

$$w(t) = \begin{cases} \sum_{k=0}^{J} b_k, & |t| \le \frac{1-\beta}{2} \\ \sum_{k=0}^{J} b_k \cos(\frac{k\pi}{\beta}(|t|) - \frac{1-\beta}{2}), & \frac{1-\beta}{2} < |t| \le \frac{1-\beta}{2} \end{cases} \quad (9)$$

It is observed from the above equation (9) that for J=1 and $a_0=a_1=1/2$, that it is reduced to the Raised Cosine (RC) having a roll-off factor of 'β'.
Then,

$$w(t) = \frac{1}{2} + \sum_{k=0}^{L} b_{u_k} \cos\left(\frac{\pi\mu_k}{\beta}(t-\varphi)\right), \frac{1-\beta}{2} < |t| \le \frac{1+\beta}{2} \quad (10)$$

Where, $L = \lfloor J - 1/2 \rfloor$, $u_k = (2k+1)$ and $\lfloor\_\rfloor$ signifies floor function, 't' determines the 'φ' value.

$\varphi = \frac{1-\beta}{2}$ for $\frac{1-\beta}{2} < t \le \frac{1+\beta}{2}$ and
$\varphi = \frac{-1-\beta}{2}$ for $\frac{-1-\beta}{2} < t \le \frac{-1+\beta}{2}$.

Now, after computing the derivatives for the p^{th} order, we get,

$$w^{(p)}(t) = \begin{cases} (-1)^{\frac{p+1}{2}} \sum_{k=0}^{L} b_{u_k} c_k^p \sin(c_k(t-\varphi)), & p\ odd \\ (-1)^{\frac{p}{2}} \sum_{k=0}^{L} b_{u_k} c_k^p \cos(c_k(t-\varphi)), & p\ even \end{cases} \quad (11)$$

Where, $c_k = \frac{\pi\mu_k}{\beta}$.

At the end-points$\left(t = \pm\frac{1+\beta}{2}\right)$, one gets the values

$$w^{(p)}\left(\pm\frac{1+\beta}{2}\right) = \begin{cases} (-1)^{\frac{p+1}{2}} \sum_{k=0}^{L} b_{u_k} (\pi\mu_k)^p & ,p\ even \\ 0 & ,p\ odd \end{cases} \quad (12)$$

Thus, it is observed that to get the first 'K' derivatives null for the endpoints series coefficients must be thus chosen so that the following condition is satisfied,

$$\sum_{k=0}^{L} b_{2k+1}(2k+1)^p = 0 \quad ,p = 2,4,\ldots.2\lfloor M/2 \rfloor \quad (13)$$

IV. EQUALIZATION

The multicarrier modulation method protects the transmitted signal against the deteriorating effects of the multipath fading channel before transmission by incorporating cyclic prefix and pilot carriers in the time domain and the frequency domain respectively. The cyclic prefix tends to prevent the inter symbol interference (ISI) by having a duration that is greater than the delay of the multipath that is observed in the channel. Also, another type of interference called the intra symbol interference exists which is the result of the symbols that interfere with each other which leads to modification of the phase and amplitude of the received signal. To mitigate these effects, sub-carriers also known as pilot carriers are transmitted with the role of estimating the multipath channel behavior. With this estimation at hand, equalization can be performed [6]. Usually, OFDM systems are designed in such a way that there aren't any variations in the channel within the Orthogonal Frequency Division Multiplexing (OFDM) symbol. But due to the rapidly varying environment (channel), the coherence time decreases to large extent and becomes lesser than the period of symbol duration for OFDM. Hence, the orthogonality between the sub-carriers which gives the OFDM technique its signature advantage of efficiency tends to deteriorate which leads to Inter-carrier Interference (ICI). These transmission impairments could be dealt with using channel equalization on the receiving side. It is used in general to compensate the ISI that is induced by the channel and that which is brought about by the filters. It is accomplished by finding the product of the Orthogonal Frequency Division Multiplexing (OFDM) spectrum and the channel impulse response for the sub-carrier frequencies. So, equalization tends to compensate for ISI impairment that is created due to multipath within channels that are dispersed in time. For the radio channel under consideration, if the bandwidth of modulation is greater than the coherence bandwidth, the modulation pulses spread out thus leading to ISI. Now, an Equalizer at the receiver stage compensates for the normal gamut of values for the delay characteristics and channel amplitude. In general, in the equalization techniques the analog signal is considered for processing by the device that determines all the decisions at the receiving end. The values of the data bits received are determined by it. Then, it applies a thresholding (slicing) function to determine its value. Here in the zero forcing equalizer that is used the input signal isn't considered while adapting the equalizer through a feedback path thus leading to a linear operation.

A. *Zero Forcing (ZF) Equalizer*

In order to remove the ISI, the simplest way is to choose a transfer function $H_E(Z)$ for an LTI filter so that we obtain the information as the equalizer output i.e. $\widehat{I_k} = I_k$ for every k considering the absence of any noise component. This is accomplished simply by taking the value of transfer function as, $H_E(Z) = 1/J(z)$. The above mentioned technique is known as ZF (Zero Forcing) equalization as the components for ISI are forced to zero at the equalizer output [7]. Now, although the effect of the equalizing filter is neglected in the design of the said filter but the noise component is always present. To see this, here we evaluate the SNR at the ZF (Zero Forcing) Equalizer output of the ZF equalizer. The conditions for the above observation are a fixed value of the transmission filter $H_T(f)$ and a matched filter composition of the receiving filter i.e.,

$$H_R(f) = H_T^*(f)H_C^*(f) \quad (14)$$

Here, the digital filter $H(Z)$ is given by:

$$H(e^{j2\pi fT}) = \frac{1}{T}\sum_{n=-\infty}^{\infty} \left|H_T(f-\tfrac{n}{T})H_C(f-\tfrac{n}{T})\right|^2 \quad (15)$$

Gaussian noise sample's Power Spectral Density (n_k) is,

$$\varphi_{n_k}(e^{j2\pi fT}) = \frac{N_0}{2T}\sum_{n=-\infty}^{\infty} \left|H_T(f-\tfrac{n}{T})H_C(f-\tfrac{n}{T})\right|^2 \quad (16)$$

Therefore, the NW (Noise-Whitening) filter $H_w(z)$ could be,

$$H_w(e^{j2\pi fT}) = \frac{1}{\sqrt{H(e^{j2\pi fT})}} \quad (17)$$

Thus, the Power Spectral Density of the samples of noise that are whitened $(\widetilde{n_k})$ could be, $N_0 = 2$. Therefore the overall digital filter, $J(z)$

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 8, August 2014

$$J(e^{j2\pi fT}) = H(e^{j2\pi fT})H_w(e^{j2\pi fT}) = \sqrt{H(e^{j2\pi fT})} \quad (18)$$

Now, we choose the zero-forcing equalizer coefficient $H_E(Z)$ as,

$$H_E(e^{j2\pi fT}) = \frac{1}{J(e^{j2\pi fT})} = \frac{1}{\sqrt{H(e^{j2\pi fT})}} \quad (19)$$

As the ZF equalizer just inverts the channel effects on the originally sent bits of information or symbols (I_k), the received component of the signal must also be (I_k). Now, should we try and model the symbol information as unity value for variance and the null mean values for 2nd random variables, then the Power Spectral Density of the component of the signal would be unity, therefore at the output of the equalizer, the signal energy would just be,

$$\int_{-1/2T}^{1/2T} df = \frac{1}{T}. \quad (20)$$

Also, the Power Spectral Density for the component of the noise at the output of the equalizer is, $\frac{N_0}{2} H_E(e^{j2\pi fT})^2$. This implies that the noise energy at the output of the equalizer is, $\int_{-1/2T}^{1/2T} \frac{N_0}{2} \left|H_E(e^{j2\pi fT})\right|^2$.

V. SIMULATION AND RESULTS

A. BER for OFDM

The analytical expressions of Bit Error Rate (BER) considering M-ary QAM mapping technique for Orthogonal Frequency Division Multiplexing (OFDM) considering the Additive White Gaussian Noise (AWGN) channel and the Rayleigh fading channel is [8],

$$P_e = \frac{2(M-1)}{M\log_2 M} Q\left(1 - \sqrt{\frac{6\,E_b.\log_2 M}{N_0.M^2-1}}\right) \quad :\text{AWGN} \quad (21)$$

$$P_e = \frac{(M-1)}{M\log_2 M}\left(1 - \sqrt{\frac{3\gamma\,\log_2 M/(M^2-1)}{3\gamma\,\log_2 M/(M^2-1)+1}}\right) \quad :\text{Rayleigh} \quad (22)$$

Where γ and M denote SNR and the Order of Modulation, while Q (.) is the traditional Q-function given by,

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{-t^2}dt \quad (23)$$

B. Results and Discussions

In the simulation, we considered OFDM system using 16-QAM modulation scheme. Figure 2 shows the simulation result of the BER performance of the OFDM systems without Raised Cosine (RC) window function or Equalization in different channels namely AWGN and Rayleigh Fading channels. It's clear from the figure 2 that the theoretical value of Bit Error Rate (BER) for AWGN channel is better than that for Rayleigh Channel.

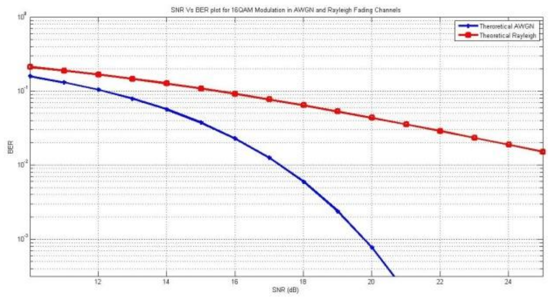

Fig. 2. Bit Error Rate (BER) versus Signal-to-Noise Ratio (SNR) for traditional OFDM with 16-QAM modulation scheme for AWGN and Rayleigh Fading Channels.

Figure 3 shows the comparison between the theoretical BER vs. SNR result for the AWGN channel and the simulated result obtained after applying the Raised Cosine (RC) window function and Equalization operation on the OFDM system that is achieved using 16-QAM modulation scheme.

It is observed that the Orthogonal Frequency Division Multiplexing (OFDM) using the modulation technique of 16-QAM modulation along with RC (Raised Cosine) window function and ZF (Zero Forcing) Equalization technique has achieved the Signal-to-Noise Ratio (SNR) of 16 dB as opposed to 21 dB for $10^{-2.9}$ Bit Error Rate (BER) for Traditional Orthogonal Frequency Division Multiplexing (OFDM) under the AWGN channel. So, we have achieved a 5 dB improvement for the proposed OFDM system.

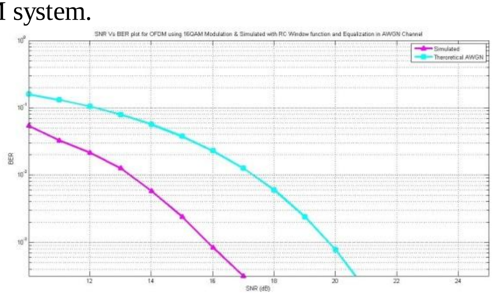

Fig. 3. Bit Error Rate (BER) versus Signal-to-Noise Ratio (SNR) for Orthogonal Frequency Division Multiplexing (OFDM) with 16-QAM modulation scheme with RC (Raised Cosine) windowing and ZF (Zero Forcing) Equalization for traditional OFDM in AWGN Channel.

Figure 4 shows the comparison between the theoretical BER vs. SNR result for the Rayleigh Fading channel and the simulated result obtained after applying the Raised Cosine (RC) window function and Equalization operation on the OFDM system that is achieved using 16-QAM modulation scheme. It is observed that the Orthogonal Frequency Division Multiplexing (OFDM) using 16-QAM modulation technique and Raised Cosine (RC) window function and Zero Forcing (ZF) Equalization technique achieves the value of Signal-to-Noise Ratio (SNR) of 34 dB as compared to the Signal-to-Noise Ratio value of 19 dB for $10^{-2.9}$ BER for the AWGN channel. So, a 15 dB improvement has been achieved with the Orthogonal Frequency Division Multiplexing (OFDM) system that is proposed as opposed to the traditional system.

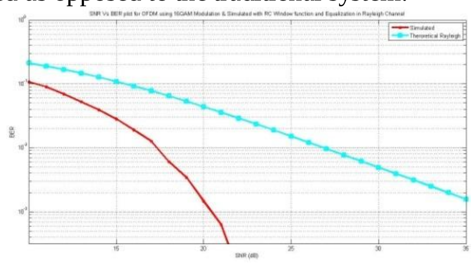

Fig. 4. Bit Error Rate (BER) versus Signal-to-Noise Ratio (SNR) for Orthogonal Frequency Division Multiplexing (OFDM) with 16-QAM modulation scheme with RC (Raised Cosine) windowing and ZF (Zero Forcing) Equalization for traditional OFDM in Rayleigh Fading Channel.

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 8, August 2014

Finally all the results achieved for the proposed OFDM system with Raised Cosine (RC) window and Zero-Forcing (ZF) Equalization under both the channels namely AWGN and Rayleigh Fading channel have been compared in Figure 5. The BER vs. SNR results for OFDM using 16-QAM modulation technique are plotted together. It is observed that the least BER is for the AWGN channel. The value of BER increases for Rayleigh Fading channel.

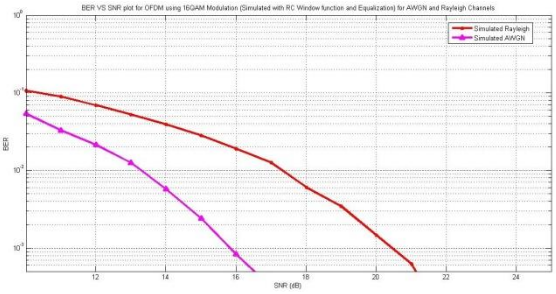

Fig. 5. Bit Error Rate (BER) versus Signal-to-Noise Ratio (SNR) for Orthogonal Frequency Division Multiplexing (OFDM) with 16-QAM modulation scheme with RC (Raised Cosine) windowing and ZF (Zero Forcing) Equalization in AWGN and Rayleigh Fading Channel.

VI. CONCLUSION

OFDM is a technique for modulation where many carriers that have a lower data rate are combined, thereby giving rise to a high data rate composite transmission signal. Overlap of the sub channels is allowed thereby making an efficient use of the limited available spectrum. The OFDM technique is much more resistant to fading that is frequency selective due to its multi-carrier transmission characteristics. In this paper, the Bit Error Rate (BER) analysis is done considering the Fast Fourier Transform (FFT) based Orthogonal Frequency Division Multiplexing (OFDM) scheme. The FFT based OFDM under consideration uses 16-QAM technique for modulation for two channel models namely Additive White Gaussian Noise (AWGN) and Rayleigh Fading Channel. These channel models coupled with the window function of Raised Cosine (RC) and equalization technique of Zero-Forcing (ZF) are used for calculating the Bit Error Rate result. In this paper, we have used RC (Raised Cosine) Window function and ZF (Zero Forcing) Equalization technique in the traditional Orthogonal Frequency Division Multiplexing (OFDM) system using the modulation technique of 16-QAM modulation at $10^{-2.9}$ Bit Error Rate (BER). The result is that a 5 dB improvement is achieved in the Signal-to-Noise Ratio (SNR) value for Additive White Gaussian Noise (AWGN) Channel as compared to traditional OFDM used in the same channel model. And a 15dB improvement is achieved in the Signal-to-Noise Ratio (SNR) value for Rayleigh Channel as compared to traditional OFDM for the same channel model at $10^{-2.9}$ Bit Error Rate (BER).

REFERENCES

[1] I. Kuzle, Hrvoje Pandzic, and Darjan Bosnjak, "The true inventor of the radio communications," IEEE History of Telecommunications Conference, pp. 20-23, 2008.
[2] L. Dell Uomo and E. Scarrone, "The Path towards the 4G Network and Services: The Wine Glass Vision," 5th Personal Mobile Communications Conference, pp. 169 – 175, 2003.
[3] Bae Kitaek, Shin Changyong, and E.J. Powers, "Performance Analysis of OFDM systems with Selected Mapping in the presence of Non-Linearity," IEEE Transactions on Wireless Communications, vol. 12, no. 5, pp. 2314 – 2322, 2013.
[4] D. Castanheira and A. Gameiro, "Novel Windowing Scheme for Cognitive OFDM Systems," IEEE Wireless Communications Letters, vol. 2, no. 3, pp. 251 – 254, 2013.
[5] Akhilesh Chandra Bhatnagar, R.L. Sharma, and Rajesh Kumar, "BER Improvement Using Windowing Technique in OFDM Systems," International Journal of Engineering and Innovative Technology, vol. 2, no. 1, 2012.
[6] S.H. Song and K.B. Letaief, "Diversity Analysis for Linear Equalizers over ISI Channels," IEEE Transactions on Communications, vol. 59, no. 9, pp. 2414 – 2423, 2011.
[7] Chun-Hsien Wu and Shiunn-Jang Chern, "Minimum BER Block-Based Precoder Design for Zero-Forcing Equalization: An Oblique Projection Framework," IEEE Transactions on Signal Processing, vol. 55, no. 12, pp. 5630-5642, 2007.
[8] A Sudhir Babu and Dr. K.V. Sambasiva Rao, "Evaluation of BER for AWGN, Rayleigh and Rician Fading Channels under Various Modulation Schemes," International Journal of Computer Applications, vol. 26, no. 9, 2011.

BIOGRAPHIES

Ankush Kansal received his B.Tech. and M.Tech. Degree in Electronics and Communication Engineering from PTU, Jalandhar. He is currently pursuing Ph.D. from Thapar University, Patiala in the area of Wireless Communication. He is currently working as Assistant Professor in Thapar University, Patiala. He has published 10 research articles in referred international journals, international conference and national conference. He is a life time member of ISTE. His research interest includes Networking, Wireless Communication and Embedded Systems.

Nikhil Bhardwaj received his Diploma in Electronics and Communication Engineering from Thapar Polytechnic Institute, Patiala, Punjab, in 2006; B.Tech. Degree in Electronics and Communication Engineering from Chitkara Institute of Engineering and Technology (PTU) Punjab, in 2009. He is currently pursuing his M.E. degree in Electronics and Communication Engineering from Thapar University, Patiala under the guidance of Mr. Ankush Kansal. His current research interests include wireless communication, multi-carrier communication and OFDM.