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Performance of Discrete Wavelet Transform Based on OFDM with Adaptive Modulation

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Abstract: In the mobile environments, the channel will be highly hostile at high data rate transmission. To combat with this problem, many designs were proposed and developed, such as, Orthogonal Frequency Division Multiplexing (OFDM) system. Adaptive modulation improves the system efficiency by matching transmission parameters to channel variations, so that, OFDM system with Adaptive modulation technique will be achieved an efficient bandwidth transmission technique in wireless fading environments. In this paper, Discrete Wavelet Transform (DWT) is used in OFDM system and illustrates the improvement of Bit Error Rate (BER) and throughput performances compared with used Discrete Fourier Transform (DFT). DWT with Zero Padding (DWT-ZP) is also used as addition technique which supports high performances for the system, all tested in frequency selective fading channel. The obtained results show that a significant improvements in BER and throughput can be achieved demonstrating the superiority of use DWT compared with use traditional DFT in Adaptive OFDM system.

Keywords: Adaptive modulation, OFDM system, Wavelet Transform, zero padding.

1. Introduction:

OFDM is a special form of multi-carrier transmission technique. It is widely applied in wireless communication systems due to its high rate transmission capability with high bandwidth efficiency and its robustness with regard to multi-path fading and delay [1,2]. In OFDM, the bandwidth is subdivided among orthogonal subcarriers over which information is modulated. If the number of subcarriers is large enough, each individual subchannel is characterized by flat fading rather than frequency selective fading, thereby precluding the need for otherwise necessary equalization to combat intersymbol interference [3].

Adaptive modulation scheme is an efficient scheme to increase the transmission rate by changing the channel modulation scheme according to the estimated channel state information (CSI), since its implementation depends on the channel environment of the system and control period by using feedback information [1,2] . The basic premise of adaptive modulation is a real-time balancing of the link budget in flat fading through adaptive variation of the transmitted power level [4, 5], symbol transmission rate, constellation size, BER, coding rate/scheme, or any combination of these parameters. Thus, without wasting power or sacrificing BER, these schemes provide a higher average link spectral efficiency (bps/Hz) by taking advantage of flat fading through adaptation. Good performance of adaptive modulation requires accurate channel estimation at the receiver and a reliable feedback path between the receiver and transmitter. The used of adaptive modulation with OFDM system is one of the promising approaches to fourth generation of mobile telecommunications technology (4G).

However, the conventional OFDM is implemented by means of IDFT and DFT operators. In its frequency spectrum, the main lobe doesn't concentrate energy effectively and side lobe attenuates slowly; the multipath fading or synchronization error will cause severe performance degradation due to the inter-channel interference (ICI), and inter-symbol interference (ISI) [6,7]. To search for an efficient multicarrier scheme, a number of improved multicarrier systems have been proposed. Among them, wavelet based multicarrier systems as in[6, 8, 9] attract some interests due to their better ability to combat ICI and ISI than conventional DFT based multicarrier system. So, wavelet has been developed as a new signal processing tool which enables the analysis on several timescales of the local properties of compiles signals and its offer transform flexibility, lower sensitivity to channel distortion and interference, and better utilization of spectrum [8,10].

This paper demonstrate the performance of OFDM system with adaptive modulation employing Wavelet transform and the simulation results show that this system can be better than the conventional OFDM system that uses Fourier Transform in terms of BER probabilities and throughput parameter. The paper is organized as follows; section 2 describes the main differences of used Fourier Transform and Wavelet Transform in a Multicarrier systems. The adaptive modulation and system model of OFDM is presented in section 3. In section 4, the simulation results of BER and throughput performances of the system using Fourier Transform and Wavelet transform are presented. Finally, conclusions are presented in section 5.

2. Fourier Transform versus Wavelet Transform:

Fourier Transform based Conventional OFDM system has been a popular choice for wireless transmission over a long time for its transmission performances. In Fourier analysis we break up a signal into a set of an infinite sum of *Sines* and *Cosines* to exploit the orthogonality relationship between them. The large spectral overlap between frequency responses of filters corresponding to different subchannels is weakness of DFT. This can lead to substantial leakage of power between subchannels and consequently induce inter channel interference. Therefore, an efficient Discrete Wavelet can be used in order to improve subchannel separation, in which perfect reconstruction filter banks are used as transceivers [6,11].

Wavelet transform provides variations in time-frequency resolutions due to the variation in it basis function in terms of frequency and scale which is a major advantage over Fourier transform. The wavelet basis function divides the data into different frequency components and chooses the component that relates to its scale.

In wavelet transform, the signal is first decomposed by a low-pass and a high-pass filter. Half of the frequency components have been filtered out at filter outputs and hence can be down-sampled. Finally, approximate and detail coefficients from $g(n)$ and $h(n)$ filters are gotten respectively as shown in Fig. 1 [6,11].

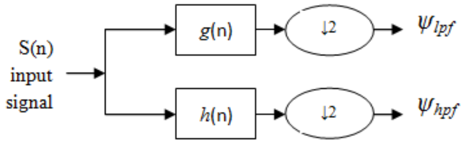

Fig. 1 Block Diagram of Wavelet Decomposition

where $g(n)$ and $h(n)$ are the wavelet's half-band low pass filter and high pass filter impulse responses respectively, and ψ_{lpf} and ψ_{hpf} is approximate and details coefficients respectively and can be written as:[11]

$$\psi_{lpf}(n) = \sum_{k=-\infty}^{k=\infty} S(k)g(2n-k) \qquad (1)$$

$$\psi_{hpf}(n) = \sum_{k=-\infty}^{k=\infty} S(k)h(2n-k) \qquad (2)$$

Fig. 2 shows three level decomposition wavelet Transform (DWT) [6], The multi-level DWT is computed by successive lowpass and highpass filtering of the discrete time-domain signal. At each level, the high pass filter produces detail information denoted by $d(n)$, while the low pass filter associated with scaling function produces coarse approximations denoted by $a(n)$. At each decomposition level, the half band filters produce signals spanning only half the frequency band. This doubles the frequency resolution as the uncertainty in frequency is reduced by half. The decimation by 2 halves the time resolution as the entire signal is now represented by only half the number of samples. Thus, while the half band low pass filtering removes half of the frequencies and thus halves the resolution, the decimation by 2 doubles the scale. The filtering and decimation process is continued until the desired level is reached. The DWT of the original signal is then obtained by concatenating all the coefficients, $a(n)$ and $d(n)$, starting from the last level of decomposition.

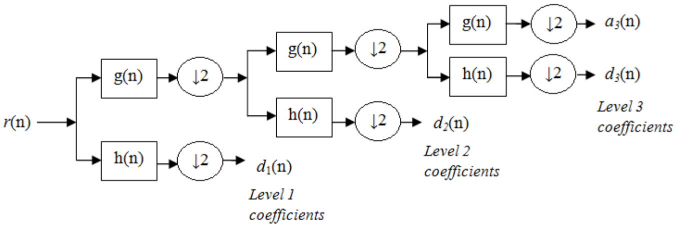

Fig.2 Three level decomposition wavelet Transform (DWT)

Fig. 3 is depicted the reconstruction of the original signal from the wavelet coefficients. Basically, the reconstruction is the reverse process of decomposition. The approximation and detail coefficients at every level are upsampled by two, passed through the low pass and high pass synthesis filters and then added. This process is continued through the same number of levels as in the decomposition process to obtain the original signal [6].

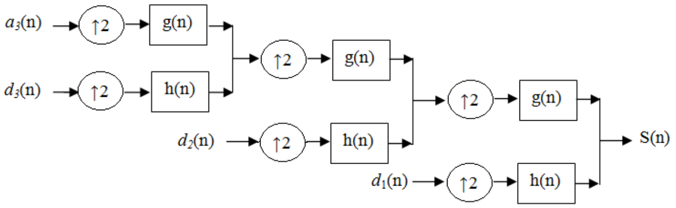

Fig. 3 Three level reconstruction wavelet Transform (IDWT)

Haar, Daubechies, Symlets and Coiflets are a different wavelet family types that can be used in communication systems. These wavelet families have different filter length and values of approximated and detailed coefficients. In this paper, Haar Wavelet is tested and compared with DFT performances.

3. Adaptive Modulation and System Model:

3.1 Adaptive Modulation:

Fixed modulation is usually designed for a certain minimum Signal to Noise Ratio (SNR), which is related to the maximum coverage distance of the link; in such a way that the maximum allowed error probability is guaranteed within the coverage area. With it, the transmitter does not have any information on the received SNR or other channel parameters available. In an adaptive modulation method, on the other hand, channel information is made available to the transmitter. In its simplest form, the instantaneous SNR is made available but for more complex channels, more channel information can be made available [5]. The following steps have to be considered to design an Adaptive modulation system:

i- Channel quality estimation: In order to appropriately select the system parameters to be employed for the next transmission, a reliable estimate of the CSI during the next active transmission time slot is necessary. Pilot symbol assisted modulation (PSAM) has been proposed as an attractive technique to detect the CSI in the fading environment by periodically inserting known symbols, from which the receiver derives its amplitude and phase reference [12].

ii- Adaptation rate: The adaptation rate determines what kind of channel variations the AM algorithm is tracking. If the channel is changing faster than it can be estimated and feedback to the transmitter, adaptive transmission techniques will perform poorly, and other means to mitigate the effects of fading should be used. It is easy to understand that faster adaptation leads to larger capacity gain, since the channel variations are exploited in a more accurate manner. However, fast adaptation has practical limitations such as hardware constraints. Besides, fast adaptation increases the number of mode-change messages sent to the receiver, which consume bandwidth and time resources [12].

iii- Feedback: The feedback messages inform the transmitter of the CSI estimated or the transmission mode decided by the receiver[12]. In this paper, perfect feedback channel is assumed.

Thresholds SNR values are satisfied for each modulation scheme that is used in adaptive modulation process and selected according to desired BER level. The received feedback information (CSI) is used to compute estimated SNR that is used with thresholds SNR values to select appropriate modulation scheme that has BER under the desired BER level for received signal and to give good spectrum efficiency (bit/sec/Hz).With higher SNR estimation, high modulation level will be chosen and spectrum efficiency will be increased.

One of the parameter that is illustrating the efficiency of adaptive OFDM system is throughput rate. The throughput rate is defined as the number of information bits transmitted successfully per unit time and is measured in bit/sec. Throughput (η) is defined as [13]:

$$\eta = R_b * \frac{N_{suc}}{N_{trans}} \qquad (3)$$

where R_b is the total information bit rate, N_{trans} and N_{suc} are the total number of transmitted and correctly received data blocks, respectively.

3.2. System Model:

Fig. 4 shows the block diagram of adaptive OFDM system used. The system consists of a transmitter, a receiver and a Rayleigh communication channel. At the transmitter, the data serial bit sequences are converted to the parallel bit sequences and then modulated with one of various modulation mappings. According to the SNR estimated and threshold value required for each modulation scheme, the modulation mapping is chosen to maintain the required BER. The adaptive modulators select from different modulation type formats: BPSK, QPSK, 8QAM, and16QAM. This means that 0, 1, 2, 3 and 4 bit per subcarrier can be transmitted. The channel estimation can be performed by inserting pilot tones into all of the subcarriers of OFDM symbols with a specific period (block type). Sending blocks of pilot symbols in the beginning of transmission that used to find channel state information (CSI) and channel frequency response ($\hat{H}$) at each subcarrier that is used to equalize many OFDM data symbols tracking in each frame as in [13]. The OFDM time signal is generated by an inverse DWT with N=128 input symbols and is transmitted over the Rayleigh fading channel. Cyclic extension has been inserted with length equal to an eighth of transmitted block length (N=128) before transmission when DFT is used instead of DWT.

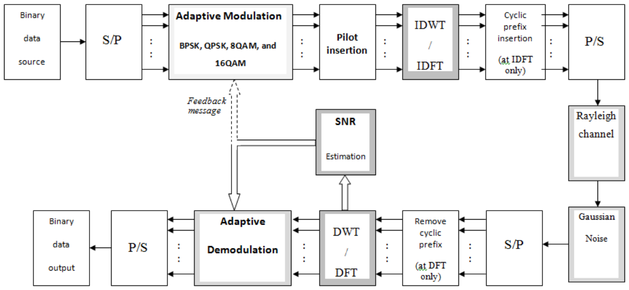

Fig. 4 Block diagram of adaptive Modulation technique in OFDM system.

At the receiver, after converted the received signal from serial to parallel, the data is prepared to enter DWT/DFT block. To compensate the impact of the channel, Equalizer is frequently used after the DWT/DFT operation. The information obtained from pilot symbols are used to find frequency channel response that is used to estimate SNR for the channel and feedback it to transmitter to select appropriate modulation scheme. After that, the symbols are demodulated and converted to serial bits form.

Estimated SNR determines for each OFDM symbol by sending two consecutive block of pilot transmitted (N_p=2) as channel estimation sequence (CES) in the frame. Each block can easily generate an estimate of the channel frequency response (CFR) vector as in Eq.4 [14]

$$\hat{W}[p,i] = \hat{H}_i - H[p,i]$$

$$H_i = (H[p,0]....H[p,i]....H[N_p, N \;\; -1]) \qquad (4)$$

where H[p,N] is the CFR at the i^{th} subcarrier estimated by the p^{th} CES. Calculate $\hat{H}_i$ by averaging the N_p estimates of CFR at the i^{th} subcarrier. Thus, the noise at the i^{th} subcarrier in the p^{th} CES is:

(5)

The signal power can be estimated as:

$$P_s = \frac{1}{N} \sum_{i=1}^{N} \left| \hat{H}_i \right|^2 \qquad (6)$$

and the noise power can be estimated as:

$$P_n = \frac{1}{N_p N} \sum_{p=1}^{N_p} \sum_{i=1}^{N} \left| \hat{W}[p,i] \right|^2 \qquad (7)$$

Thus, we have the estimated SNR as:

$$\hat{SNR} = \frac{P_s}{P_n} \qquad (8)$$

Now, each symbol will be modulated by one type of modulation according to threshold of that modulation value and SNR estimation.

Wavelet with Zero Padding (DWT-ZP) [7] based on adaptive OFDM system is applied also in this paper. By use of this technique, the details coefficients transmitted as zero bits data and reconstruction with the information data as approximated coefficients for IDWT in adaptive OFDM system transmitter. Zero bits are discarded at the decomposition of DWT in the receiver side of the system and extract the information data from the approximated coefficients. In this paper, the comparison between performances of BER and throughput for OFDM system based on DFT, DWT and DWT-ZP is shown.

4. Performance Comparisons of Adaptive OFDM Based DWT and DFT:

The simulation results of BER performance of adaptive OFDM system based Wavelet and Fourier Transforms are presented using MATLAB. The channel is considered as frequency selective Rayleigh fading channel modeled as Jake's model with 10 Hz Doppler frequency. The Standard parameters that have been used in simulation are listed in Table (1).

Table (1) Simulation parameters

PARAMETER	VALUE at DFT	VALUE at DWT
Data rate	3M symbol/sec	3M symbol/sec
Delays of Paths	(0, 0.4) µsec,	(0, 0.4) µsec,
gains of Paths	(0, -10)dB	(0, -10)dB
Modulation types	BPSK, QPSK, 8QAM, 16QAM	BPSK, QPSK, 8QAM, 16QAM
Input size (N)	128	128
DWT family	---	3- Level Haar family
Cyclic prefix interval	16 (chips)	----
Pilot rate	1/30	1/30

4.1. Performance of OFDM with respect to modulation type:

The BER and throughput performances versus SNR values of OFDM system with BPSK modulation using DFT, DWT, and DWT-ZP are illustrated in Fig.5 and Fig.6 respectively.

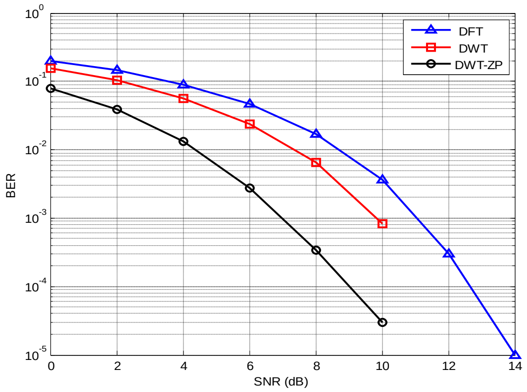

Fig. 5 BER performance of OFDM with BPSK modulation

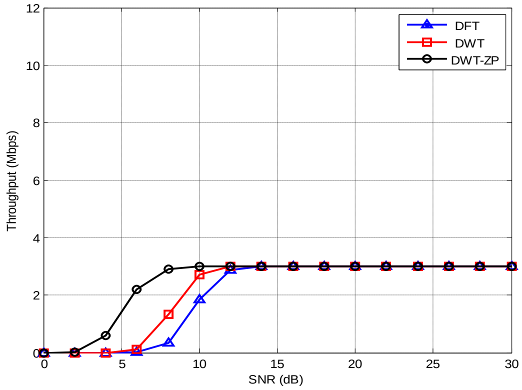

Fig. 6 Throughput performance of OFDM with BPSK modulation

The use of DWT and DWT-ZP reduces BER performance for OFDM with BPSK by 1.2dB and 4.1dB benefit respectively compared with used DFT at BER=10^{-3} and increases throughput by 0.95Mbps and 1.9 Mbps benefit respectively at SNR= 8dB, as example.

Fig.7 and Fig.8 are illustrated the BER and throughput performances versus SNR values of OFDM system with QPSK modulation using DFT, DWT, and DWT-ZP respectively.

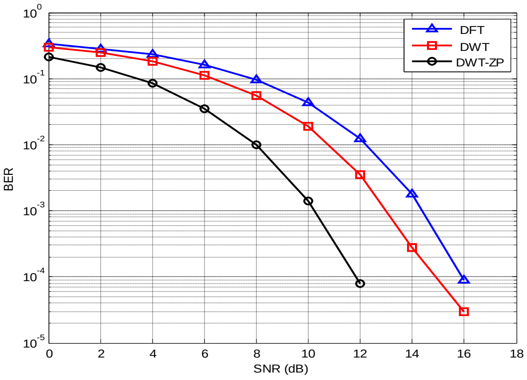

Fig.7 BER performance of OFDM with QPSK modulation

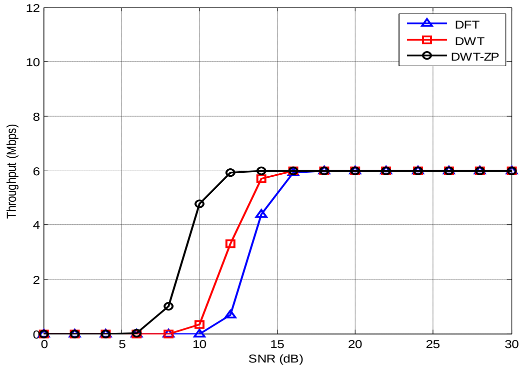

Fig.8 Throughput performance of OFDM with QPSK modulation

Also, we show the use of DWT and DWT-ZP reduces BER performance for OFDM with QPSK by 1.5dB and 4.2dB benefit respectively compared with used DFT at BER=10^{-3} and increases throughput by 2.6Mbps and 4 Mbps benefit respectively at SNR= 8dB, as example.

Fig.9, and Fig.10, are illustrated the BER and throughput performances versus SNR values of OFDM system with 8QAM modulation using DFT, DWT, and DWT-ZP respectively.

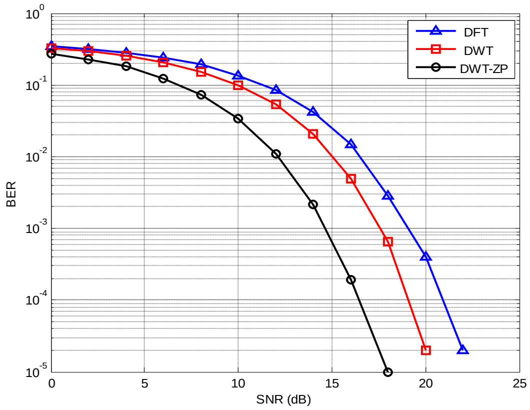

Fig.9 BER performance of OFDM with 8QAM modulation

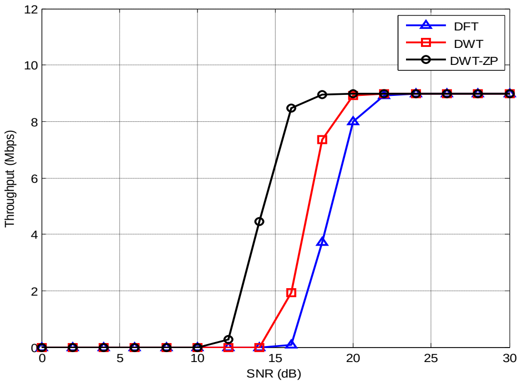

Fig.10 Throughput performance of OFDM with 8QAM modulation

The use of DWT and DWT-ZP reduces BER performance for OFDM with 8QAM by 1.5dB and 4.5dB benefit respectively compared with used DFT at BER=10^{-3} and increases throughput by 3.6Mbps and 5.2 Mbps benefit respectively at SNR= 18dB, as example.

Fig.11, and Fig.12 are illustrated the BER and throughput performances versus SNR values of OFDM system with 16QAM modulation using DFT, DWT, and DWT-ZP respectively.

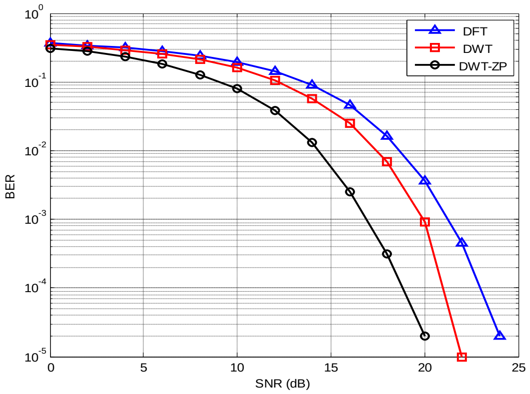

Fig.11 BER performance of OFDM with 16QAM modulation

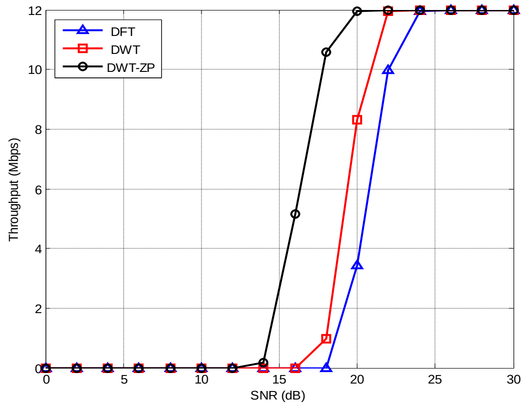

Fig.12 Throughput performance of OFDM with 16QAM modulation

The use of DWT and DWT-ZP reduces BER performance for OFDM with 16QAM by 1.5dB and 4.6dB benefit respectively compared with used DFT at BER=10^{-3} and increases throughput by 4.9Mbps and 8.5 Mbps benefit respectively at SNR= 20dB, as example.

4.2. Performance of DWT based on Adaptive OFDM:

In order to decide the proper switching levels from all above plots according to desired BER needed for the system, in this paper, a BER of (10^{-3}) is used as an operating point (at that level, SNR is chosen as switching values between various modulation types). This means that the adaptive OFDM system will try and keep a BER lower than (10^{-3}) with the most spectrally efficient modulation scheme whenever possible. Therefore, with this operating point, and the given BER plots, Table (2) shows SNR ranges for each modulation types and with respect to transform type that used.

Table (2) SNR ranges for each modulation types

Modulation		BPSK	QPSK	8QAM	16QAM
Rate (bit/symb)		1	2	3	4
SNR(dB) at BER=10^{-3}	DFT	**11.1**	**14.5**	**19**	**21.3**
	DWT	**9.9**	**13**	**17.5**	**19.8**
	DWT-ZP	**7**	**10.3**	**14.5**	**16.7**

According to these levels and estimated SNR, the Transmitter will be sent appropriate modulation scheme to maintain BER of the system less than the desired BER (10^{-3}). The BER and throughput performances versus SNR values of Adaptive OFDM system with DFT using various modulation schemes are illustrated in Fig.13 and Fig.14 respectively.

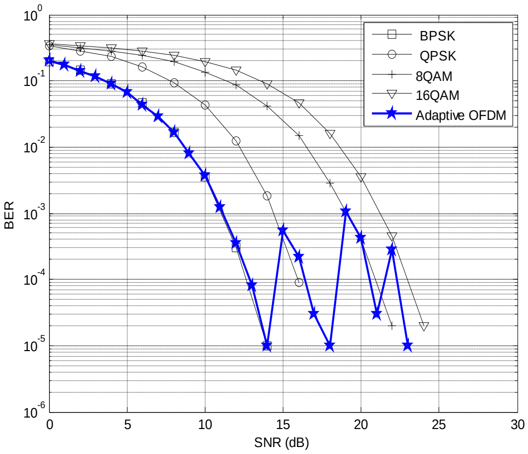

Fig.13 BER performance of adaptive OFDM with DFT

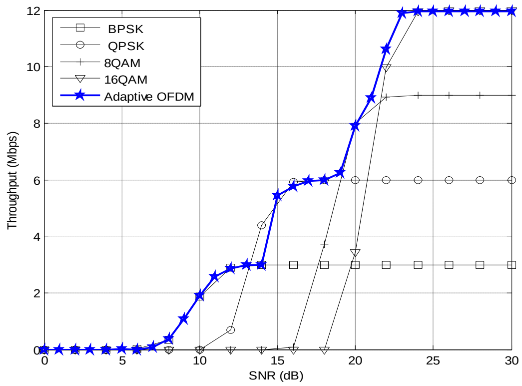

Fig.14 Throughput performance of adaptive OFDM with DFT

From Fig.13, and Fig.14, the BER performance of adaptive OFDM is generally less than desired BER and it is have increasing throughput performance with increase SNR that is the transmitter modulate signal with various bit rate (modulation scheme) with respect to estimated SNR .This process guarantee a high efficient data rate transmission with error below or equal to 10^{-3} can be eliminated using an efficient code.

The comparison between BER and throughput performance versus SNR values of DFT, DWT, and DWT-ZP based on adaptive OFDM system are shown in Fig.15, and Fig.16 respectively.

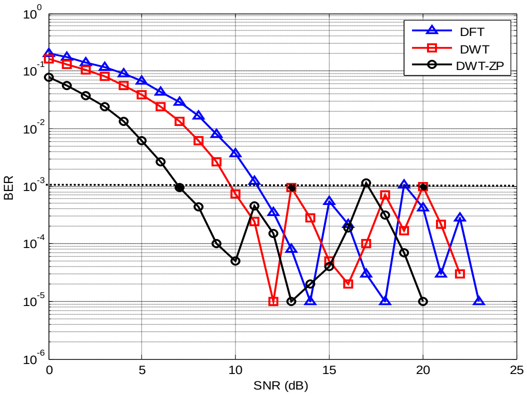

Fig.15 BER performance of adaptive OFDM with DFT and DWT

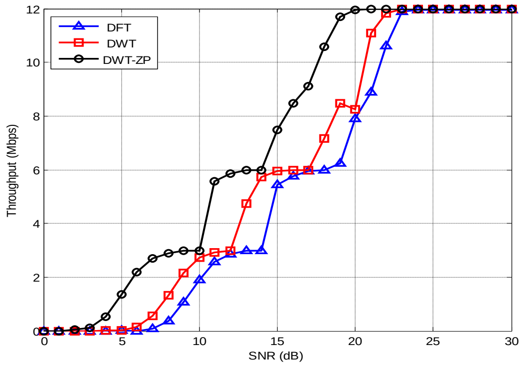

Fig.16 Throughput performance of adaptive OFDM with DFT and DWT

The use of DWT and DWT-ZP reduces BER performance for adaptive OFDM by 1.2dB and 4.1dB benefit respectively compared with used DFT at BER=10^{-3} and increases throughput by 0.5Mbps and 2Mbps benefit respectively at SNR= 15dB.

5. Conclusions:

During simulation and discussion of the results, the important points that are noted as:

1. The spectral efficiency of a radio link can be improved by using daptive modulation for a given maximum required quality. At low SNR, the system achieves 1 bits per symbol, as BPSK is primarily used. However, as the SNR increases,the system achives more bits with QPSK, 8QAM, or 16QAM ,according to switching level and estimated SNR, and throughput improves steadily.
2. Compared with use traditional DFT, DWT is an sufficient trnsform can be used in adaptive OFDM system to give high BER and throughput performances versus SNR.
3. DWT with ZP approach improves the BER and throughput performances in adaptive OFDM system compared with used DWT. The result shown 2.9dB improvement at BER=10^{-3}, and 1.5 Mbps improvement at 15 dB respectively.

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