A Wavelet-Based Approach with NLMS Equalization and Fading Channel Compensation for Improved Spectral Efficiency and Error Rate

Harilal J[1], Kalpana K[1], Shirisha[1]

[1]*Assistant Professor, Department of ECE*
[1]*Malla Reddy Engineering College and Management Sciences, Hyderabad, Telangana, India*

Abstract

Within the realm of communication, Orthogonal Frequency Division Multiplexing (OFDM) has emerged as a highly effective and commendable approach. The fundamental structure of Orthogonal Frequency Division Multiplexing (OFDM) encompasses the utilization of Fast Fourier Transform (FFT) to efficiently compute the Discrete Fourier Transform (DFT) of a given source signal through expedited computational processes. Nevertheless, the Orthogonal Frequency Division Multiplexing (OFDM) system utilizing Fast Fourier Transform (FFT) encounters various limitations, such as inadequate localization, increased error rates at high data rates, and limited spectrum efficiency. In order to tackle these issues, the utilization of wavelet-based orthogonal frequency division multiplexing (OFDM) emerged as an alternative to substitute the fast Fourier transform (FFT) with the discrete wavelet transform (DWT). In this study, we have designed an upgraded discrete wavelet transform-orthogonal frequency division multiplexing (DWT-OFDM) system using normalized least mean squares (NLMS) equalization approach. The objective of this implementation is to minimize the bit error rate (BER) values in comparison to the conventional fast Fourier transform-orthogonal frequency division multiplexing (FFT-OFDM) system. Furthermore, a channel equalization technique is also suggested for fading environments, such as Rayleigh, Rician, and additive white Gaussian noise (AWGN) circumstances. Additionally, the BER comparison also includes various modulation levels, which reveal the effectiveness of the proposed system compared to the typical FFT-OFDM method.

Keywords: OFDM, FFT, DWT, normalized least mean square, AWGN, Rayleigh, Rician.

1. Introduction

Rapid enhancement of the technology has made it potential for the communication systems to transfer the data everywhere. But due to the assigned bandwidth limitation, it restricts the availability of bandwidth to the many users, which motivated the researchers to implement the bandwidth efficient transmission of data over a wireless communication system. Due to the frequency selective (FS) fading channels there is an occurrence of inter symbol interference (ISI), which in results degradation in the communication system channels performance which operates for higher data rates. Generally, the impairments like ISI, shadowing and fading caused due to the multiuser accessibility. These impairments create unnecessary distortions in the communication system which leads to the system degradation and higher the BER values. To address this issue, multicarrier modulation (MCM) approach is presented, which transmits the input serial data stream as few parallel streams with low data rate [1-2]. Orthogonal frequency division multiplexing (OFDM) is a such technique which operates based on multi-carrier modulation approach. OFDM generates few parallel subcarriers by dividing the available spectrum and then each of them gets modulated by a low rate data stream at various carrier frequencies [3]. Figure 1 disclosed that the DFT-based OFDM system which multiplexes the modulated signal using inverse fast fourier transform (IFFT) in the transmitter section later fast fourier transform (FFT) utilized in the receiver section that reduces the complexity at both transmitter and receiver end [4]. OFDM is constituted of a modulation and multiplexing combination. In OFDM, many independent signals will be generated by splitting the original data streams, each of which is modulated at a various frequency ranges and then these are multiplexed to produce an OFDM carrier. Due to the orthogonality nature of each subcarrier in OFDM, simultaneous transmission can be done without interference over the same bandwidth [4]. It makes the stronger high-speed data streams those are against to the impairments caused in radio channel environment.

OFDM is an effective approach to deal with the higher data rate transmission even under multipath fading environment. With the assistance of OFDM, parallel transmission of overlapped narrowband orthogonal subcarriers is done within the availability of transmission bandwidth, which in results efficient utilization of available spectrum. It also has the capability to fulfil this requirement for larger capacities and it is more economical and reliable to handle the processing power of digital signal processors [5]. All these advantages make OFDM a strong candidate for the 5^{th} generation wireless communication systems. Nowadays, it is utilized in various applications in the field of communication systems and telecommunication networks like IEEE 802.11 wireless standard, general switched telephone network (GSTN), cellular radios, digital audio, terrestrial digital video and high-definition television (HDTV) broadcasting, modems with digital subscriber line (DSL) and asymmetric DSL (ADSL), high performance local area network (HIPERLAN) type I and type II. Discrete wavelet transforms based OFDM (DWT-OFDM) [6], which is also an MCM technique, possesses almost all advantages and disadvantages of conventional (Fourier based) OFDM.

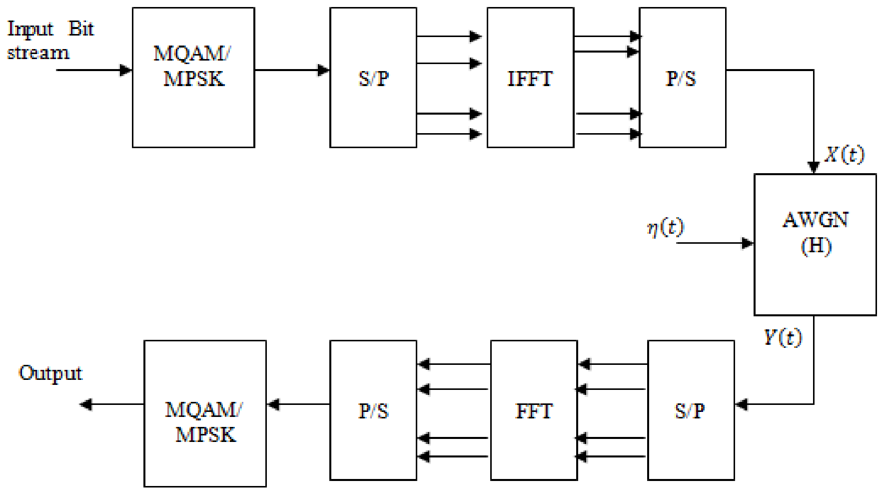


Figure 1. DFT based OFDM system.

In this technique, the sub bandwidth division is obtained by using the inverse discrete wavelet-based transforms, whereas conventional OFDM uses IFFT [7]. Another main difference is that W-OFDM symbols overlap in both time and frequency domains, whereas OFDM symbols overlap only in frequency domain. Therefore, adding CP to the DWT-OFDM symbol frame does not have any effect on the bit error rate (BER) performance, as also shown in this work. One major advantage of DWT-OFDM compared to OFDM is that DWT-OFDM is more bandwidth efficient than OFDM [8-9].

The novel contributions of this work can be summarized as follows:

- Novel utilization of DWT based OFDM under fading channel environment conditions.

- A fully new framework for DWT-OFDM system is proposed by utilizing NLMS equalization with fading channel environment.
- We mainly aimed at enhancing the spectral efficiency, mitigation of BER performance and channel equalization under fading conditions which was not focused in the past research work done in this field.

The rest of the paper is organized as follows: Section II provides a brief description of the related work. The proposed system model is described in Section III. Section IV explains the results and comparative evaluations against various works presented in the literature. Finally, Section V concludes the paper followed by references.

2. Related Work

Author in [10] presented a performance assessment of DFT-OFDM and DWT-OFDM in presence of high-power amplifier (HPA) non-linearity. In [11], author has presented a DWT-IDWT based OFDM transmitter and receiver that achieved better performance in terms BER for AWGN channel. It has proven that all the wavelet performs better over the conventional IFFT-FFT implementation. Later they presented a comparative analysis on DWT-OFDM and FFT-OFDM systems. Also, selection of mother wavelet is disclosed in this [12] with various wavelet families. In [13], DCT based OFDM system is presented and compared with the W-OFDM system which worked on 60GHz band of frequency. Author in [14] disclosed the comparison analysis of DFT-OFDM with DCT-OFDM under Rayleigh fading channel. Performance evaluation of DFT-OFDM and DWT-OFDM with channel estimation techniques like least square (LS) and linear minimum mean square error (LMMSE) is presented in [15]. Further, they evaluated the performance of BER with various wavelets and the performance of mean square error (MSE) with LS and LMMSE estimators through block type pilot-based methodology.

3. Proposed Methodology

3.1. Wavelet based OFDM system

General OFDM system with inclusion of wavelet by replacing the FFT block provides an efficient spectral efficiency with reduced BER since the advancement of wavelets over FFT-OFDM. A perfect reconstruction of a signal is possible by the DWT approach and it reduces the complexity of hardware since the DWT-OFDM doesn’t need the cyclic prefix (CP), which leads to the mitigation of bandwidth wastage and transmission power thereby enhances the data rate transmission to the ultra-speed. It is an effective approach for analyzing the signals in both spatial and spectral domain and found that the better orthogonality can be provided by the DWT since it has compact localization in both time and frequency domains. Due to the properties of high spectral restraint, DWT could combat the narrowband interference and can make the communication system more robust and effective against the inter-carrier interference (ICI), which is a huge drawback of conventional FFT realization based OFDM. Due to these advancements, DWT has utilized in various fields like compression, computer vision, radar systems, astronomy, nuclear engineering, biomedical, acoustics, computer graphics and animation, seismology, satellite and remote sensing, fractals and pure mathematics.

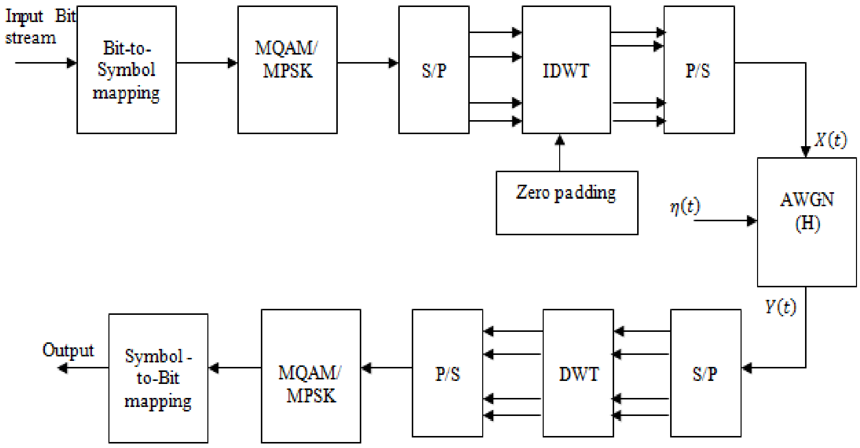


Fig. 2: DWT based OFDM system with AWGN channel.

The structure of DWT-based OFDM system is demonstrated in figure 2. The modulated signal is transmitted using zero padding and vector transposing. DWT can decompose the input signal into number of sub bands which is known as approximated and detail coefficients as shown in figure 2. These coefficients provide a far better analysis of a signal with both time and frequency scaling. Since DWT has many advantages such as flexibility, lesser sensitivity against interference and channel distortion with the optimal spectrum utilization, it has been proposed to design the advanced wireless communication systems like 5G networks and beneficial in various aspects such as modelling of channel, designing of transceivers data representation, source and channel coding, energy efficient networking and signal de-noising in wireless communication systems.

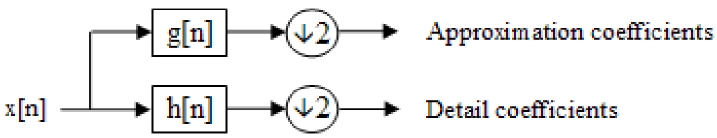


Fig. 3: Filter analysis diagram of wavelet.

As shown in figure 3, approximated and detail coefficients of a source signal x is computed by passing it via filter series like lowpass and high-pass filter banks. The input samples sent via a low-pass filter with impulse response g leads to the convolution of the two:

$$y[n] = (x * g)\,[n] = \sum_{k=-\infty}^{\infty} x[k]g[n-k] \qquad (1)$$

A simultaneous decomposition is done by utilizing the high-pass filter h which produces the detail coefficients. It is vital that the both low-pass and high-pass filters should be related to each other, which can also call as quadrature mirror filter (QMF). Figure 4 show that the multi-level decomposition of DWT process. It demonstrated that the 3-level decomposition. In first level of decomposition approximated and detail coefficients is obtained after applying the down-sampling process. In second and third stage, the detail coefficients from the level one and two ignored respectively and only approximated coefficients further decomposed into approximated and detail coefficients.

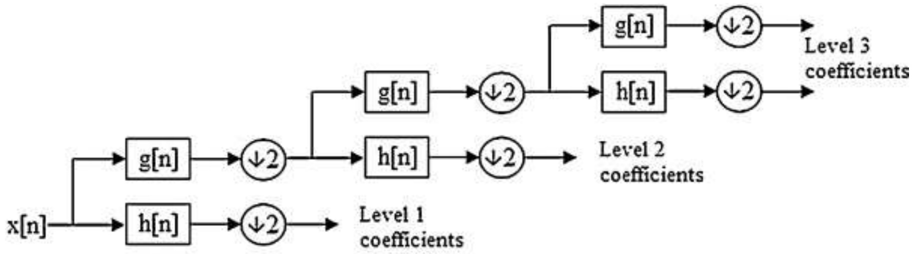


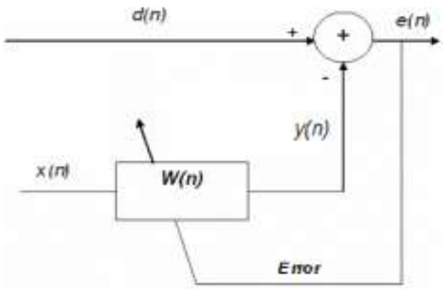
Fig. 4: Multi-level decomposition of DWT.

3.2 LMS Algorithm

Consider a length L, LMS based adaptive filter, depicted in Figure 5, that takes an input sequence $x(n)$ and updates the weights as

$$w(n+1) = w(n) + \mu x(n) * e(n) \quad (2)$$

where, $w(n) = [w_1(n)\, w_2(n) \cdots\, w_{L-1}(n)]^t$ is the tap weight vector at the n^{th} index, $x(n) = [x(n)\, x(n-1) \cdots\, x(n-L+1)]^t$, error signal $e(n) = d(n) - w^t(n)x(n)$, with d(n) being so-called the desired response available during initial training period and μ denoting so-called step-size parameter.



-

Fig. 5: Adaptive filter structure.

In order to remove the noise from the signal, the signal $s_1(n)$ corrupted with noise signal $p_1(n)$ is applied as the desired response $d\,(\,n)$ to the adaptive filter shown in Fig. 5. If the noise signal $p_2(n)$, possibly recorded from another generator of noise that is correlated in some way with $p_1(n)$ is applied at the input of the filter, i.e., $x(\,n) = p_2(n)$ the filter error becomes $e(n) = [s_1(n) + p_1(n)] - y(n)$. Where, $y(n)$ is the filter output and it is given by

$$y(n) = w^t(n) * x(n) \quad (3)$$

Since the signal and noise are uncorrelated, the mean square error (MSE) becomes

$$E[e^2(n)] = E\{[s_1(n) - y(n)]^2\} + E[p_1^2(n)]$$

Minimizing the MSE results in a filter output which is the best least-squares estimate of the signal $s_1(n)$.

3.3 NLMS Algorithm

Normalized LMS (NLMS) algorithm is another class of adaptive algorithm used to train the coefficients of the adaptive filter. This algorithm considers variation in the signal level at the filter output and selecting the normalized step size parameter that results in a stable as well as fast converging algorithm. The weight update relation for NLMS algorithm is as follows

$$w(n+1) = w(n) + \left[\frac{\mu}{p+x^t(n)x(n)}\right] * x(n)e(n) \quad (4)$$

The variable step can be written as,

$$\mu(n) = \frac{\mu}{p + x^t(n)x(n)}$$

Here μ is fixed convergence factor to control maladjustment.

4. Results and Discussion

Simulations have been done in MATLAB 2014a version with 4GB RAM. We tested the conventional and proposed scheme with various modulation levels that are used for the LTE. Modulations that could be used for LTE are 4-QAM, 16-QAM and 32-QAM (Uplink and downlink).

Table 1. Simulation parameters.

Parameters	**FFT-OFDM**	**DWT-OFDM**
Input data	10^4 bits	10^4 bits
No. of Subcarriers	32, 64, 128 and 256	32, 64, 128 and 256
Cyclic prefix	1	---
Channel model	AWGN, Rayleigh and Rician	AWGN, Rayleigh and Rician
Modulation scheme	QAM	QAM
Constellation points	4, 8,16, 32, … and 128	4, 8,16, 32, … and 128
OFDM block size	8	8
Zero padding	---	Yes

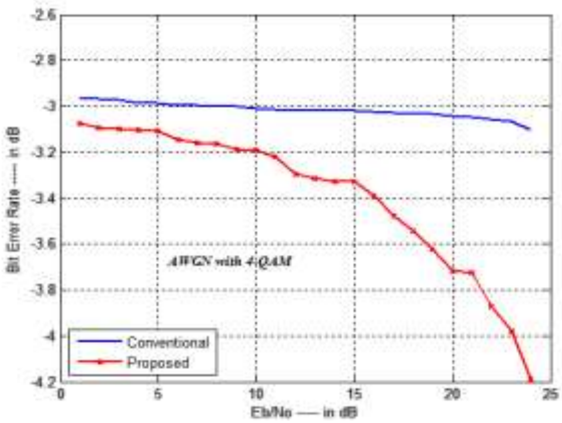


Fig. 6. BER performance of proposed and conventional system with AWGN and 4-QAM.

For the purpose of simulation, signal to noise ratio (SNR) of different values are introduced through Rayleigh, Rician and AWGN channel. Data of 10,000 bits is sent in the form of 100 symbols, so one symbol is of 100 bits. Averaging for a value of SNR for all the symbols is done and BER is obtained, and same process is repeated for all the values of SNR and final BERs are obtained. Fig. 6 show that the comparison of BER performance for FFT-OFDM and DWT-OFDM using 4-QAM modulation techniques. This figure shows the relationship between BER and SNR. The values of SNR are from 0 dB to 25 dB and the scale of SNR is linear. The similar performances of BER with the FFT-OFDM and DWT-OFDM is shown in fig. 7 and fig. 8 for 16-QAM and 32-QAM respectively.

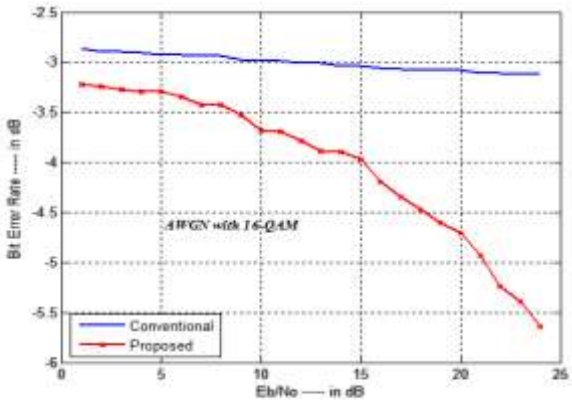


Fig. 7: BER performance of proposed and conventional system with AWGN and 16-QAM.

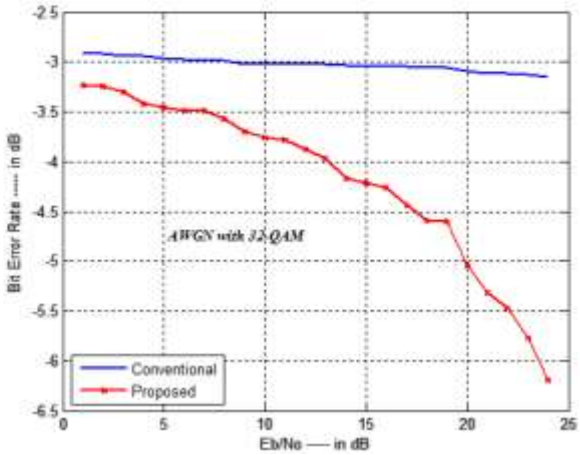


Fig. 8: BER performance of proposed and conventional system with AWGN and 32-QAM.

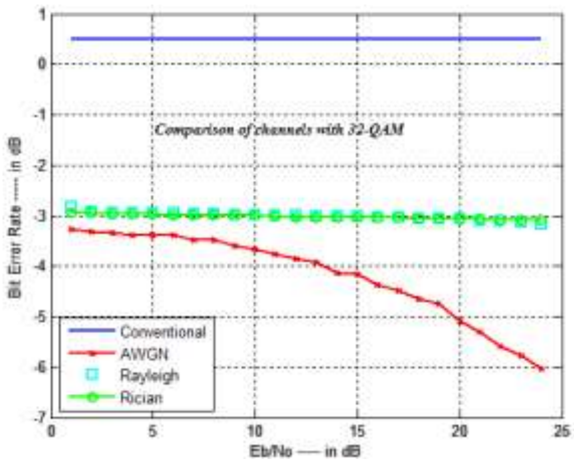


Fig. 9: BER performance of proposed and conventional system with 32-QAM under AWGN, Rayleigh and Rician channels.

Fig. 9 demonstrated that the outcome of BER performance with various fading channels like AWGN, Rayleigh and Rician, out of which AWGN shown the superior performance. Further, performance of equalization methods disclosed in fig. 11 and fig. 12 which utilizes the recursive least square (RLS) and proposed NLMS respectively.

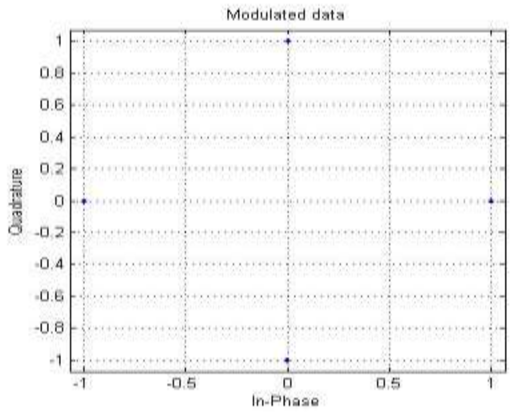


Fig. 10: Modulated data using 4-QAM.

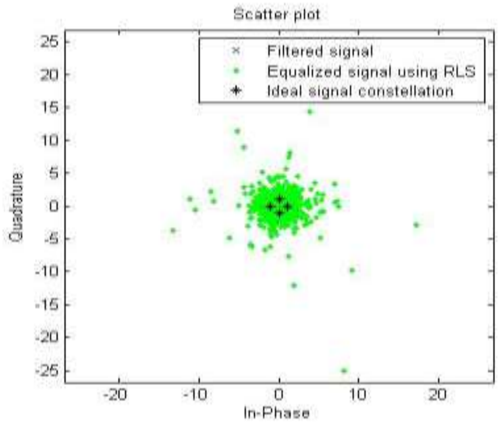


Fig. 11: Performance of equalization using RLS algorithm.

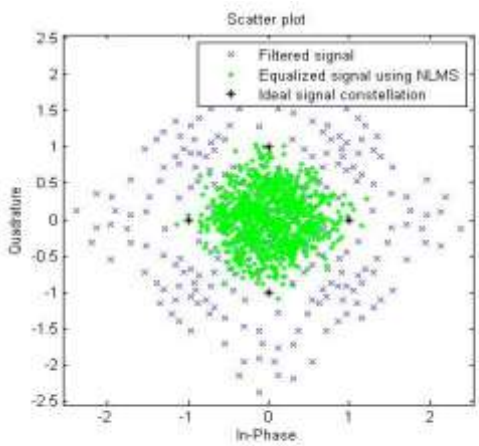


Fig. 12: Performance of equalization using NLMS algorithm.

Fig. 13 depicted that the BER values of proposed NLMS and RLS equalization algorithms, it also compared the BER value of DWT-OFDM system without any equalization method. NLMS algorithm has got a BER of 0.1620, whereas without equalization it is around 0.364 and RLS equalization is 0.74

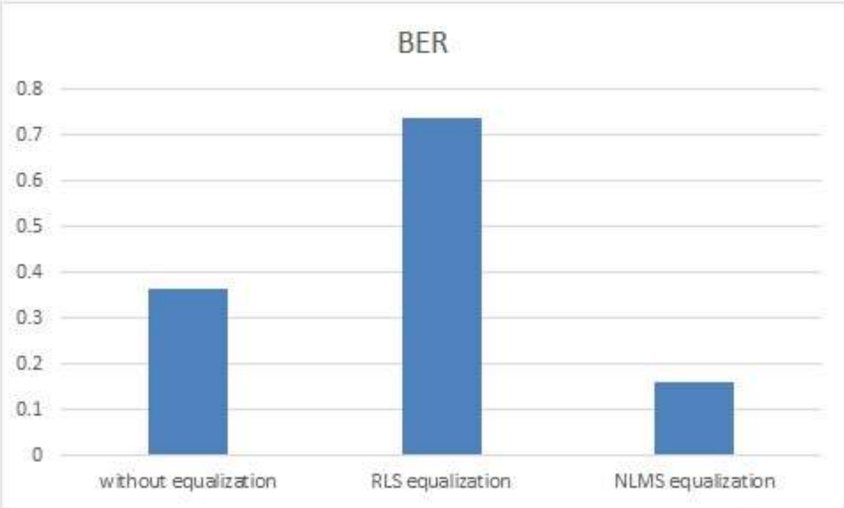


Fig. 13: Performance BER with equalization methods.

5. Conclusion

The FFT-OFDM and DWT-OFDM system is studied over flat fading channels using AWGN, Rayleigh and Rician model for 10000 bits. Proposed DWT-OFDM outperformed the existing FFT-OFDM in terms BER performance. Further, it concludes that performance of DWT-OFDM in AWGN gives better performance than Rayleigh and Rician because of including direct path signal also with reflected and scattered signals. Then the performances are furthermore improved by NLMS equalization in both models. The NLMS algorithm changes step by step with different iterations and weight vector will change in straight weight. Hence, it is restricted by updated filter output and its estimated values.

References

[1] J. A. C. Bingham, "Multicarrier modulation for data transmission: An idea whose time has come", *IEEE Communication Magazines*, Vol. 28, No. 5, pp. 5–14, 1990.

[2] P. Gotz, U. Jorn, K. Werner and Z Georg, "A comparison of various MCM schemes", *In: Proc. of 5th International Workshop on OFDM*, Hamburg, Germany, pp. 20-1 – 20-5, 2000.

[3] L. Jun, T. T. Thiang, F. Adachi and H. C. Li, "BER performance of OFDM-MDPSK system in frequency selective Rician fading and diversity reception", *IEEE Transactions on Vehicular Technology*, Vol. 49, No. 4, pp. 1216-1225, 2000.

[4] D. N. Muhammad, N. Hans and H. Thomas, "On Performance Limits of DFT Spread OFDM Systems", *In: Proc. of IST Mobile and Wireless Communications Summit*, Budapest, Hungary, pp., 2007.

[5] T. Hwang, C. Yang, W. Gang, S. Li and G. Y. Li, "OFDM and Its Wireless Applications: A Survey", *IEEE Transactions on Vehicular Technology*, Vol. 58, No. 4, pp. 1673-1694, 2009.

[6] R.W. Klein, M.A. Temple, R.A. Raines, and R.L. Claypoole Jr., "Interference Avoidance Communications using Wavelet Domain Transformation Techniques", *IEEE Electronic Letters*, Vol. 37, No. 15, pp. 987–989, 2001.

[7] D. Guptha, Vipin B Vats and K. Kamal Garg, "Performance Analysis of DFT-OFDM, DCT-OFDM and DWT-OFDM Systems in AWGN Channel", *In: Proc. of International Conference on Wireless and Mobile Communications,* Athens, Greece, pp. 214-216, 2008.

[8] M. B. Veena and M.N.S. Swamy, "Performance analysis of DWT based OFDM over FFT based OFDM and implementing on FPGA", *International Journal of VLSI design & Communication Systems*, Vol.2, No. 3, pp. 119-130, 2011.

[9] B. Gupta, G. Gupta, and D. S. Saini, "BER Performance Improvement in OFDM System with ZFE and MMSE Equalizers", *In: Proc. of International Conference on Electronics Computer Technology*, Kanyakumari, India, pp. 193-197, April 2011.

[10] A. Kaini, G. Baghersalimi and B. Zanj, "Performance assessment of DFT-OFDM and DWT-OFDM systems in the presence of the HPA Nonlinearity", *In: Proc. of International Conference on Telecommunications,* Graz, Austria, pp. 273-278, 2011.

[11] R. Bodhe, S. Narkhede and S. Joshi, "Design of Simulink Model for OFDM and Comparison of FFT-OFDM and DWT-OFDM", International Journal of Engineering Science and Technology, Vol. 4, No. 5, pp. 1914-1924, 2012.

[12] R. Bodhe, S. Joshi and S. Narkhede, "Performance Comparison of FFT and DWT based OFDM and Selection of Mother Wavelet for OFDM", *International Journal of Computer Science and Information Technologies,* Vol. 3, No. 3, pp. 3393-3397, 2012.

[13] A. Deshmukh and S. Bodhe, "Comparison of DCT and Wavelet Based OFDM System Working in 60 GHz Band", *International Journal of Advancements in Technology*, Vol. 3, No. 2, pp. 74-83, 2012.

[14] L. Patidar and A. Parikh, "BER Comparison of DCT-based OFDM and FFT-based OFDM using BPSK Modulation over AWGN and Multipath Rayleigh Fading Channel", *International Journal of Computer Applications*, Vol. 31, No. 10, pp. 38-41, 2011.

[15] G. M. Kumar and S. Tiwari, "Performance evaluation of conventional and wavelet based OFDM system", *International Journal of Electronics and Communications*, Vol. 67, No. 4, pp. 348-354, 2013.

[16] Sunitha Sirvi and Lokesh Tharani, "Wavelet based OFDM system over flat fading channel using NLMS equalization", *International Conference on Computing, Communication and Automation,* Noida, India, Jan. 2017.