Performance of Discrete Wavelet Transform Based on MC-MC-CDMA in Frequency Selective channel

Abbas Salman Hameed

Assistant Lecturer at Diyala University,
College of Engineering/ Electronic Engineering Department
Iraq, Diyala
Email: abbasfuture@yahoo.com

Abstract:

Transmission of high data rate in a mobile environment makes the channel highly hostile. To combat with the problem, many designs were proposed and developed, such as, Multi-Code CDMA and Multicarrier CDMA (MC-CDMA) systems. Multi-Code Multicarrier CDMA (MC-MC-CDMA) system allows to benefit the advantages of both schemes, this system can satisfy multi-rate services using multi-code schemes and multi-carrier services used for high rate transmission.

In this paper, Discrete Wavelet Transform (DWT) is used in MC-MC-CDMA system and illustrates the improvement of BER performance compared with used Discrete Fourier Transform (DFT). DWT with Zero Padding (DWT-ZP) is also used as addition technique support high bit error rate (BER) performance for the system, all tested in frequency selective fading channel.

The obtained results show that a significant improvements in terms of bit error rate (BER) can be achieved demonstrating the superiority of use DWT compared with use traditional DFT in MC-MC-CDMA System.

Keywords: MC-MC-CDMA System, Wavelet Transform, Walsh Hadamard code, zero padding.

1. Introduction:

Future wireless systems such as fourth generation (4G) cellular need to flexibly provide subscribers with a variety of services such as voice, data, images and video. Because these services have widely different data rates and traffic profiles, future generation systems will have to accommodate a wide variety of data rates. Code division multiple access (CDMA) has proven very successful for cellular voice systems, but there is some scepticism about whether CDMA will be well-suited to non-voice traffic. This has motivated research on multi-code CDMA systems which allow variable data rates by allocating multiple codes and hence varying degrees of capacity to different users. Meanwhile, multicarrier CDMA (MC-CDMA) has emerged as a powerful alternative to conventional direct sequence CDMA (DS-CDMA) in mobile wireless communications and has been shown to have superior performance to single carrier CDMA in multipath fading (Kim, 2004; Takaoka, 2006; Takeda, 2008).

MC-MC-CDMA system achieves the advantages of both systems; variable data rates with less interference and enhanced robustness to a multipath fading channel. Moreover, the system has both time and frequency spreading gain to exploit the diversity and interference averaging properties of multicarrier modulation and CDMA (Kim, 2004).

However, the conventional multicarrier CDMA 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), inter-symbol interference (ISI) and multi-access interference (MAI) (Yu, 2009). To search for an efficient multicarrier scheme, a number of improved multicarrier systems have been proposed. Among them, wavelet based multicarrier systems as in (Matiqul, 2000; Kimura, 2003; Saad, 2010; Muayyadi, 2011) 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 (Muayyadi, 2011; Haleh, 2014).

This paper demonstrate the performance of MC-MC-CDMA system employing Wavelet transform and the simulation results show that this system can be better than the conventional MC-MC-CDMA system that uses Fourier Transform in terms of bit error rate (BER) probabilities. The paper is organized as follows; section 2 describes the main differences of used Fourier Transform and Wavelet Transform in a Multicarrier systems. The system analysis and model of MC-MC-CDMA based Wavelet transform is presented in section 3. In section 4, the simulation results of BER performance of MC-MC-CDMA using Fourier Transform and Wavelet transform in two type family Haar and Daubechies10 are presented. Finally, conclusions are presented in section 5.

2. Fourier Transform vs. Wavelet Transform:

Fourier Transform based Conventional Multicarrier 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. A weakness of DFT is the large spectral overlap between frequency responses of filters corresponding to different subchannels. 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. 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 Figure1 (Saad, 2010; Hasan, 2012).

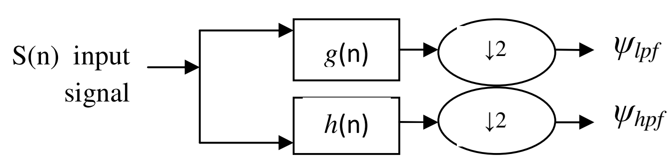

Figure 1 Block Diagram of Wavelet Decomposition

Where g(n) and h(n) are the wavelet's half-band low pass filter and high pass filter impulse responses, and ψ_{lpf} and ψ_{hpf} is approximate and details coefficients respectively and can be written as:(Hasan, 2012)

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

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

Figure 2 (Saad, 2010), show three level decomposition wavelet Transform (DWT), 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.

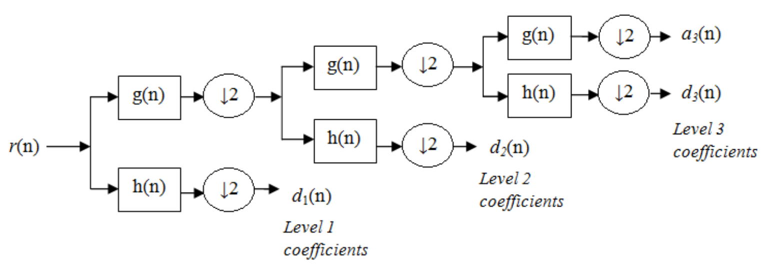

Figure 2 Three level decomposition wavelet Transform (DWT)

The reconstruction of the original signal from the wavelet coefficients is depicted in Figure 3 (Saad, 2010). 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 (Saad, 2010).

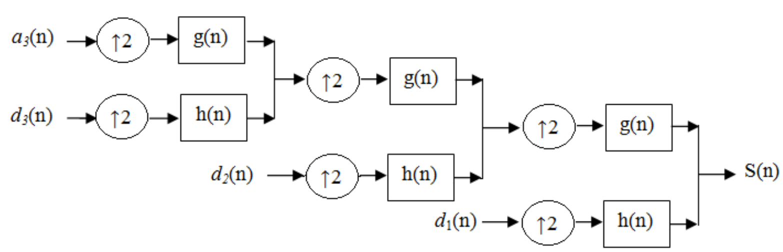

Figure 3 Three level reconstruction wavelet Transform (IDWT)

There are a number of family types that can be used in communication systems such as Haar, Daubechies, Symlets and Coiflets. These wavelet families have different filter length and values of approximated and detailed coefficients. Haar wavelet is one of the oldest and simplest wavelet. While Daubechies wavelets are the most popular wavelets.

3. System Analysis and Model

Consider MC-MC-CDMA system (Kim, 2004). The proposed system shown in Figure 4, uses a set of M codes called the *code sequence set* for M-ary modulation. Each user has the same code sequence set which represents an information data symbol of $\log_2 M$ bits. This code length N is fixed over all different values of M. Thus, varying the data rate does not change the code length N, but it does change the size of the code sequence set M. In order to maintain linear independence between the code sets, it is required that $M \leq N$.

In (Kim, 2004)., subcarrier multiplications and summation are used in the transmitter and receiver. In this work, Inverse Discrete Wavelet Transform (IDWT) and Discrete Wavelet Transform (DWT) each has L inputs replaces the subcarrier multiplications and summation at the transmitter and receiver respectively. Also, Inverse Discrete Fourier Transform (IDFT) and Discrete Fourier Transform (DFT) each of size L is used at the transmitter and receiver respectively to illustrate the benefit of use Wavelet transform in MC-MC-CDMA system.

As shown in Figure 4, (Kim, 2004). an M-ary symbol selects one of M pre-mapped code sequences for transmission, Walsh Hadamard code is used here. Each code sequence has a time domain spreading ratio of N. Each bit of the length N code sequence is copied onto the L sub-branches and multiplied with the user-specific scrambling code of the corresponding branch, $C_{k,l}$. , Walsh Hadamard code is used here and can be written as:

$$C_{k,i} = \left[C_{k,1} + C_{k,2} + \ \ldots\ldots + C_{k,L}\right]^T \quad (3)$$

Note that the $C_{k,i}$ are static in time so that the spreading at this stage is only in frequency, allowing users to choose specific codes that have low cross correlations. Each of these branches then modulates one of the L sub-branches Wavelet Transform and the results are summed (Kim, 2004).

Unlike OFDM, which is used to increase the ISI-free data rate, in multicarrier CDMA, the same information bit is replicated on all subcarriers to achieve a spreading gain for multiple access. Also, a cyclic prefix is not typically employed in multicarrier CDMA because self-ISI is a minor effect compared to multiple access interference. To formalize the analysis, consider that each user has the same code sequence set which can be written as (Kim, 2004):

$$\Omega = \{V_m(n) \mid 1 \leq m \leq M \,,\, N\text{-}1 \geq n \geq 0\} \quad (4)$$

User k's i^{th} M-ary data symbol $b_{k,i}$ is mapped to one of the code sequences in Ω. Thus, the i^{th} transmit sequence of user k before multicarrier modulation can be written as (Kim, 2004):

$$S_{k,i} = V_{b_{k,i}} \,.\, C_{k,i} \qquad N\text{-}1 \geq n \geq 0 \quad (5)$$

After that $S_{k,i}$, will go through Inverse Wavelet Transform has L inputs and the transmitted signal of user k is generated as $S_k(n)$.

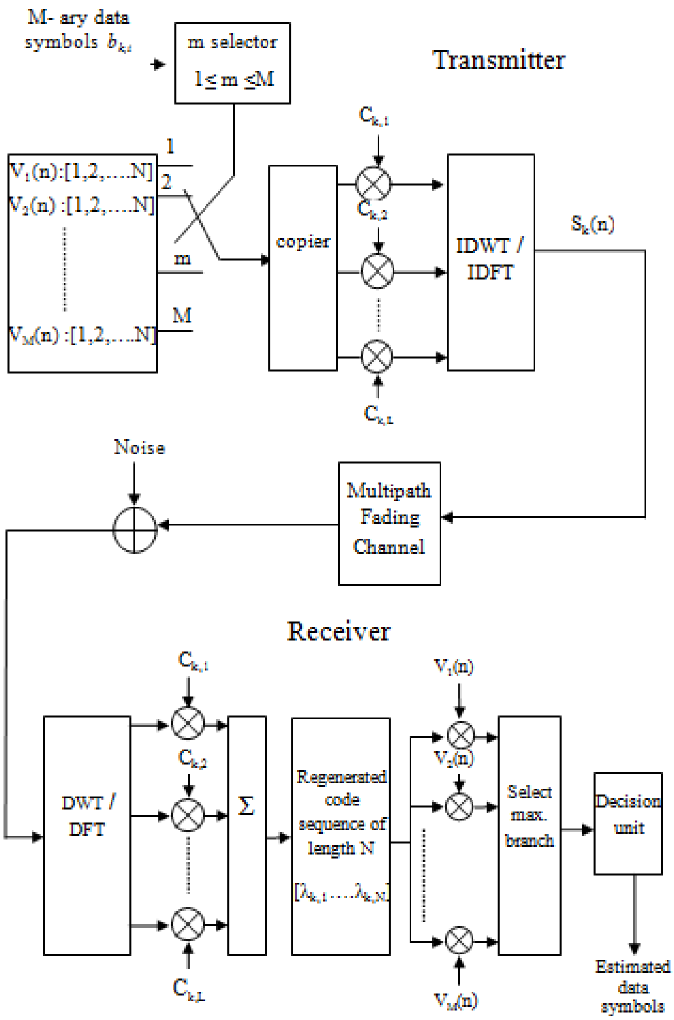

Figure 4 MC-MC-CDMA system block diagram

After that, $S_k(n)$passes through frequency selective Rayleigh fading channel which is modeled using Jake's model as in (Zhifeng, 2010). In the receiver of Figure1, a wavelet transform is applied to the input and the output is then despread to generate the received sequence code which can be written as:

$$r_k(n) = \left[\sum_{i=1}^{M}\sum_{k=1}^{K}\sum_{l=1}^{L} h_{k,n_c} v_{k,i} c_{k,l}\right] + [w_1, w_2, \ldots \ldots, w_l]^T \quad (6)$$

Where $h_{k,l}$, is a Rayleigh distributed amplitude attenuation, and w_l is the additive white Gaussian noise with zero mean and unit variance. For despreading, the same user-specific code is used, each branch that comes out of the DWT is multiplied by the corresponding to $C_{k,l}$. The results are combined to give the estimated code $\lambda_{k,i}$. The process above is repeated N times to give the estimated code sequence of length N [$\lambda_{k,1}$ $\lambda_{k,2}$ ….. $\lambda_{k,N}$] for each user. The correlator has the same M code sequences, it makes correlation between the estimated code sequence and each of the M code sequences (V_M) and selects a sequence that gives maximum correlation. This sequence is then mapped back into an M-ary symbol.

In this paper Wavelet with Zero Padding (DWT-ZP) is applied as in (Abdullah, 2009). 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 MC-MC-CDMA system transmitter. At the DWT in the receiver side of the system, the decomposition of DWT is discarded of zero bits and extracts the information data from the approximated coefficients. The BER performance of DWT-ZP is achieved and compared with the performance of DWT and DFT without zero padding.

4. Performance Comparisons of MC-MC-CDMA Based DWT and DFT

The simulation results of BER performance of MC-MCCDMA system based Wavelet and Fourier Transforms are presented using MATLAB. QPSK is used in the system, the channel is considered as frequency selective Rayleigh fading channel modeled as Jake's model (Zhifeng, 2010). The Walsh Hadamard code is used as M-code V_M sequence and frequency spreading code $C_{k,i}$.

Figure 5 and Figure 6, show the BER performance versus SNR values of MC-MC-CDMA system using DWT and DFT for two and four users respectively. In both figures the M-code sequence length is N=4 and frequency spreading code length is L=16. Haar and Daubechies10 as DWT are used. It can be noticed that BER performance for DWT is better than using DFT.

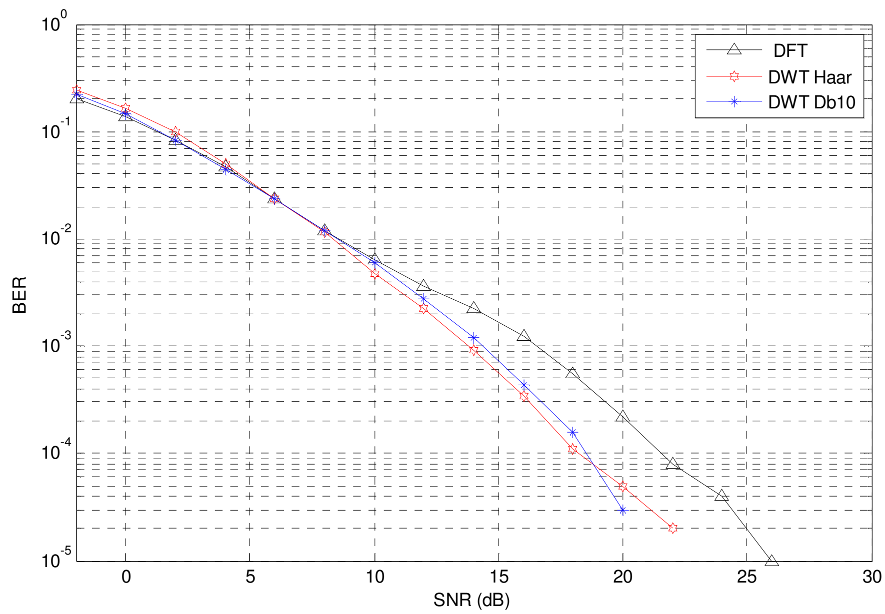

Figure 5 BER performance of 2-user MC-MC-CDMA system using DWT and DFT

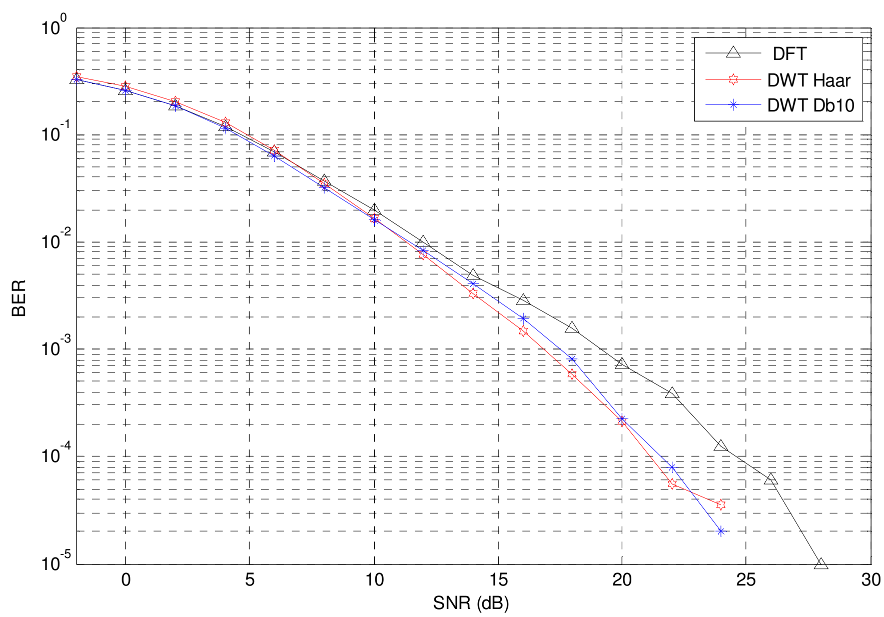

Figure 6 BER performance of 4-user MC-MC-CDMA system using DWT and DFT

In Figure 7, the system uses different number of M-code sequence (N=4 and N=8) and constant spreading code length L=16. It can be noticed that as N increases, the BER performance gets better.

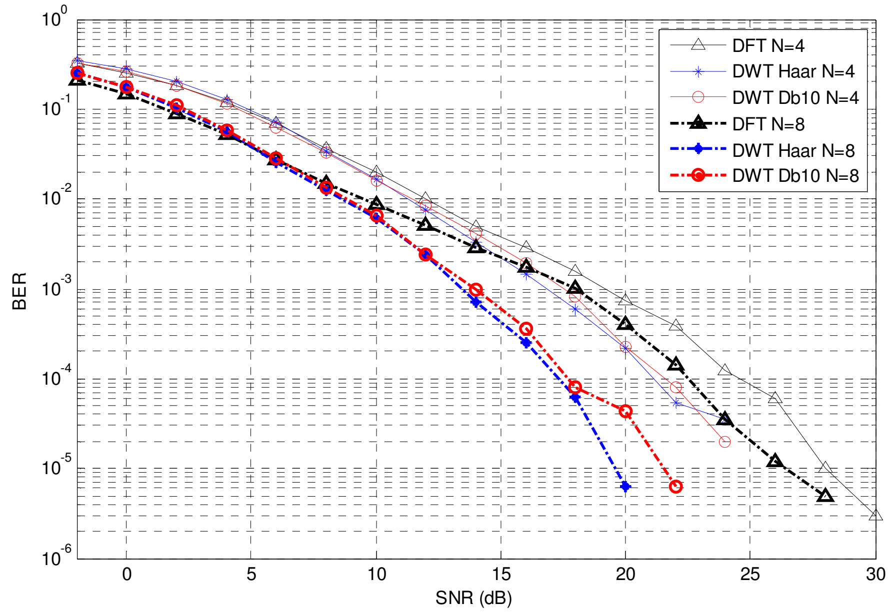

Figure 7 BER performance of 4-user MC-MC-CDMA system using DWT and DFT with L=16 and different values of N

In Figure 8, the system uses different number of L with constant M-code sequence length N=4. In general, it can be seen that when L decreases, the BER performance of the system becomes worse.

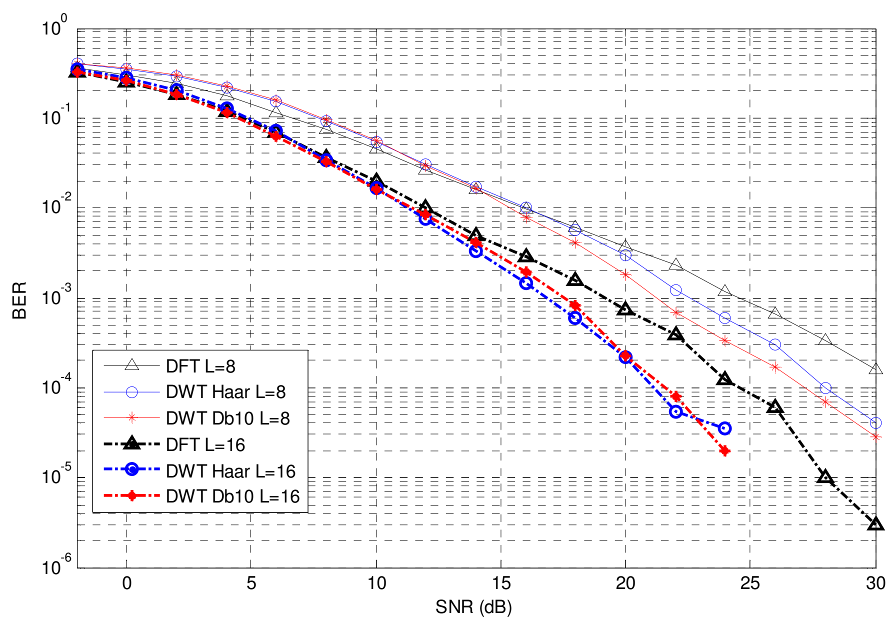

Figure 8 BER performance of 4-user MC-MC-CDMA system using DWT and DFT with N=4 and different values of L

Figure 9, shows BER performance versus SNR of 4-user MC-MC-CDMA system with DFT, DWT and DWT-ZP, all at N=4 and L=16.

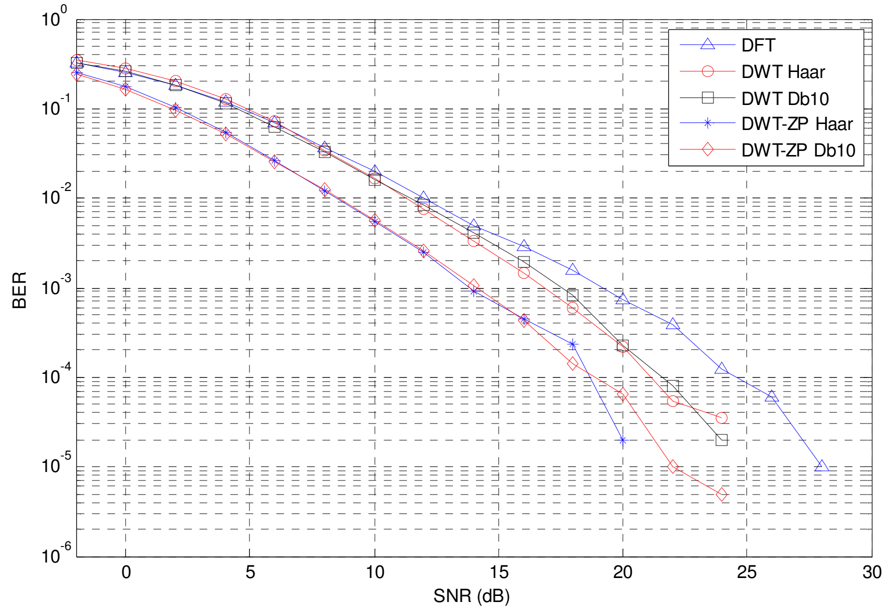

Figure 9 BER performance of 4-user MC-MC-CDMA system using DFT, DWT and DWT-ZP

This figure illustrates that high improvement getting by use DWT-ZP in MC-MC-CDMA system compared with use of DFT or DWT without zero padding. For example, in Figure 9, at BER= 10^{-4}, there are 3.5 dB, 3.1 dB, 6 dB and 5.8 dB improvement when Haar DWT, Db10 DWT, Haar DWT-ZP and Db10 DWT-ZP, is used respectively instead of DFT.

Figure 10, shows BER performance versus number of users (*K*) at SNR= 16 dB in MC-MC-CDMA system with DWT and DFT, all at N=4 and L=16.

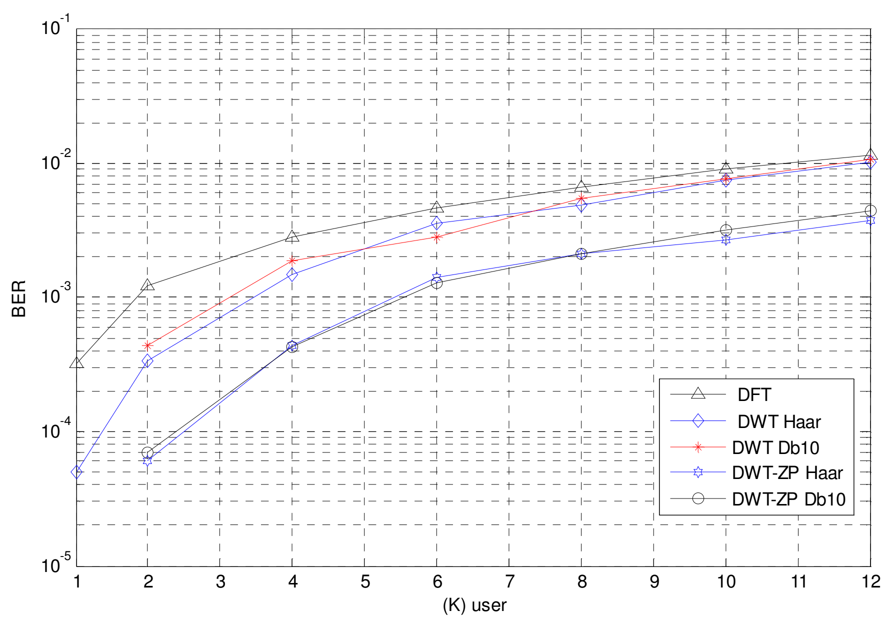

Figure 10 BER performance versus number of users (K) of MC-MC-CDMA system using DWT and DFT

It can be noticed that, as many users are transmitting signal simultaneously, the SNR decreases. Hence, the higher number of users, the higher multiuser interference caused by the unwanted user and consequently the performance become worse. This is a trade off between cost and quality, since a higher number of users will leads to increase in capacity but with less quality of services. In general the performance of system using DWT-ZP is better than the performance with using DFT or DWT especially at high number of users.

Table 1, summarized the SNR improvement at BER= 10^{-4} for MC-MC-CDMA system with DWT compared with MC-MC-CDMA system with DFT at *K*= 1, 2, and 4 users respectively, all at N=4 and L=16.

Table .1. summarized improvement of SNR at BER= 10^{-4} for MC-MC-CDMA system

K	SNR improvement (dB)			
	DWT		DWT-ZP	
	Haar	Db10	Haar	Db10
1	3	5.1	6.8	7.7
2	3.2	2.9	6.8	6
4	3.5	3.1	6	5.8

Table 1, shows the advantage of use DWT and DWT-ZP compared with used DFT in MC-MC-CDMA system. At all users DWT is more sufficient Discrete Transform and Zero Padding make it excellent Transform with respect of DFT.

5. Conclusions

The important points that are noted during simulation and discussion of the results as:

1. DWT is an sufficient trnsform can be used in MC-MC-CDMA System to give high BER performance versus SNR compared with use traditional DFT.
2. DWT with ZP approach improves the BER performance in MC-MC-CDMA System compared with used DWT. The result shown 3.8, 3.6 and 2.5 dB improvement for Haar and 2.6, 3.1, and 2.7 dB improvement for Db10 all with *K*= 1,2, and 4 users respectively.
3. Performance of MC-MC-CDMA System using of DWT-ZP at better than Performances with used DFT or DWT at user's number increases.

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