Performance comparison of Wavelet based and conventional OFDM systems - A review

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***Abstract* - Growth in technology has led to unprecedented demand for high speed architectures for complex signal processing applications. In 4G wireless communication systems, bandwidth is a precious commodity, and service providers continuously met with the challenge of accommodating more users with in a limited allocated bandwidth. To increase data rate of wireless medium with higher performance, OFDM (orthogonal frequency division multiplexing) is used. OFDM is multicarrier modulation (MCM) technique which provides an efficient means to handle high speed data streams on a multipath fading environment that causes ISI. Normally OFDM is implemented using FFT and IFFT's. To decrease the bandwidth waste brought by adding cyclic prefix, Wavelet based OFDM is employed. Due to use of wavelet transform the transmission power is reduced. In this paper we review the replacement of Fourier transform by Wavelet transform and its effects on the overall system.**

Index Terms – BER, DFT, FFT, OFDM

I. INTRODUCTION

In the current and future mobile communications systems, data transmission at high bit rates is essential for many services such as high quality audio and video and mobile integrated service digital network. When the data is transmitted at high bit rates, over mobile radio channels, the channel impulse response can extend over many symbol periods, which lead to Inter-symbol Interference (ISI). In OFDM signal the bandwidth is divided into many narrow sub-channels which are transmitted in parallel [1][2]. Each sub-channel is typically chosen narrow enough to eliminate the effect of delay spread. OFDM is multi-carrier modulation technique for transmission of signals over wireless channels. It converts a frequency-selective fading channel into a collection of parallel sub channels, which greatly simplifies the structure of the receiver. A combination of modulation and multiplexing constitutes to Orthogonal Frequency Division Multiplexing Independent signals that are sub-set of a main signal are multiplexed in OFDM and also the signal itself is first split into independent channels, modulated by data and then remultiplexed to create OFDM carrier. Orthogonality of subcarriers is the main concept in OFDM. The property of orthogonality allows simultaneous transmission of a lot of sub-carriers in a tight frequency space without interference from each other. This acts as an undue advantage in OFDM. Therefore, OFDM is becoming the chosen modulation technique for wireless communication. With the help of OFDM, sufficient robustness can be achieved to provide large data rates to radio channel impairments. In an OFDM scheme, a large number of orthogonal, overlapping narrow band sub-channels or sub-carriers transmitted in parallel by dividing the available transmission bandwidth. Compact spectral utilization with utmost efficiency is achieved with the help of minimally separated sub-carriers. Main attraction of OFDM lies with how the system handles the multipath interference at the receiver end. OFDM is multicarrier modulation (MCM) technique [3] which provides an efficient means to handle high speed data streams on a multipath fading environment that causes ISI. The spectral containment of the channels is better since it does not use cyclic prefix. One type of wavelet transform is Discrete Wavelet transforms have been considered as alternative platforms for replacing IFFT and FFT. [4][5][6]. It employs Low Pass Filter (LPF) and High Pass Filter (HPF) operating as Quadrature Mirror Filters satisfying perfect reconstruction and orthogonal properties. Wavelet transform [7-11] is a tool for studying signals in the joint time–frequency domains. Wavelets have compact support (localization) both in time and frequency domain, and possess better orthogonality. Orthogonal wavelets are capable of reducing the power of inter symbol interference (ISI) and inter carrier interference (ICI) which are caused by loss of orthogonality between the carriers as a result of multipath propagation over the wireless fading channels. In OFDM inter symbol interference (ISI) and inter channel interference (ICI) reduced by use of cyclic prefix (CP). In wavelet based OFDM, CP is not required. CP is 20% or more of symbol. Thus wavelet based OFDM gives 20% or more bandwidth efficiency [12-15]. Wavelet based OFDM is less affected by Doppler shift. In wavelet based OFDM a prototype wavelet filter provides both orthogonality and good time–frequency localization. Wavelet provides phase linearity and significant out-of-band rejection. Its energy compaction is also high. Wavelet based OFDM (WOFDM), which is also an MCM technique, possesses almost all advantages and disadvantages of conventional (Fourier based) OFDM. In this technique, the sub bandwidth division is obtained by using the inverse discrete wavelet based transforms, whereas conventional OFDM uses IFFT. Another main difference is that WOFDM symbols overlap in both time and frequency domains, whereas OFDM symbols overlap only in frequency domain. Therefore, adding CP to the WOFDM symbol frame does not have any effect on the bit error rate (BER) performance, as also shown in this work. One major advantage of WOFDM compared to

OFDM is that WOFDM is more bandwidth efficient than OFDM.

In a wireless environment, the channel is much more unpredictable than a wire channel because of a combination of factors such as multi-path, frequency offset, timing offset, and noise. This results in random distortions in amplitude and phase of the received signal as it passes through the channel. These distortions change with time since the wireless channel response is time varying[16-18]. The channel estimation is a process of characterizing the effect of the transmission channel on the input signal. Channel estimation attempts to track the channel response. A dynamic estimation of channel is necessary before the demodulation of OFDM signals since the radio channel is frequency selective and time-variant for wideband mobile communication systems [19-20]. The channel estimate can then be used by an equalizer to correct the received constellation data so that they can be correctly demodulated to binary data.

This paper is organized as: in Section I, a brief introduction of the previous work demonstrated on COFDM and W-OFDM is discussed. The Section II presents the comparison of OFDM & WOFDM and result discussion, followed by the conclusion drawn in Section III on the basis of our observations.

II. OFDM & WOFDM

A. *Fourier-Based OFDM*

In OFDM, IFFT transform is used is used. In Fig. 1[21], the data $\{d_k\}$ is processed by *M*-ary QAM modulator to map the data before IFFT, with *N* subcarriers. Its output is the sum of the information signals in the discrete time bearing as following:

$$x(k) = 1/\mathrm{N} \sum_{m=0}^{N-1} \left(X_{m e^{j2\pi km/N}} \right) \tag{1}$$

where $\{X_k | 0 \leq k \leq N-1\}$ is a sequence in the discrete time domain, $\{X_m | 0 \leq m \leq N-1\}$ are complex numbers in discrete frequency domain. The cyclic prefix (CP) is added before transmission to minimize the inter-symbol interference.

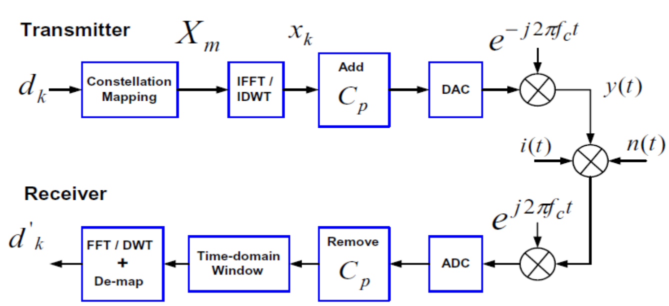

Fig. 1 OFDM transceiver

At the receiver side, the processed is reversed to obtain and decoded the data. The CP is removed to obtain the data in discrete time domain. The data is then processed to the Time-Domain(TD) windowing for eliminating the narrowband interference before FFT. The output of FFT is the sum of the received signal in discrete frequency domain as follows:

$$X(m) = \sum_{k=0}^{N-1} \left(x_{k e^{-j2\pi km/N}} \right) \tag{2}$$

B. *Wavelet-Based OFDM*

In the wavelet transform, inverse discrete wavelet transform (IDWT) and discrete wavelet transform (DWT) have replaced the IFFT and FFT in modulation and demodulation of FFT-OFDM system. Due to the overlapping nature of wavelet properties, the wavelet based does not need cyclic prefix to deal with delay spreads of the channel[22-24]. As a result, it has higher spectral containment than that of Fourier-based OFDM. The data $\{d_k\}$ is processed as per FFT-OFDM. However, the difference is that the system does not require CP to be added to the OFDM symbol, and the system uses inverse discrete wavelet transform (IDWT) and discrete wavelet transform (DWT) to replace IFFT and FFT in transmitter and receiver, respectively. The output of the inverse discrete wavelet transform (IDWT) can be represented as:

$$s(k) = \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} S_m^n 2^{m/2} \psi(2_k^m - n)$$

Where $\{S^n_m\}$ are the wavelet coefficients and $\psi(t)$ is the wavelet function with compressed factor *m* times and shifted n times for each subcarrier (number *k*, $0 \leq k \leq N-1$). The wavelet coefficients are the representation of signals in scale and position or time. The scale is related to the frequency. Low scale represents compressed wavelet which means that the signal is rapidly changing, or the signal is in high frequency. On the other hand, high scale represents stretched wavelet which means that the signal is slowly changing, or the signal is in low frequency. Thus, Xm can be represented to $\{S_m^n\}$ before it is processed to IDWT. At the receiver side, the process is inversed. The output of discrete wavelet transform (DWT) is

$$S_m^n = \sum_{k=0}^{N-1} s(k) 2^{m/2} \psi(2_k^m - n)$$

S_m^n can be decoded to *Xm* before the recovery of data to QAM demodulator.

At first the results have been compared for the BER performance of Wavelet based OFDM system, and DFT based OFDM system over both Rayleigh fading and AWGN channel. The BER performance as a function of signal to noise ratio (Eb/No) is examined for Rayleigh fading and frequency selective fading with Doppler frequencies (fd = 200 Hz). Figs. 2 and 3 shows the BER performance of DFT based OFDM and wavelet based OFDM under Rayleigh fading channel and AWGN channel respectively.

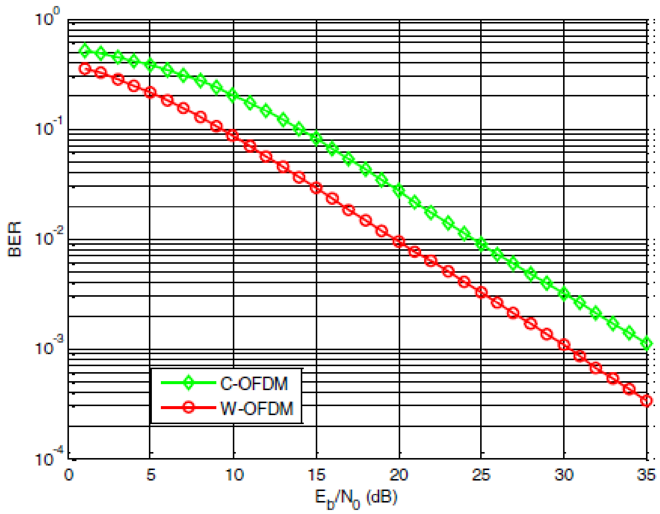

Fig. 2[25] BER for C-OFDM and W-OFDM over Rayleigh fading channel

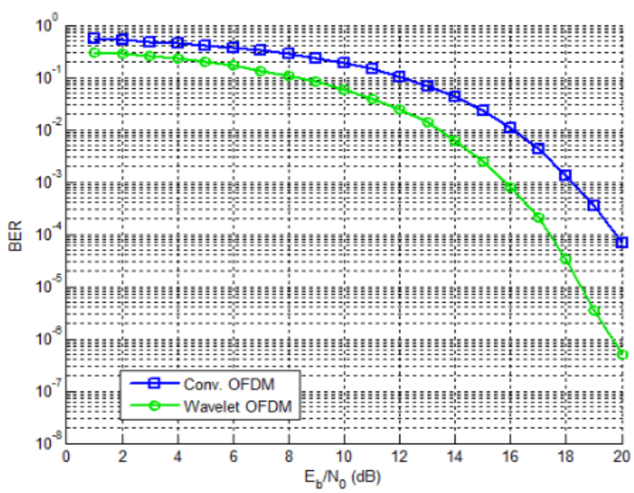

Fig. 3[25] BER for C-OFDM and W-OFDM over AWGN channel

It is clear from shown figures that Wavelet based OFDM have better BER performance as compared to DFT based OFDM.

Now the results have been evaluated for the MSE performance of Wavelet and DFT based OFDM system. For MSE performance, LMMSE estimator and LS estimator has been considered. Figs. 3–4 show that LMMSE estimator has 15–20 dB better performance than LS estimator.

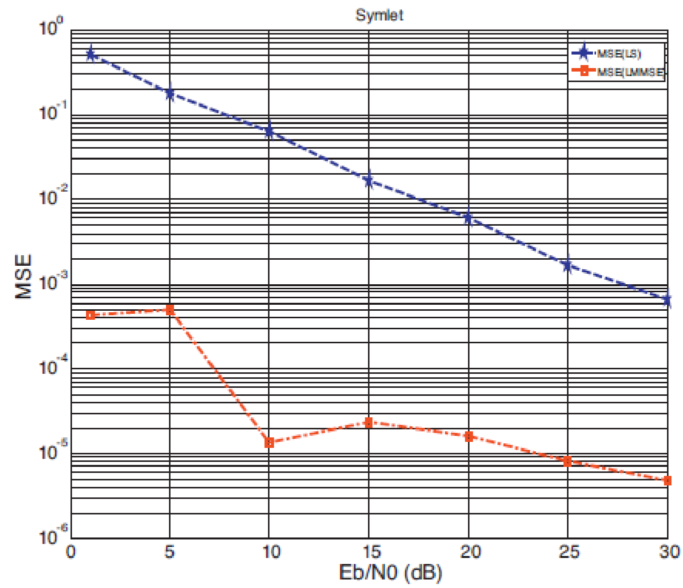

Fig. 3[4] Performance of Wavelet based OFDM system.

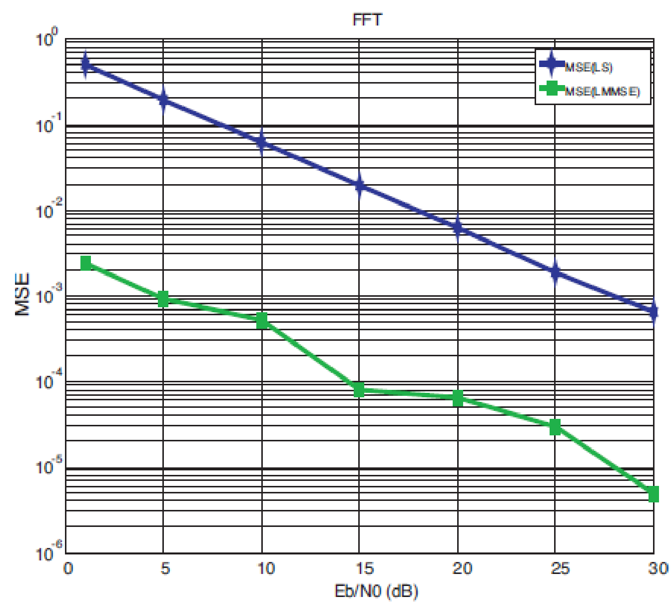

Fig. 4[4] Performance of FFT based OFDM system.

At last performance have been compared for the power spectral density (PSD) of wavelet based OFDM system with DFT based OFDM system. Fig.5 shows that the wavelet based OFDM system is more spectral efficient then DFT based OFDM system. For comparative analysis between wavelet based OFDM system and conventional OFDM system , the Biorthogonal wavelet was considered. The Wavelet based OFDM system is out performing

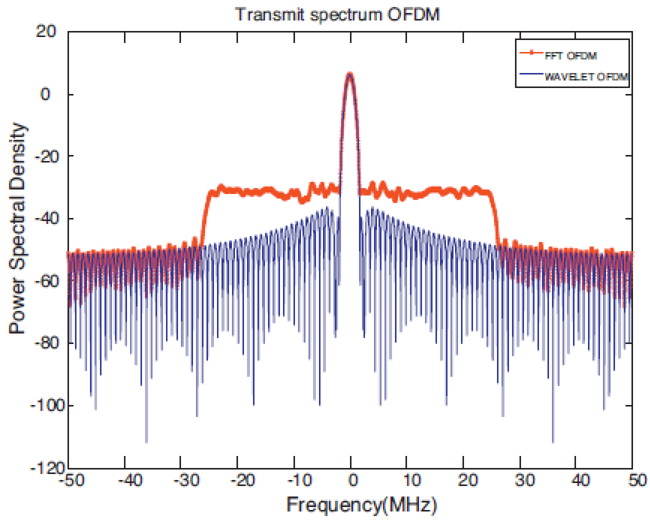

Fig. 5[4] Comparison of power spectral density.

III. Conclusion

A comprehensive review of performance of conventional OFDM system and its comparison with wavelet based OFDM is presented in this work. Wavelet based OFDM system is a very flexible system which is also simple, and has a low complexity as only low order filters are needed instead of complex FFT processors and in addition, the filter type can be dynamically chosen depending on the condition of the channel or the data. In the comparison of BER performance of DFT and wavelet based OFDM system, wavelet based OFDM system have better performance in AWGN channel as well as Rayleigh fading channel. Wavelet based OFDM gives SNR improvement in AWGN channel As well as in Rayleigh fading channel. In the channel estimation of wavelet based OFDM and conventional OFDM the LMMSE estimator gives improvement than LS estimator. Power spectral density of wavelet based OFDM system is much better than conventional OFDM system. The main focus of this work is to put attention towards the realization of future high performance networks by introducing the Wavelet based OFDM in place of conventional OFDM systems.

References

[1] Mallat S., "A wavelet tour of signal processing", 2nd edition, California: Academic Press, Elsevier, 1999.

[2] Lakshmanan M.K. and Nikookar H., "A review of wavelets for digital wireless communication", Wireless Personal Communication, Vol. 37, pp: 387–420, 2006.

[3] R. Mirghani and M. Ghavami, "Comparison between Wavelet-based and Fourier-based Multicarrier UWB Systems", IET Communications, Vol. 2, Issue 2, pp: 353-358, 2008.

[4] R. Dilmirghani and M. Ghavami, "Wavelet Vs Fourier Based UWB Systems", 18th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, pp: 1-5, 2007.

[5] N. Ahmed, "Joint Detection Strategies for Orthogonal Frequency Division Multiplexing", Dissertation for Master of Science, Rice University, Houston, Texas, pp: 1-51, 2000.

[6] S. D. Sandberg and M. A. Tzannes, "Overlapped Discrete Multi-tone Modulation for High Speed Copper Wire Communications", IEEE Journal on selected areas in communications, Vol. 13, pp: 1571-1585, 1995.

[7] A. N. Akansu, and L. Xueming, "A Comparative Performance Evaluation of DMT (OFDM) and DWMT (DSBMT) Based DSL Communications Systems for Single and Multi-tone Interference", proceedings of the IEEE International Conference on Acoustics, Speech and Signal processing, Vol. 6, pp: 3269-3272, 1998.

[8] Bingham JAC., "Multi-carrier modulation for data transmission: An idea whose time has come", IEEE Communication Magazine, pp: 5-14, 1990.

[9] Resnikoff HL. and Wells RO., "Wavelet analysis", Springer, 1998.

[10] Broughton SA., Bryan K., "Discrete Fourier analysis and wavelets", New Jersey, John Wiley, 2009

[11] Pollet T., Van Bladel M. and Moeneclaey M., "BER sensitivity of OFDM systems to carrier Frequency offset and Wiener phase noise", IEEE Trans Communication, Vol. 43, Issue 234, pp: 191-193, 1995.

[12] Chang S, Lee M, Park J. "A High speed VLSI architecture of discrete wavelet transform for MPEG-4", IEEE Transactions on Consumer Electronics, Vol. 43, Issue 3, pp: 623-627, 1997.

[13] Mahesh Kumar Gupta and S. Tiwari, "Performance evaluation of conventional and wavelet based OFDM system", Elsevier, 2012.

[14] Volkan Kumbasar, Oguz Kucur, "Performance comparison of wavelet based and conventional OFDM systems in multipath Rayleigh fading channels", Digital Signal Processing, Vol. 22, pp: 841–846, 2012

[15] Abbas Hasan Kattoush, Waleed A. Mahmoudb, S. Nihad," The performance of multiwavelets based OFDM system under different channel conditions", Digital Signal Processing, Vol. 20, pp: 472–482, 2010

[16] M. Guatier, J. Lienard, and M. Arndt, "Efficient Wavelet Packet Modulation for Wireless Communication", AICT'07 IEEE Computer Society, 2007.

[17] M. Guatier, and J. Lienard, "Performance of Complex Wavelet acket Based Multicarrier Transmission through Double Dispersive Channel", NORSIG 06, IEEE Nordic Signal Processing Symposium (Iceland), June 2006.

[18] C. V. Bouwel, J. Potemans, S. schepers, B. Nauwelaers, and A. Van Caelle, "wavelet packet Based Multicarrier Modulation", IEEE Communication and Vehicular Technology, SCVT 2000, pp. 131-138, 2000.

[19] C. Schurgers and M. B. Srivastava, "A systematic approach to peak – to – average power ratio in OFDM," in SPIE's 47th Annual meeting, San Diego, CA, 2001, pp. 454-464.

[20] Panchamkumar D SHUKLA, "Complex wavelet Transforms and Their Applications" Master Thesis 2003. Signal Processing Division. University of Strathclyde Department of Electronic and Electrical Engineering.

[21] Haixia Zhang, Dongfen Yuan, and Matthias Patzold, "Novel Study on PAPRs Reduction in Wavelet–Based Multicarrier Modulation Systems", Elsevier, digital signal processing, 17(2007) 272-279, 5 sptember 2006.

[22] Zhou Lei, Li Jiandong, Liu Jing, and Zhang Guanghui, "A Novel wavelet Packet Division Multiplexing Based on Maximum Likelihood Algorithm and Optimal pilot Symbol Assisted Modulation for Reyleigh Fading Channels", circuit system signal processing, vol. 24, No 3, 2005, PP. 287-302.

[23] G. Wornell, "Emerging Applications of Multirate Signal Processing and Wavelets in Digital Communications", *Proc. IEEE*, Vol. 84, pp. 586–603, April 1996.

[24] N.G. Kingsbury, "The dual-tree complex wavelet transform: A new technique for shift invariance and directional filters," in Proc. 8th IEEE DSP Workshop, Utah..

[25] Vishal Sharma and Gurpreet Singh, "Wavelet-OFDM (W-OFDM) over Diverse Fading Channels" 2014 IEEE DOI 10.1109/ACCT.2014.43