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BER performance evaluation of conventional OFDM system and Wavelet Packet Modulator System in 4G LTE

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Abstract: *The increased demand for high data rate in the 21st century has necessitated a more efficient method of data spectrum usage. Conventional OFDM is a Multi-Carrier Modulation (MCM) scheme, capable of providing higher data rate, which is traditionally implemented using Fast Fourier Transform (FFT) for modulation and demodulation, which has a few drawbacks including the inefficient use of the available spectrum due to the addition of cyclic prefix, and higher power requirement [1]. Thus, there is need for an MCM system that overcomes these drawbacks. Wavelet Packet Modulator (WPM) based system eliminates the above drawbacks, as it does not require the addition of cyclic prefix. It provides far better orthogonality of adjacent channel signals because wavelet bases are much longer in length than the duration of a symbol and can overlap in the time domain without losing their orthogonality. In this work MATLAB® tool is used to simulate both FFT OFDM and WPM systems, and to analyze their performance using Bit Error Rate (BER) as a metric. These outputs are evaluated in the presence of AWGN for different constellations of Phase Shift Keying (PSK) and Quadrature Amplitude Modulation (QAM) is implemented in the simulation.*

Keywords: *Bit Error Rate (BER), Cyclic Prefix, Multi-Carrier Modulation (MCM), Orthogonal Frequency Division Multiplexing (OFDM), Wavelet Packet Modulation (WPM)*

I. Introduction

The motivation for the use of multi-carrier is to design a wireless communication system that can overcome the challenges posed by wireless channels and also offer higher data rate transmission. OFDM is a multi-carrier technique used for transmission of data through the use of subcarriers that are orthogonal to each other. It is imperative to understand the various technological developments that materialized in the present high data rate communication system using OFDM.

In 1971, Weinstein and Ebert used discrete Fourier transform (DFT) to perform baseband modulation and demodulation focusing on efficient processing. This eliminated the need for bank of subcarrier oscillators, thus paving the way for easier, more useful and efficient implementation of the system. All the proposals until this time used guard spaces in frequency domain and a raised cosine windowing in time domain to combat ISI and ICI [2].

Lindsay carried out the theoretical work which formed the link between wavelet packet and its application in digital communication. He demonstrated that the WPM transmitter and receiver can be implemented with a pair of quadrature mirror filters [3].

In the early 90's the advancement of Digital Signal Processing(DSP) paved way for OFDM system to be implemented for Wideband data communication over mobile radio which has enabled the fourth generation wireless system such as Long Term Evolution(LTE) which is the primary system being implemented using both FFT and WPT based OFDM.

Relevant Work

The technical papers reviewed in this section are chosen from different online resources, but share a lot of common concepts. Some of the papers adopted different methods of implementation and still arrived at approximately the same conclusion, though with different results. The topics discussed in these papers cover DFT based OFDM system, Digital Video Broadcasting (DVB), WIMAX, LTE, Wavelet Based OFDM (WOFDM), Wavelet Packet Transform (WPT), OWDM (Orthogonal Wavelet Division Multiplexing), Channel Fading, Channel Models, QAM and QPSK Modulation etc.

In the paper “The performance of multi wavelets based OFDM system under different channel conditions” [4], the authors discuss the reliability of Orthogonal Frequency Division Multiplexing (OFDM) based on Fast Fourier Transform (FFT) because of the time varying nature of the channel which causes interference like Inter Carrier Interference (ICI) and also increases imprecise channel tracking. The authors also discuss the importance of Discreet Wavelet Transform (DWT) in combating Inter-Symbol Interference (ISI), power loss due to inefficient use of bandwidth etc. Haar wavelet was used and the authors conclude that wavelet achieves much better Bit Error Rate (BER) than FFT.

The authors of "Alamouti coded wavelet based OFDM for multipath fading channels" [5], examine the output of conventional DFT based OFDM and Wavelet based OFDM with or without Alamouti coding over multipath Rayleigh channel model. Results depict that the Wavelet based OFDM system Alamouti coding offers better performance in terms of BER than DFT based OFDM system.

Antony et al [6], propose an OFDM system based on Dual-Tree Complex Wavelet Transform (DT CWT), the proposed system according to the authors uses DT-CWT in place of FFT. The authors conclude that the DT-CWT system offers better BER and PAPR than the FFT based OFDM system.

In [7], the authors discuss the various applications of wavelets in digital communication system like Data Compression, source and channel coding, signal de-nosing, channel modeling, the various properties of wavelet and the recent trends in the application of wavelet in wireless communication. The authors also gave a review on single carrier modulation and multicarrier modulation using wavelet.

Khaizuran et al [8] discuss the implementation of FFT OFDM system and DWT OFDM system and also examine the BER performance of both the systems. They opine that DWT OFDM offered far better BER performance than FFT based OFDM.

In [9] Kattoush discusses the application of finite radon transform mapper in wavelet transform to increase orthogonality of subcarriers. In this application, Finite Radon Transform and Discrete Wavelet Transform are implemented in a new design for orthogonal frequency division multiplexing. The proposed system was tested and compared with conventional FFT based OFDM, Radon-based OFDM, and Discrete Wavelet Transform based one (DWT-OFDM) for Additive White Gaussian Noise (AWGN) channel, flat fading channel, and multi path selective fading channel. the author concludes that the result showed that the proposed system has increased spectral efficiency and reduced inter symbol interference and inter carrier interference, and improved BER performance compared with other systems.

In [10] the author carried out the pioneering work that led out the theoretical background to establish the link between wavelet packet and digital communication. The work also demonstrates that the entire WPN transmitter and receiver system can be implemented with a pair of conjugate quadrature mirror filters.

The rest of the paper is organized as follows: OFDM system is presented in part 2, Wavelet Packet Modulator (WPM) system and the proposed wavelet packet based OFDM design is presented in part 3 and the results obtained from the simulation are presented in part 4. The paper is concluded in part 5.

II. Conventional OFDM System

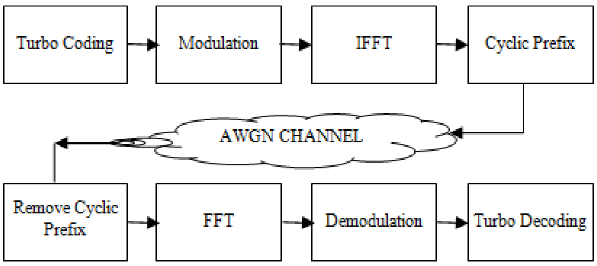

Figure 1 Conventional OFDM System

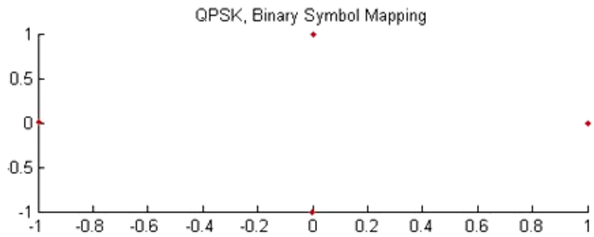

Figure 2 Simulated QPSK constellation

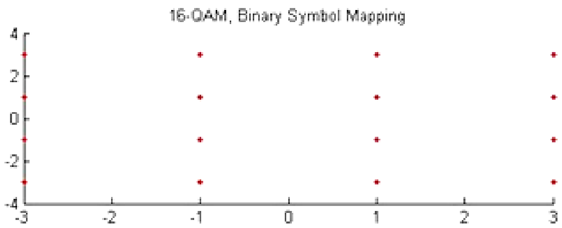

Figure 3. Simulated 16 QAM constellation

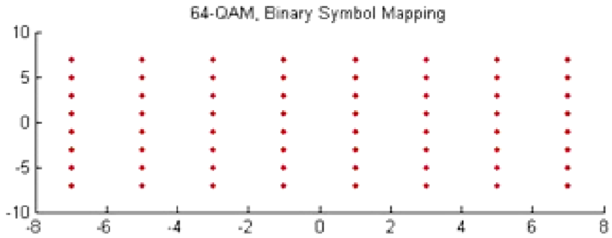

Figure 4.Simulated 64 QAM constellation

Most of the recent wireless communication systems like 4G LTE make use of OFDM. OFDM System offers some advantages for 4G LTE as it makes its signal more robust against frequency selective fading. The intrinsic design of an OFDM system prevents interference among the carriers (also called subcarriers or tones). This is the reason why the subcarriers are orthogonal to each other.

Fig. 1 above shows the basic components that make up a conventional OFDM system. The first step is to generate the data which is given as an input to the OFDM system. The input data is a sequence of random generated data. The second step in the transmit chain is the encoding of the input data to combat noise interference in the wireless channel; the encoded signal is converted from serial to parallel. The encoded data is modulated by mapping bits to complex data symbols. The characteristic of complex data symbols is that each symbol describes a two dimensional vector with a phase and amplitude. A complex data symbol has an in-phase and a quadrature component. These symbols are called In-phase Quadrature (IQ) samples.

Fig.s 2-4 show the complex modulation schemes and the corresponding bit mappings. Mapping a higher number of bits to symbols is possible by using higher modulation order like 16 and 64 QAM which results in a high spectral efficiency; which means transmitting more bits per cycle of the utilized bandwidth. OFDM systems see the modulated symbols as modulated frequency tones, which are to be transformed to a signal over time in order to be transmitted; which means that, the modulated symbols are mapped to orthogonal subcarriers of the baseband spectrum. The transformation from frequency domain to the time domain is performed by an inverse Fast Fourier Transform (iFFT). The inverse Fourier transform maps the orthogonal spectrum of each subcarrier to the resulting baseband spectrum. A timely guard interval known as Cyclic Prefix(CP) between OFDM symbols is needed to prevent inter-symbol interference due to channel delay spread (signal arriving at different time due to multipath effect). This is implemented by copying a portion of the end of each OFDM symbol in front of the OFDM samples to be transmitted. Cyclic-prefix insertion is very important in OFDM implementation using FFT because it makes the OFDM signal to be less sensitive to time dispersion of the channel and as long as the length of the cyclic prefix is not less than the time dispersion the OFDM signal is then transmitted over an AWGN channel. The OFDM signal corrupted with noise is received at the receiver, where the redundant cyclic prefix is removed and FFT is carried out to de-map the signal for demodulation, the demodulated signal is decoded with turbo decoder and the original signal at the input recovered.

III. Wavelet Packet Modulator (WPM) System

A wavelet, which literally means small or little wave, is an oscillating zero-average function that is well localized in a small period of time. A wavelet function, known as a mother wavelet, gives rise to a family of wavelets that are translated (shifted) and dilated (stretched or compressed) versions of the original mother wavelet [11]. The smallness refers to the condition that this (window) function is of finite length (compactly supported). The term mother implies that the functions with different region of support that are used in the transformation process are derived from one main function, or the mother wavelet. In other words, the mother wavelet is a prototype for generating the other window functions [12].

$$w_x(u,s) = \int_{-\infty}^{\infty} x(t)\varphi_{u,s}(t)dt \qquad (1)$$

In the equation (1) given above, the input signal $x(t)$ is correlated with dilation parameter s and translation parameter u. The transform changes a signal into coefficients that represent both frequency and time information, with frequency resolution at low frequency and time resolution at high frequency [12]. A fast way of computing a wavelet transform is with a cascade of quadrature mirror filters in which the input signal is fed into two filters labeled h(n) and g(n). The filters produce two sets of coefficients which are down sampled by a factor of 2 as shown in the Fig. 6 below.

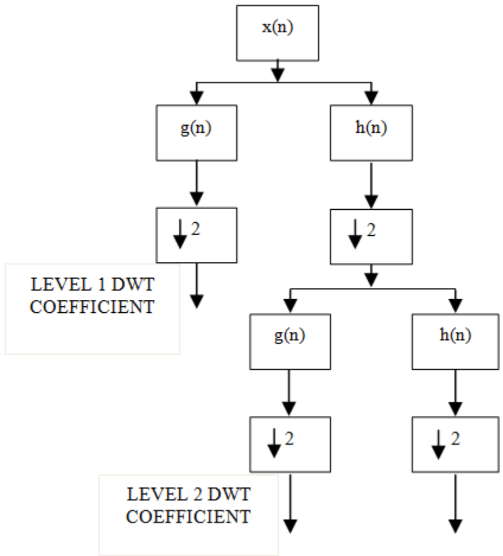

Figure 5 Wavelet Transform

WPT is a form of wavelet transform that offers a richer range of application for signal analysis which gives the best matched analysis to a signal. it performs level by level transform of signal from the time domain into the frequency domain and vice versa. It is implemented using a series of filter which decimates the signal leading to decrease in the time resolution and increase in frequency resolution. The frequency bins unlike in wavelet transform, are of equal width, since in WPT, both the low and high frequency sub-band are divided. In wavelet analysis, a signal is split into an approximation and a detail coefficient. The approximation coefficient is then itself split into a second-level approximation coefficients and detail coefficients, and the process is repeated.

In wavelet packet analysis the detail coefficient as well as the approximation coefficient can be split, that is not only can the low-pass filter output be iterated through further filtering, but the high-pass filter can be iterated as well. This ability to iterate the high-pass filter outputs means that the WPT allows for more than one basis function (or wavelet packet) at a given scale, versus the WT (Wavelet Transform) which has one basis function at each scale other than the deepest level, where it has two. The set of wavelet packets collectively make up the complete family of possible bases, and many potential bases can be constructed from them. If only the low-pass filter is iterated, the result is the wavelet basis. If all low-pass and high-pass filters are iterated, the complete tree basis results. The top level of the WPD tree is the time representation of the signal. As each level of the tree is traversed there is an increase in the tradeoff between time and frequency resolution. The bottom level of a fully decomposed tree is the frequency representation of the signal. Fig. 6 shows the level 2 decomposition using wavelet packet transform.

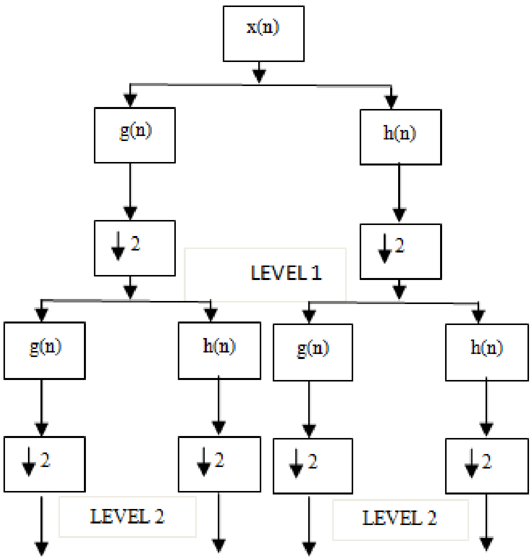

Figure 6 Wavelet Packets Transform

IV. Proposed WPM System

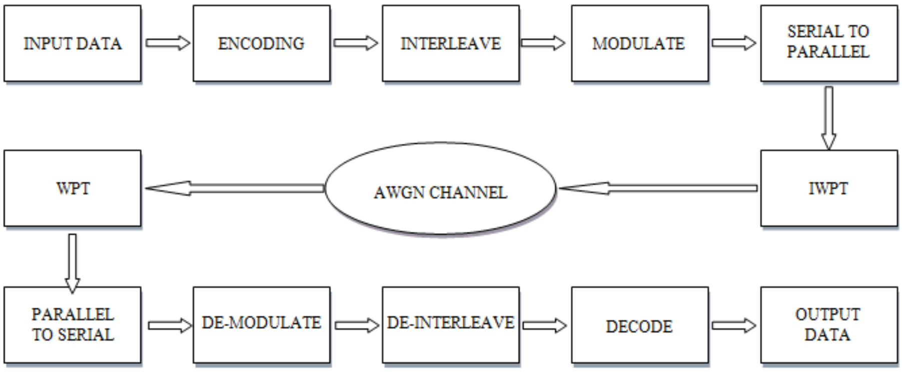

Figure 7 Wavelet Packet Modulation Systems

In this proposed model, IWPT and WPT is used in place of IFFT and FFT and the WPM system does not require cyclic prefix as shown in Fig. 7. In this system the first stage is to encode the signal to withstand errors due to channel noise. The turbo encoder is used for the encoding process which is also used for the interleaving process; the interleaved data is converted from binary to decimal bits for modulation. After modulation, the IWPT is implemented by sub-dividing the modulated signal into four signal blocks which represents a second level reconstruction and decomposition. The subdivided signal blocks is given as input to four channel filter banks which adds the modulated signal into coarse (low-frequency) and detail (high-frequency) components. The high- and low-pass filters selects the lower- and upper-half frequency components, respectively. To maintain the equivalent number of samples, the filter outputs are up sampled by a factor of 2. The reconstruction process consisting of half band filtering and up sampling increases the time resolution by a half and increases the frequency band spanned by the signal by half as well. The scheme is then iterated successively on both the coarse and detailed versions until the desired degree of resolution to form a cascaded tree structure as shown in Fig. 6. The cascaded two channel filter banks structure recursively reconstructs the signal being estimated and maps the signal components into the frequency domain. The output wavelet packet node corresponds to a frequency band signal which is transmitted over AWGN channel. At the receiver, WPT is performed which is a reverse of IWPT as depicted in Fig. 7 and the output of the WPT is demodulated. Demodulated data is converted to binary form, then de-interleaved and decoded to get the original data transmitted as shown in Fig. 7.

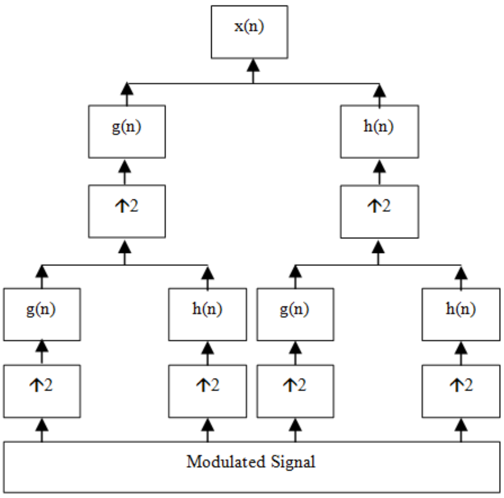

Figure 8 Inverse Wavelet Packet Transform tree

V. BER Performance Analysis

The software used for all the simulations presented in this paper is known as MATLAB. MATLAB stands for Matrix Laboratory. It is a simulation software that allows matrix manipulation and data plotting[13][26]. By using the MATLAB tools, the performance characteristic of DFT based OFDM and wavelet packet based OFDM are obtained for different modulations that are used for the LTE which include QPSK,16-QAM, 64-QAM shown in Fig.s 9-11. For the purpose of simulation, signal to noise ratio (SNR) of different values are introduced through AWGN channel. Data of 6400 bits is sent in the form of 100 symbols, so one symbol is of 64 bits. BER is obtained by comparing the output data at the receiver with the input data at the transmitter and is repeated for all the values of SNR and the final BERs are obtained. This process is repeated for different modulation scheme.

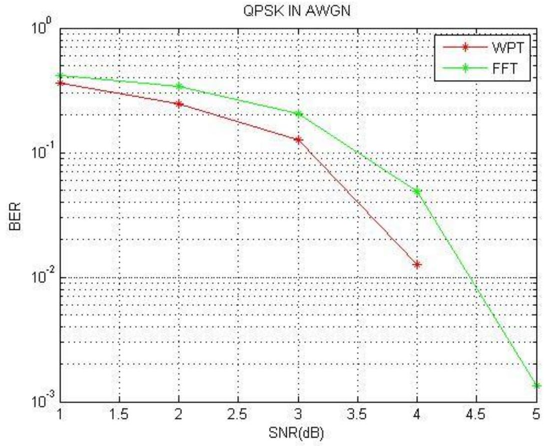

Figure 9 BER Performance comparisons for QPSK in WPM and OFDM

Fig. 9 depicts that when QPSK modulation is used, the WPT curve shows better BER and SNR than the FFT curve, which means that the WPM system offers better BER and SNR than conventional OFDM system. WPM outperformed the traditional OFDM system by 1 dB. This shows that WPM system is more robust than conventional OFDM System even in the presence of Noise.

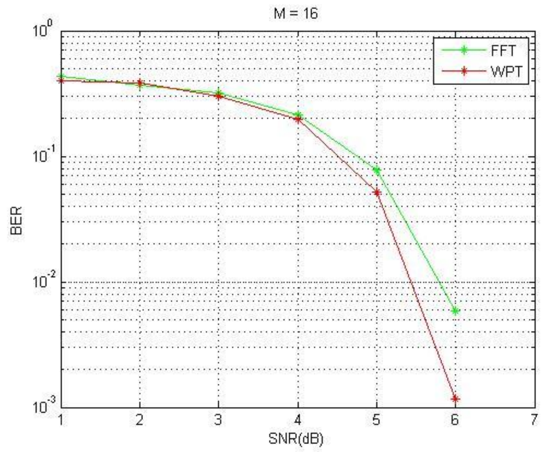

Figure 10 BER Performance comparisons for 16 QAM in WPM and OFDM

In Fig. 10, it can be observed that the SNR of both system is the same when 16-QAM modulation is used, but the WPT curve shows better BER than the FFT curve, which means that the WPM system offers better BER than conventional OFDM system, and shows that WPM system is more robust than conventional OFDM System even in the presence of Noise.

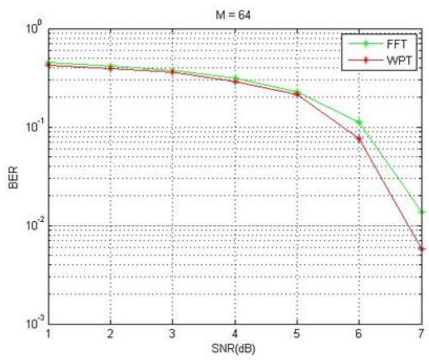

Figure 11 BER Performance comparisons for 64 QAM in WPM and OFDM

In Fig. 11, the SNR of both system is the same when 64-QAM modulation is used, but the WPT curve shows better BER than the FFT curve, which means that the WPM system offers better BER than conventional OFDM system, and shows that WPM system is more robust than conventional OFDM System even in the presence of Noise

VI. Conclusion and Future work

In this paper, the performance of both Wavelet Packet Modulation and conventional OFDM system is examined and compared. The BER performance curve shown in Fig. 9-11 illustrate that the WPM system offers a far better BER than the conventional OFDM system for all the modulation(QPSK,16-QAM,64-QAM) techniques used in LTE. The mother wavelet used for the Wavelet Packet Transform is Haar wavelet, which is the simplest form of wavelet.

It is imperative to state here that the application of Wavelet Packet Transform is useful in other signal processing field like encoding, compression, de-noising etc. this shows that there is an innumerable work to be carried out with wavelet, which means that the wavelet field is still in the development stage. There are still possibilities for future work on the project presented in this paper and they are summarized as follows:

a. The integration of transceiver hardware for real time simulation of Wavelet Packet Modulator system over a wireless channel.
b. Channel encoding of Wavelet Packets using different encoding techniques.
c. Evaluating the BER performance of Wavelet Packet Modulator System Using Equalization Techniques.

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