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Study: The Performance FFT and Wavelet Packet of OFDM Systems from through Demonstrated Numerical Examples

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Abstract: A major goal of the next-generation wireless communication systems is the development of a reliable high-speed wireless communication system that supports high user mobility. Multi-Carrier Modulation (MCM) technique is an attractive approach for high-speed digital radio communication systems in order to achieve a high spectral efficiency and to combat the frequency selectivity of the channel. Orthogonal frequency division multiplexing (OFDM) is a kind of MCM techniques. As proven by the success of OFDM, multicarrier modulation has been recognized as an efficient solution for wireless communications. Waveform bases other than sine functions could similarly be used for multicarrier systems in order to provide an alternative to OFDM. Wavelet Packet Modulation (WPM) was proposed as one of the multicarrier transmission methods like OFDM. Since it is a multicarrier transmission method.

In this paper, we study the performance of FFT-OFDM and wavelet Packet (WP)- OFDM from through demonstrated numerical examples, and evaluation of FFT-OFDM and DWPT-OFDM in AWGN channel , Flat fading channel and Selective Fading Channel.

Keywords: OFDM, FFT-OFDM, Wavelet Packet (WP), DWPT-OFDM.

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1. Introduction

In recent years, OFDM has attracted much attention as one of the multicarrier transmission methods according to the demands for high-speed mobile communications. Using a guard interval and a frequency domain equalizer (FDE), OFDM is robust to the frequency selective fading, and has high frequency efficiency. Hence, OFDM has been adopted in terrestrial digital broadcasting, wireless LAN, and power line communications modem, and so on [1].

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Low complexity OFDM receivers can be implemented using Fast Fourier Transform (FFT). Time synchronization errors originating from misalignment of symbols at demodulator is a serious OFDM design consideration. This is because they cause Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI) which severely degrade the OFDM performance. A lot of research energy has been expended to address this problem. A few efforts in the literature on this topic can be found in [2] - [5].

Wavelet transformation has recently emerged as a strong candidate for digital modulation [6]. WPM was first proposed by Lindsey [7] in 1997 as an alternative to OFDM. The fundamental theories of OFDM and WPM have many similarities in their way of functioning and performance but there are some significant differences which give the two systems distinctive characteristics. OFDM signals only overlap in the frequency domain while the wavelet packet signals overlap in both, time and frequency. Due to time overlap WPM systems can not use cyclic prefix (CP) or any kind of guard interval (GI) that is commonly used in OFDM systems. OFDM utilizes CP to overcome interference caused by dispersive channels. The greatest motivation for pursuing WPM systems lies in the freedom they provide to communication systems designers. Unlike the Fourier bases which are static sines/cosines, WPM uses wavelets which offer flexibility and adaptation that can be tailored to satisfy an engineering demand. By altering the design specifications a wavelet based system that is more robust against synchronization errors could be developed without compromising on spectral efficiency or receiver complexity [8].

In [9] wavelet packet based multicarrier modulation is introduced and compared to the useful OFDM modulation in a wireless environment with narrowband interferences and multipath channel interferences. In [10] proposes a novel scheme of M-ary multicarrier spread spectrum based on wavelet packet. The scheme has good performance in multipath channel because of taking advantages of the properties of wavelet packet. its performance is investigated for a multipath, slow Rayleigh fading channel.

A novel wavelet packet division multiplexing (WPDM) system based on channel equalization is studied for multipath fading channels in [11] and in [12] investigate bit error rate (BER) performances of OFDM and WPM systems in the presence of carrier frequency offset and phase noise. Also in [13] propose a novel multi-channel modulation scheme for UWB transmissions based on the discrete wavelet packet transform (DWPT) and DWT combined with spread spectrum and multiband approaches (as analogous to multicarrier CDMA and multiband OFDM). In [8] investigate the BER performance degradation of WPM systems in the presence of timing offset and compare it with OFDM. And in [14] the performance of WPM over the mobile satellite channel is presented and analyzed. The theory analysis and the simulation results show that the orthogonality of WPM can help the system be robust to the multipath effect and the extend period of WPM symbols can decrease the frequency selective fading of the system. And the performance comparison of OFDM and WPM for several multipath wireless channels in [15].

In this paper we study the performance of FFT-OFDM and wavelet Packet (WP)- OFDM from through demonstrated numerical examples, and evaluation of FFT-OFDM and DWPT-OFDM in AWGN channel , Flat fading channel and Selective Fading Channel.

This paper is organized as follows: in section 2: presents FFT-OFDM System, and A Demonstrated Numerical Example on FFT-OFDM is presented in Section 3, Section 4 is presented Proposed WP- OFDM System, section 5, A Demonstrated Example on WP-OFDM, section 6 Computer Simulation and Results followed by section 7 which concludes the paper.

2. FFT-OFDM System

The block diagram of the proposed system for OFDM is depicts in figure (1). The OFDM modulator and demodulator of FFT-based OFDM is shown in figure (2). Figure 1, illustrates a typical OFDM system used for multicarrier modulation. The transmitter accepts data, and converts it into lower rate sequences via serial to parallel conversion, these lower rate sequences are mapped to give sequences of channel symbols. This process will convert data to corresponding value of M-ary constellation which is complex word, i.e. real and imaginary part.

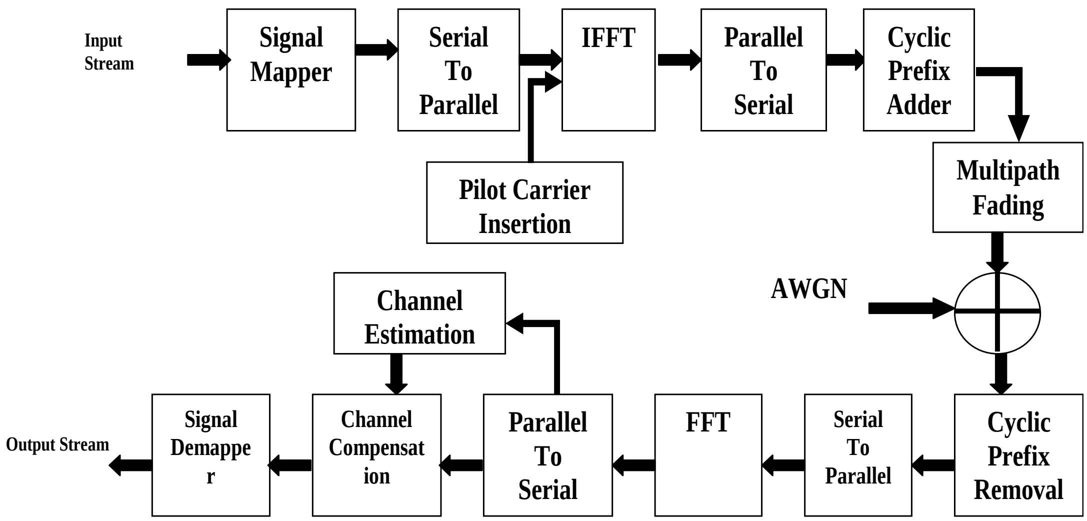
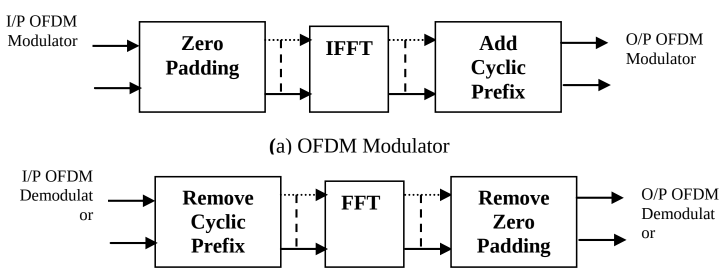


Fig. 1 Block Diagram of OFDM System



(a) OFDM Modulator

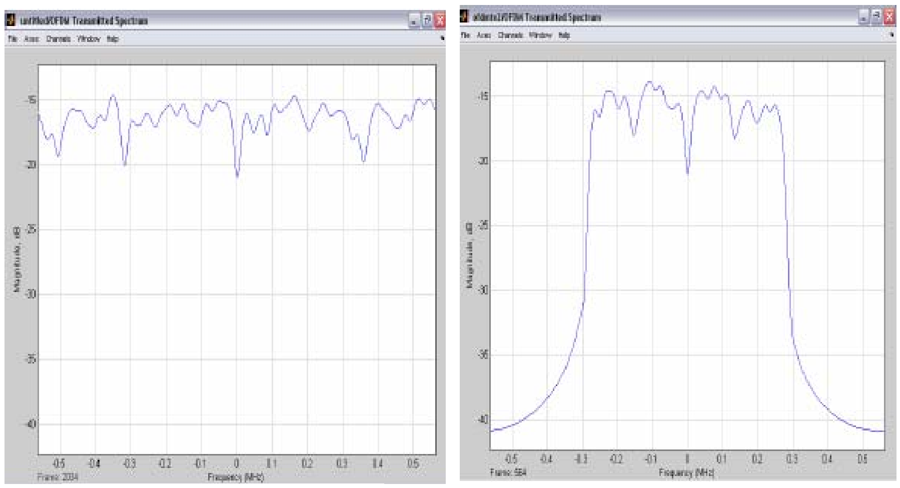
(b) OFDM Demodulator

Fig.2 The OFDM modem system

The training frame (pilot sub-carriers frame) will be inserted and sent prior to information frame. This pilot frame will use to make channel estimation that's used to compensate the channel effects on the signal. To modulate spread data symbol on the orthogonal carriers, an NF-point Inverse Fast Fourier transform IFFT will be used, as in conventional OFDM. Zeros will be inserted in some bins of the IFFT in order to make the transmitted spectrum compacts and reduce the adjacent carriers interference. The spectrum of the signal with zeros at some sub-carriers and without zeros can be shown in the figure (3).

The added zeros to some sub-carriers will limit the bandwidth of the system, while the system without zeros pad has a spectrum which is spread in frequency. The last case is unacceptable in communication systems, since one limitation of communication systems is the width of bandwidth. The addition of zeros to some sub-carriers means that not all the sub-carriers will be used; only subset (NC) of total sub-carriers (NF) will be used. Therefore, the number of bits in OFDM symbol is equal to log2 (M)*NC. Orthogonality between carriers is normally destroyed when the transmitted signal is passed through a dispersive channel. When this occurs, the inverse transformation at the receiver cannot recover the data that was transmitted perfectly. Energy from one subchannel leaks into others, leading to interference. However it is possible to Rescue orthogonality by introducing a cyclic prefix

(CP). This CP consists of the final v samples of the original K samples to be transmitted, prefixed to the transmitted symbol. The length v is determined by the channel's impulse response and is chosen to minimize ISI. If the impulse response of the channel has length less than or equal to v, the CP is sufficient to completely eliminate ISI and ICI. The efficiency of the transceiver is reduced by a factor of $\frac{k}{k+v}$, so it desirable to make v as small, or K as large as possible. So the drawbacks of the CP are the loss of data throughput as precious bandwidth is wasted on repeated data. For this reason it is required to find another structure for OFDM to mitigate these drawbacks.



(a) With zero pad **(b) Without zero pad.**

Fig. 3 OFDM spectrum: (a) with zero pad (b) without zero pad.

At the receiver, assuming synchronization condition is satisfied, the inverse operations are employed. The received signal is converted to parallel version, after that discarding the interfered cyclic prefix. The FFT is used to transfer the signal back to the base band frequency domain, and then the channel effects are compensated (by using pilot carrier to estimate the channel frequency response). If the number of subchannels is sufficiently large, the channel power spectral density can be assumed virtually flat within each subchannel. In these types of channels, multicarrier modulation has long been known to be optimum when number of subchannels is large. The size of subchannels required to be approximate optimum performance depends on how rapidly the channel transfer function varies with frequency.

3. Demonstrated Numerical Example on FFT-OFDM System

The above operations can be illustrated through the following example. Let the input data binary sequence T_{data} consists of 16-bits, and assume that there are 8 sub channels and a QPSK signal mapper.

$$T_{data} = [1\ 0\ 1\ 0\ 1\ 1\ 1\ 0\ 0\ 0\ 0\ 1\ 0\ 1\ 0\ 0]^t \tag{1}$$

Step 1: Serial to parallel conversion:

The input data sequence will be converted from serial form to parallel form. The S/P will put 2-bits on each sub-channel, thus the output of the S/P will be:

$$T_{s/p} = \begin{bmatrix} 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 1 & 1 \end{bmatrix}^t \equiv \begin{bmatrix} 2 & 2 & 3 & 2 & 0 & 1 & 1 & 1 \end{bmatrix}^t \tag{2}$$

Step 2: Signal Mapper

The signal mapper that used here is the QPSK modulation as assumed above. It converts the 2-bits on each sub-channel to their corresponding constellation. The constellation diagram of QPSK modulation is shown in figure (4). Therefore, the output of signal mapper for the current example will be:

$$T_{SignalMapp} = \begin{bmatrix} 1-i & 1-i & -1-i & 1-i & 1+i & -1+i & -1+i & -1+i \end{bmatrix}^t \quad (3)$$

Step 3: Generation and insertion of Pilot Carriers

A pilot-carrier (training sequence) is generated which is a bipolar sequence $\{\pm 1\}$.The receiver will be informed about this sequence previously. The training sequence that was used here in this demonstrated example is:

$$T_{training} = \begin{bmatrix} 1 & 1 & -1 & -1 & -1 & 1 & 1 & -1 \end{bmatrix}^t \quad (4)$$

The two sequences {data+training} will insert as follows:

$$T_{data+training} = \begin{bmatrix} 1 & 1 & -1 & -1 & -1 & 1 & 1 & -1 \\ 1-i & 1-i & -1-i & 1-i & 1+i & -1+i & -1+i & -1+i \end{bmatrix}^t \quad (5)$$

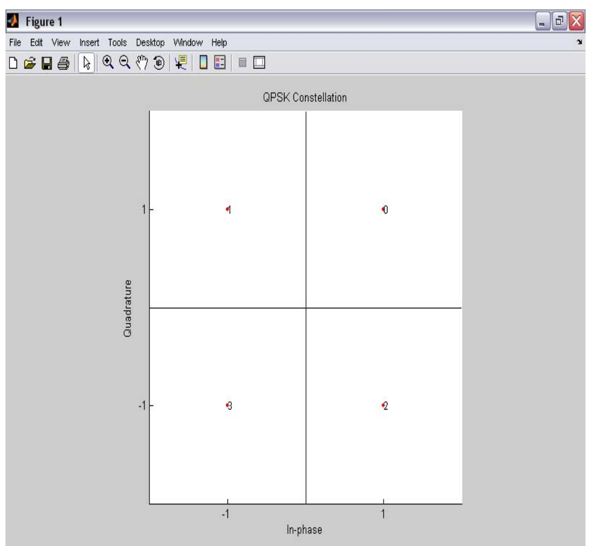


Fig.4 QPSK constellation

Step 4: The OFDM Modulator

The first step in the OFDM modulator is the addition of zeros to the input sequences. The number of zeros that added in this example equal to 8 zeros [4 at the beginning and 4 at the ending]. Thus the output of the zero pad block will be:

$$T_{ZeroPad} = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 1 & -1 & -1 & -1 & 1 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1-i & 1-i & -1-i & 1-i & 1+i & -1+i & -1+i & -1+i & 0 & 0 & 0 & 0 \end{bmatrix}^t \quad (6)$$

The second step is to apply the IFFT to the produced sequence. Hence the resultant IFFT coefficients are:

$$T_{IFFT} = \begin{bmatrix} 0 & 0 \\ 0.0625 + 0.0418i & 0.3401 + 0.1633i \\ -0.125 + 0.125i & -0.3018 - 0.0518 \\ 0.0625 - 0.3142i & -0.0574 - 0.0574i \\ 0.25i & 0.25 \\ 0.0625 - 0.0124i & -0.1091 + 0.0676i \\ -0.125 - 0.125i & -0.0518 - 0.0518i \\ 0.0625 + 0.0935i & 0.0383 + 0.0383i \\ 0 & 0 \\ 0.0625 - 0.0935 & 0.0135 - 0.1633i \\ -0.125 + 0.125i & 0.0518 + 0.3018 \\ 0.0625 + 0.0124i & -0.1926 - 0.1926i \\ -0.25i & 0.25 \\ 0.0625 + 0.3142i & -0.2444 - 0.0676i \\ -0.125 - 0.125i & 0.3018 + 0.3018i \\ 0.0625 - 0.0418i & -0.2883 - 0.2883i \end{bmatrix} \quad (7)$$

The other step to be performed is the addition of the cyclic prefix, in this example a 25% cyclic prefix is used.
The sequence after adding this cyclic prefix is:

$$T_{Cycic\ \Pr efix} = \begin{bmatrix} -0.25i & 0.25 \\ 0.0625 + 0.3142i & -0.2444 - 0.0676i \\ -0.125 - .0125i & 0.3018 + 0.3018i \\ 0.0625 - 0.0418i & -0.2883 - 0.2883i \\ 0 & 0 \\ 0.0625 + 0.0418i & 0.3401 + 0.1633i \\ -0.125 + 0.125i & -0.3018 - 0.0518i \\ 0.0625 - 0.3142i & -0.0574 - 0.0574i \\ 0.25i & 0.25 \\ 0.0625 - 0.0124i & -0.1091 + 0.0676i \\ -0.125 - 0.125i & -0.0518 - 0.0518i \\ 0.0625 + 0.0935i & 0.0383 + 0.0383i \\ 0 & 0 \\ 0.0625 - 0.0935i & 0.0135 - 0.1633i \\ -0.125 + 0.125i & 0.0518 + 0.3018i \\ 0.0625 + 0.0124i & -0.1926 - 0.1926i \\ -0.25i & 0.25 \\ 0.0625 + 0.3142i & -0.2444 - 0.0676i \\ -0.125 - 0.125i & 0.3018 + 0.3018i \\ 0.0625 - 0.0418i & -0.2883 - 0.2883i \end{bmatrix} \quad (8)$$

Step 5: Sequences Insertion and Parallel to Serial Converter

After that the two sequences (training plus data) will be converted to one sequence, and P/S converts the signal from parallel form to a serial form. This will produce a transmitted sequence vector of [40*1] elements.

Step6: The Channel Effect

The transmitted signal will transfer through the channel to the receiver. In this example AWGN channel type with SNR equal to 20db is assumed.

Step 7: The S/P and sequence separation

The S/P converts the received sequence to a parallel form; also the separation of the two sequences will be done. The signal at the input of the OFDM Modulator(R) is:

$$R = \begin{bmatrix} 0.017 - 0.2416\,i & 0.2630 - 0.0104\,i \\ 0.0981 + 0.3237\,i & -0.2351 - 0.1159\,i \\ 0.0959 - 0.1651\,i & 0.3026 + 0.2493\,i \\ 0.0855 - 0.0713\,i & -0.3282 - 0.2513\,i \\ 0.0016 + 0.0430\,i & -0.0377 + .0004\,i \\ 0.0894 + 0.0365\,i & 0.3252 + 0.1377\,i \\ -0.1024 + 0.1405\,i & -0.3489 - 0.0197\,i \\ 0.0523 - 0.3107\,i & -0.0993 - 0.0481\,i \\ -0.0150 + 0.2247\,i & 0.3086 - 0.0394\,i \\ 0.0507 - 0.0347\,i & -0.1069 + 0.1209\,i \\ -0.1837 - 0.1074\,i & -0.1002 - 0.0403\,i \\ 0.0532 + 0.0558\,i & 0.0367 + 0.0971\,i \\ 0.0047 + 0.0311\,i & -0.0444 + 0.0453\,i \\ 0.0750 - 0.0709\,i & -0.0402 - 0.1905\,i \\ -0.0676 + 0.0923\,i & 0.0414 + 0.2504\,i \\ 0.0485 + 0.0019\,i & -0.1547 - 0.1955\,i \\ 0.0248 - 0.2972\,i & 0.2551 - 0.0131\,i \\ 0.0943 + 0.2266\,i & 02183 - 0.1012\,i \\ -0.0876 - 0.0858\,i & 0.2553 + 0.3216\,i \\ 0.0231 - 0.0624\,i & -0.3066 - 0.2291\,i \end{bmatrix} \qquad (9)$$

Step8: OFDM Demodulator

The *first step* in OFDM Demodulator is to discard the cyclic prefix from the sequence, the signal after removing the cyclic prefix is:

$$R_{C.P.\mathrm{Re}\,mover} = \begin{bmatrix} 0.0016 + 0.0430\,i & -0.0377 + .0004\,i \\ 0.0894 + 0.0365\,i & 0.3252 + 0.1377\,i \\ -0.1024 + 0.1405\,i & -0.3489 - 0.0197\,i \\ 0.0523 - 0.3107\,i & -0.0993 - 0.0481\,i \\ -0.0150 + 0.2247\,i & 0.3086 - 0.0394\,i \\ 0.0507 - 0.0347\,i & -0.1069 + 0.1209\,i \\ -0.1837 - 0.1074\,i & -0.1002 - 0.0403\,i \\ 0.0532 + 0.0558\,i & 0.0367 + 0.0971\,i \\ 0.0047 + 0.0311\,i & -0.0444 + 0.0453\,i \\ 0.0750 - 0.0709\,i & -0.0402 - 0.1905\,i \\ -0.0676 + 0.0923\,i & 0.0414 + 0.2504\,i \\ 0.0485 + 0.0019\,i & -0.1547 - 0.1955\,i \\ 0.0248 - 0.2972\,i & 0.2551 - 0.0131\,i \\ 0.0943 + 0.2266\,i & 02183 - 0.1012\,i \\ -0.0876 - 0.0858\,i & 0.2553 + 0.3216\,i \\ 0.0231 - 0.0624\,i & -0.3066 - 0.2291\,i \end{bmatrix} \qquad (10)$$

The *second step* is the application of the FFT process, the signal after the FFT is:

$$R_{FFT} = \begin{bmatrix} 0.0617 - 0.1166\,i & -0.2355 + 0.0964\,i \\ 0.1407 + 0.1838\,i & 0.1003 + 0.0419\,i \\ 0.0451 + 0.0678\,i & -0.4068 + 0.1458\,i \\ -0.1713 + 0.0023\,i & 0.1346 - 0.0500\,i \\ 0.9303 - 0.1704\,i & 0.9761 - 1.0026\,i \\ 0.9345 - 0.1897\,i & 0.8555 - 1.3512\,i \\ -0.7995 + 0.1630\,i & -1.1461 - 0.8349\,i \\ -0.9480 - 0.0218\,i & 1.0485 - 0.8525\,i \\ -0.9117 + 0.1992\,i & 0.8930 + 0.9140\,i \\ 1.0213 + 0.2034\,i & -1.0813 + 0.9461\,i \\ 0.7999 + 0.0288\,i & -0.9868 + 0.9760\,i \\ -0.9279 + 0.0285\,i & -0.9123 + 0.9924\,i \\ -0.0157 + 0.0942\,i & 0.2910 - 0.0350\,i \\ -0211 + 0.0095\,i & 0.0495 - 0.0298\,i \\ -0.0594 + 0.3327\,i & -0.045 + 0.1059\,i \\ -0.0531 - 0.1202\,i & -0.1372 - 0.0554\,i \end{bmatrix} \qquad (11)$$

After that the values corresponding to the zeros pad is removed, therefore the signal at the output of the OFDM demodulator is:

$$R_{OFDMdemodulator} = \begin{vmatrix} 0.9303-0.1704i & 0.9761-1.0026i \\ 0.9345-0.1897i & 0.8555-1.3512i \\ -0.7995+0.1630i & -1.1461-0.8349i \\ -0.9480-0.0218i & 1.0485-0.8525i \\ -0.9117+0.1992i & 0.8930+0.9140i \\ 1.0213+0.2034i & -1.0813+0.9461i \\ 0.7999+0.0288i & -0.9868+0.9760i \\ -0.9279+0.0285i & -0.9123+0.9924i \end{vmatrix} \qquad (12)$$

Step 9: The Channel Estimation

The training sequence will be used to estimate the channel frequency response as follows:

$$H(k) = \frac{\mathrm{Re}\,ceivedTrainingSample(k)}{TransmittedTrainingSample(k)}, k = 0,1....,7 \qquad (13)$$

The channel frequency response that obtained in this example is:

$$H_{estimate} = \begin{bmatrix} 0.9303 - 0.1704i \\ 0.9345 - 0.1897i \\ 0.7995 - 0.1630i \\ 0.9480 + 0.0218i \\ 0.9117 - 0.1992i \\ 1.0213 + 0.2034i \\ 0.7999 + 0.0228i \\ 0.9279 - 0.0285i \end{bmatrix} \qquad (14)$$

Step10: The Channel Compensation

The channel frequency response which is found in the last step will be used to compensate the channel effects on the data, and the estimated data can be found using the following equation:

$$Estimate.data(k) = H_{estimate}^{-1}(k) * \mathrm{Re}\,ceived.data(k), k = 0,1,....,7 \qquad (15)$$

The data at the output of the channel compensation is:

$$R_{AfterChannelCompensator} = \begin{bmatrix} 1.2061-0.8567i \\ 1.1611-1.2101i \\ -1.1719-1.2832i \\ 1.0848-0.9242i \\ 0.7258+1.1611i \\ -0.8408+1.0939i \\ -1.1978+1.2543i \\ -1.0150+1.0383i \end{bmatrix} \qquad (16)$$

Step 11: The Signal Demapper

The output of channel compensator will be passed through the signal demapper. The type of signal demapper will correspond to the type that was used in the transmitter. For this example the QPSK demodulator is used and its output will be:

$$R_{SignalDemapper} = \begin{bmatrix} 2 & 2 & 3 & 2 & 0 & 1 & 1 & 1 \end{bmatrix}^t \tag{17}$$

Step 12: The P/S converter

The last step here, is the P/S which converts the parallel form of the signal to a serial form and the output estimate data for the given example will be:

$$R_{o/pSignal} = \begin{bmatrix} 1 & 0 & 1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 \end{bmatrix}^t \tag{18}$$

4. WP-OFDM System

The block diagram of the proposed system for DWT-OFDM is depicts in figure (5). The overall system of OFDM is the same as in figure (1). The only difference is the OFDM modulator and demodulator. The wavelet based OFDM modulator and demodulator that used are shown in the figure (6).

The processes of the S/P converter, the signal demapper and the insertion of training sequence are the same as in the system of FFT-OFDM. Also the zeros will be added as in the FFT based case and for the same reasons. After that the inverse discrete wavelet transform (IDWT) will be applied to the signal.

The main and important difference between FFT based OFDM and WP based OFDM is that the wavelet based OFDM will not add a cyclic prefix to OFDM symbol. Therefore the data rates in wavelet based OFDM can surpass those of the FFT implementation. After that the P/S converter will convert the OFDM symbol to its serial version and will be sent it through the channel.

At the receiver, also assuming synchronization conditions are satisfied, first S/P converts the OFDM symbol to parallel version. After that the DWPT will be done. Also the zero pad will remove and the other operations of the channel estimation, channel compensation, signal demapper and P/S will be performed in a similar manner to that of the FFT based OFDM.

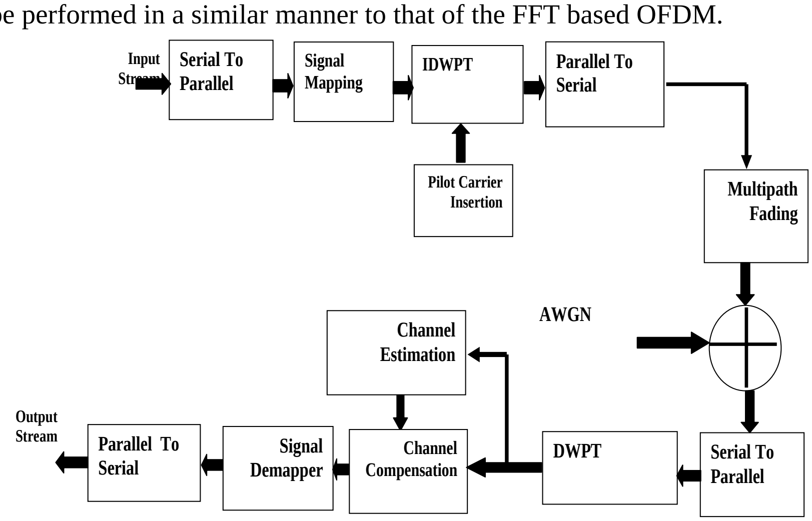


Fig.5 block diagram of WPT-OFDM.

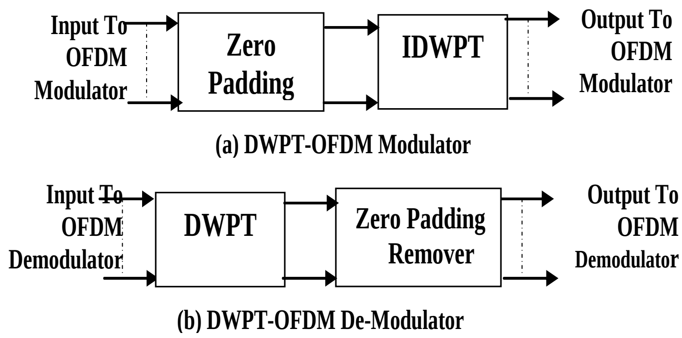


Fig.6 DWPT-OFDM modem system

5. Demonstrated Example on WP-OFDM System

A numerical example is used to illustrate the WP-OFDM system. The same parameters of the example used in the FFT-OFDM are taken. A 16 bits input binary data, for simplicity we take the same data sequence use in that example .The first 3 steps will be the same as shown for the FFT-OFDM system, hence the process will start from step 4.

Step 4: The WP- OFDM modulator

The first step is also the zero pads. Eight zeros will add, four at the beginning and four at the ending of the sequence. The sequence at the O/P of the zero pad process will be:

$$T_{ZeroPad} = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 1 & -1 & -1 & -1 & 1 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1-i & 1-i & -1-i & 1-i & 1+i & -1+i & -1+i & -1+i & 0 & 0 & 0 & 0 \end{bmatrix}^t \quad (19)$$

Secondly, the sequence will be passed through the inverse discrete wavelet packet transform (IDWPT). The output of the IDWPT is:

$$T_{IWP} = \begin{bmatrix} 0 & 0 \\ 0 & 1-2i \\ 0 & -1+2i \\ 0 & 0 \\ 1 & 1 \\ 1 & 0 \\ -1 & 0 \\ -1 & -1 \\ 0 & 0 \\ 0 & -1 \\ 0 & 1 \\ 0 & 0 \\ -1 & 1 \\ 1 & 0 \\ -1 & 0 \\ 1 & -1 \end{bmatrix} \quad (20)$$

Step 5, 6 and 7 are the same as that in the FFT- OFDM example.

Step 8: The WP-OFDM demodulator

The first step in the OFDM demodulator is the application of the wavelet packet transform (WPT). The WPT will be taken to the received sequences, the output of the WPT is:

$$R_{wp} = \begin{bmatrix} 0.0211 - 0.0074i & 0.0132 + 0.0226i \\ -0.0308 - 0.0223i & 0.0523 - 0.0131i \\ -0.0339 + 0.0069i & 0.0364 + 0.0435i \\ -0.0234 + 0.0150i & 0.0366 + 0.0514i \\ .09797 + 0.0197i & 0.09846 + 0.9968i \\ 0.9483 + 0.0067i & 1.0101 + 0.9948i \\ -1.0304 - 0.0706i & -1.0271 + 1.0508i \\ -0.9975 - 0.0375 & 1.0153 + 1.0305i \\ -1.0380 - 0.0066i & 0.9874 - 1.0101i \\ 1.0372 - 0.0424i & 0.9226 - 0.9166i \\ 1.0442 - 0.0539i & -1.0591 - 0.9438i \\ -1.0008 + 0.0336i & -0.9768 - 0.9809i \\ -0.0360 + 0.0244i & -0.0013 + 0.0412i \\ -0.0071 - 0.0808i & 0.0358 + 0.0161i \\ 0.0850 + 0.0571i & 0.0031 - 0.0591i \\ 0.0137 - 0.0120i & -0.0582 + 0.0207i \end{bmatrix} \quad (21)$$

The second operation in the WP-OFDM modulator is the zero remover, the zeros which added at transmitter will be remove in a similar manner.

Steps 9, 10, 11 and 12 are the same as that for the example of the FFT-OFDM system.

6. Computer Simulation and Results

After the systems for the FFT-OFDM and DWPT-OFDM are designed, the simulations of these proposed systems in MATLAB version 7 are achieved. The results of both systems in the three types of channels that we obtained will be examined and compared. Table (1) shows the parameters of the systems that are used in the simulation. The bandwidth used is 5MHz.

Table 1: Simulation Parameters

Modulation Types	QAM
No. of Sub Carriers	32
No. of WP point	32
No. of FFT point	32
Channel Model	AWGN
	Flat Fading + AWGN
	Frequency Selective Fading + AWGN

6.1 In AWGN Channe

In AWGN channel model a comparison was made between the DWPT-OFDM and the FFT-OFDM, the simulation results appear in figure7 and table 2 which indicates that DWPT-OFDM system performs much better than FFT-OFDM system on AWGN channel.

There are nearly 18dB gain at BER 10^{-1} in FFT-OFDM system using DWPT instead of FFT, and it can be obtain more gains when the SNR increasing. This makes the DWPT-OFDM significant on AWGN channel. This result obtained where the DWPT-OFDM doesn't use the CP which is one of the key motivation factors to implement the OFDM based on Wavelet.

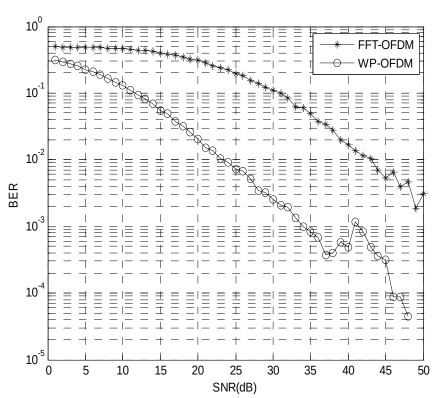


Fig.7 BER performance of DWPT-OFDM and FFT-OFDM in AWGN.

Table 2: BER performance of DWPT-OFDM and FFT-OFDM in AWGN.

Type of modulation		FFT-OFDM		DWP-OFDM	
QAM	BER	10^{-1}	10^{-2}	10^{-1}	10^{-2}
	SNR	30	42	12	24

6.2 In Flat Fading Channel

In this section the channel model is flat fading channel, where the bandwidth of the transmitted signal is smaller than the coherence bandwidth of the channel. Then all frequency components of the transmitted signal undergo the same attenuation and phase shift in transmission through the channel. The BER performance of DWPT-OFDM and FFT-OFDM systems are compared as shown in figure 8 and table 3. It shows that DWPT-OFDM perform well compared to FFT-OFDM. At 18dB SNR the BER for DWPT-OFDM is 10^{-2} and for FFT-OFDM structure at the same BER the SNR is 37dB, and it can be obtain more gains when the SNR increasing. This makes the DWPT-OFDM significant on Flat Fading channel.

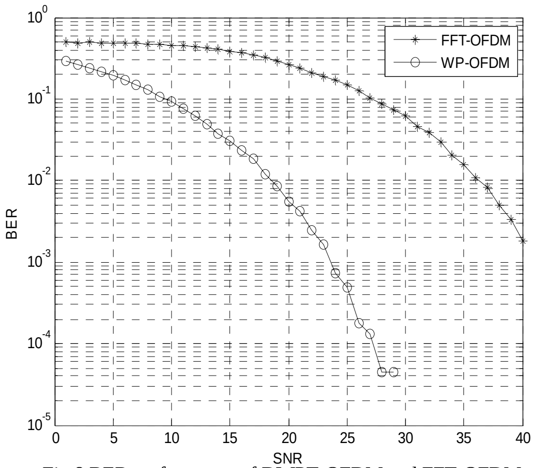


Fig.8 BER performance of DWPT-OFDM and FFT-OFDM in Flat Fading Channel.

Table 3: BER performance of DWPT-OFDM and FFT-OFDM in Flat Fading Channel.

Type of modulation		FFT-OFDM		DWP-OFDM	
QAM	BER	10^{-1}	10^{-2}	10^{-1}	10^{-2}
	SNR	27	37	9	18

6.3 In Selective Fading Channel

The aim of this section is to show the BER performance of the DWPT-OFDM and FFT-OFDM systems in the selective fading channel. Where the transmitted signal has a bandwidth greater than the coherence bandwidth of the channel. The frequency components of the transmitted signal with frequency separation exceeding the coherence bandwidth are subjected to different gains and phase shifts. It can be shown in figure9 of the BER performance that DWPT-OFDM performs better than FFT-OFDM on the lower SNR region in the selective fading channel. The DWPT-OFDM performs well compared to FFT-OFDM when SNR<30 dB. From that point the performance changed. The FFT-OFDM outperform the BER performance of DWPT-OFDM.

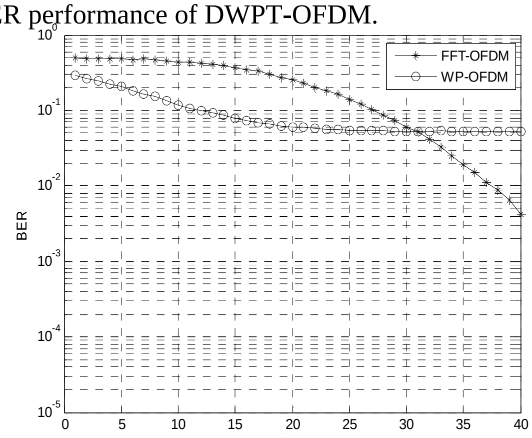


Fig.9 BER performance of DWPT-OFDM and FFT-OFDM in Selective Fading Channel.

7. Conclusion

Wavelet Packet Modulation (WPM) was proposed as one of the multicarrier transmission methods like OFDM. And it is shown that the performance of WPM is better than OFDM.

In this paper, from through the results of both systems (FFT-OFDM and WPT-OFDM) in the three types of channels (AWGN channel, Flat fading channel and Selective Fading Channel) that we obtained, examined and compared As follows:

1. In AWGN channel model, the DWPT-OFDM system performs much better than FFT-OFDM system. This makes the DWPT-OFDM significant on AWGN channel.
2. In flat fading channel, DWPT-OFDM perform well compared to FFT-OFDM, and it can be obtain more gains when the SNR increasing. This makes the DWPT-OFDM significant on Flat Fading channel.
3. In the selective fading channel. The DWPT-OFDM performs better than FFT-OFDM on the lower SNR region. The DWPT-OFDM performs well compared to FFT-OFDM when SNR< 30dB. From that point the performance changed. The FFT-OFDM outperforms the BER performance of DWPT-OFDM.

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