FRAMELET BASED ULTRA-WIDEBAND SYSTEM +

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Abstract:

Ultra-Wideband (UWB) system has been popularized as a technology for short-range, high data rate communication. Orthogonal Frequency Division Multiplexing OFDM approach for UWB provides unique advantages in short high data rate wireless applications in case of reducing the effect of multipath. This paper studies the Framelet based Ultra-Wideband (UWB) System. In Framelet based UWB, Framelet transform is used for multicarrier modulation in OFDM instead of the conventional fast Fourier transform. For the Framelet based system, due to the elimination of the cyclic prefix, an effective time domain equalizer must be used in order to reduce the effect of Inter-Symbol Interference (ISI). On the other hand, with the use of MMSE equalizer, Framelet-UWB system shows better performance than FFT-UWB with the same type of equalizer. Finally, spreading codes are used with the proposed system for multiple access of the channel by different users as similar to multicarrier-CDMA. The simulation was carried using MATLAB software package.

Index Terms: UWB, OFDM, FFT, Wavelet, Framelet, MMSE Equalizer, CDMA.

نظام الحزمة فائقة العرض باستخدام التحويل الإطاري

أثير علاء صبري حسين علي عبد

المستخلص:

تم تصميم نظام الحزمة فائقة العرض بمثابة تقنية للاتصالات القصيرة المدى بسرعة بيانات عالية. ان نظام مازج تقسيم التردد المتعامد المستخدم في التقنية فائقة العرض تحقق مكاسب مهمة لعملية نقل البيانات بسرعة عالية في القنوات المتعددة المسارات. في هذا البحث تم دراسة نظام الحزمة فائقة العرض باستخدام التحويل الاطاري. في هذا النظام يتم استخدام التحويل الاطاري في عملية التضمين متعدد الحوامل بدلا من استخدام تحويل فورير السريع كما في النظام التقليدي. في انظمة التحويل الاطاري، بسبب عدم استخدام البادئة الدورية للقضاء على تأثير الرموز المتداخلة (Inter-Symbol Interference)، فان ذلك يتطلب استخدام معادل (Equalizer) أكثر تعقيداً للتعامل مع الرموز المتداخلة في هذا النظام. ومن جهة اخرى، باستخدام المعادل MMSE Equalizer فان انظمة التحويل الاطاري و الموجي يظهران أداء أفضل من نظام تحويل فورير السريع مع نفس النوع من المعادل. وأخيراً، قمنا باستخدام الرموز الناشرة مع النظام المقترح كما في نظام تعدد الوصول بتقسيم الرمز ذو حوامل متعددة (Multicarrier-CDMA) لأغراض الوصول المتعدد للقناة لعدد مختلف من المستخدمين. المحاكاة تمت باستخدام الحقيبة البرمجية MATLAB.

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Introduction:

Ultra-Wideband (UWB) system is defined as any radio system that has a bandwidth larger than 20% of its center frequency, or has a bandwidth equal to or larger than 500-MHz. Due for its large bandwidth, wireless communications with high data rate (e.g., 400 Mbps or higher) can be formed. Currently, available industrial standards such as IEEE 802.15.3a for high data rate based on UWB technology have been introduced [1].

There are two main proposals for this standard: a frequency-hopping orthogonal frequency-division multiplexing (OFDM) proposal known as Multiband OFDM, and a code-division multiple access (CDMA) based technique proposal known as direct- sequence UWB (DS-UWB) [2].

Conventional OFDM system uses the IFFT/FFT as a multi-carrier modulation/demodulation solution. An alternative approach is the use of IDWT/DWT (inverse discrete wavelet transform/discrete wavelet transform). The ideal behind that is using wavelet signals as a sub-carrier element instead of the complex exponential used in conventional system [3-8].

Before being studied as a modulation technique, wavelets have been well known for its potential in signal and image processing, image compression and so on [3]. Similar to wavelet transform, framelet transform has been used in signal and image analysis, and it was able to overcome some drawbacks associated with wavelets. In this paper the possibility of using framelet transform is studied in implementing multi-carrier system.

Previous works had applied the discrete wavelet transform for multicarrier modulation and it was seem to bring some advantages over the conventional FFT based system in specific conditions [4-8].

FFT based OFDM for UWB System:

The OFDM approach to UWB meets the “500-MHz bandwidth” requirement by using 128 sub-carriers that are modulated with a Quadrature Phase Shift Keying (QPSK) constellation. The composite signal occupies a 528-MHz wide channel. The OFDM carriers are efficiently generated using digital Fast Fourier Transform (FFT) techniques. The OFDM composite signal persists on a channel for the information length of 242.42 ns plus the 60.61-ns cyclic prefix time [1, 2].

The OFDM approach to UWB is shown in Figure (1). The input data stream is modulated by a QPSK modulator resulting in a complex symbol *X*. This symbol stream is passed through a serial to- parallel converter, whose output is a set of *N* parallel QPSK symbols corresponding to the symbols transmitted over each of the subcarriers. Thus, the *N* symbols output from the serial-to-parallel converter are the discrete frequency components of OFDM output signal *s*(*t*). In order to generate *s*(*t*), therefore a conversion of these frequency components into time samples is needed. An inverse DFT is performed on these *N* symbols, which is efficiently implemented using the IFFT algorithm. The IFFT yields a set of parallel outputs $\{x_0, \ldots, x_{N-1}\}$, where

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi nk/N} \ , \ n = 0,1,\ldots,N-1 \qquad (1)$$

After that, a cyclic prefix is added to each OFDM symbol and then transmitted through the channel. At the receiver, the whole process is reversed. The main task performed by the receiver is taking the Fast Fourier Transform (FFT) for the data which represents the multicarrier demodulation stage to recover the data X_k, that is:

$$X_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x_n e^{-j2\pi nk/N} \ , \quad k = 0,1,. . . ,N-1 \qquad (2)$$

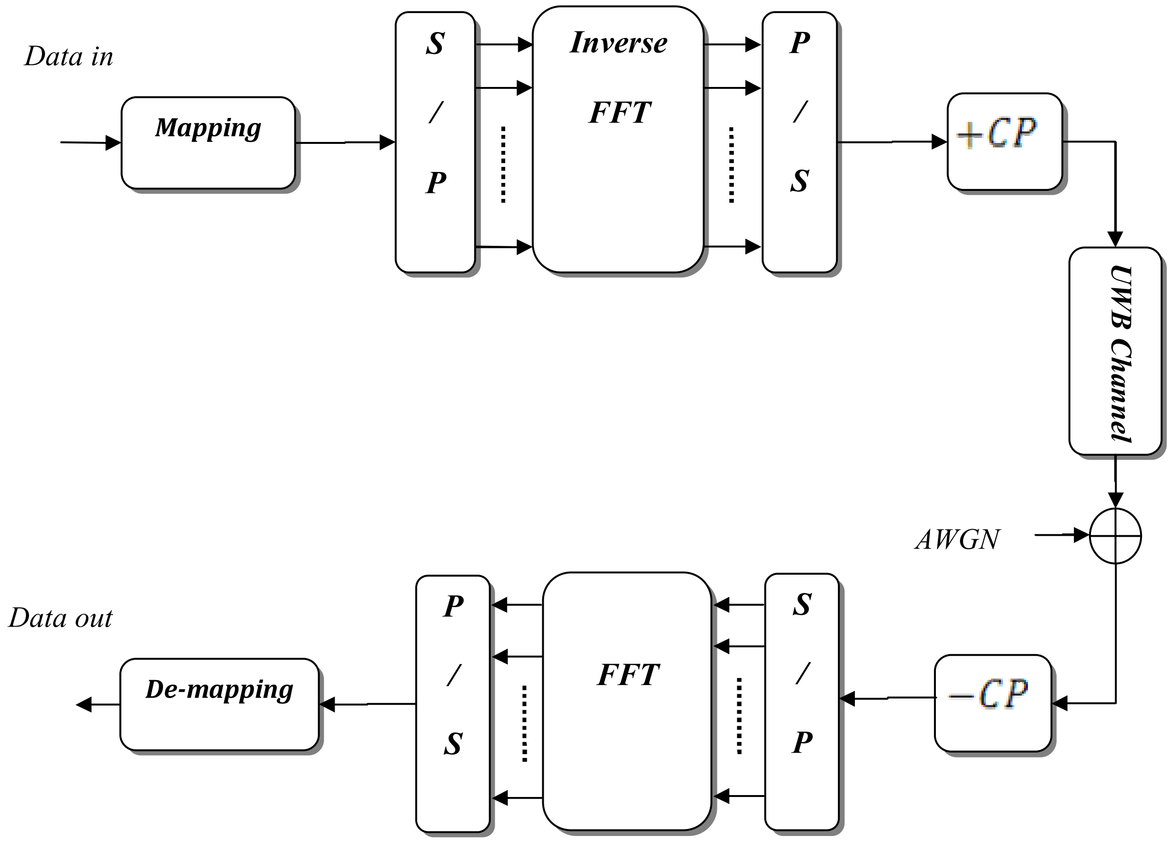

Fig. (1) Block diagram of FFT based OFDM system[3]

Framelet Transform :

Framelet is very similar to wavelets but has some important differences. Framelet has two or more high frequency filter banks, which produce more subbands in decomposition. This can achieve better time-frequency localization ability in signal processing. Moreover, Framelet is more robust. There is redundancy between the Framelet subbands, which means change in coefficients of one band can be compensated by other subbands coefficients. This can help in improving the imperceptibility of the watermark [9].

Framelet breaks out the restriction of orthogonality, and there are correlations between the Framelet filters. After Framelet decomposition, the coefficients in one subband have correlation with coefficients in other subband. This means that changes in one coefficient can be compensated by its related coefficients in reconstruction stage, which produces less noise in the original signal. This characteristic is very helpful for some applications [10].

a) Framelet Filter Bank

To construct a framelet with FIR filters the oversampled filter bank shown in Figure (2) will be used. The filter $h_0(n)$ will be a low-pass (scaling) filter, while $h_1(n)$ and $h_2(n)$ will both be high-pass (wavelet) filters. To develop the perfect reconstruction conditions, the standard multirate identities are used to write $Y(z)$ in terms of $X(z)$[9].

$$Y(z) = \frac{1}{2}[H_0(z)H_0(1/z) + H_1(z)H_1(1/z) + H_2(z)H_2(1/z)]X(z) + \frac{1}{2}[H_0(z)H_0(-1/z) + H_1(z)H_1(-1/z) + H_2(z)H_2(-1/z)]X(-z) \qquad (3)$$

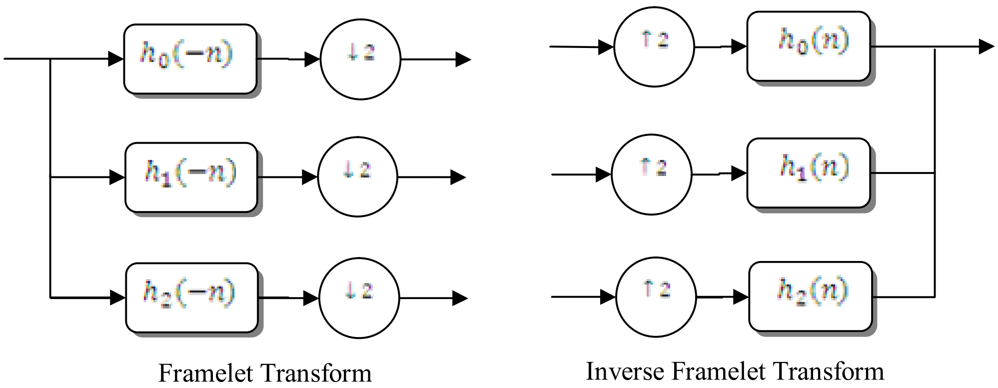

Fig. (2) Framelet filter bank

For perfect reconstruction, $Y(z) = X(z)$, it is necessary that [9]

$$H_0(z)H_0(1/z) + H_1(z)H_1(1/z) + H_2(z)H_2(1/z) = 2\,, \qquad (4)$$

$$H_0(z)H_0(-1/z) + H_1(z)H_1(-1/z) + H_2(z)H_2(-1/z) = 0\,, \qquad (5)$$

b) The Scaling and Wavelet Functions

To develop a framelet, the three-channel filter bank will be used that corresponds to a low pass frame based on a single scaling function $\varphi(t)$ and two distinct high pass $\psi_1(t)$ and $\psi_2(t)$. Following the theory of dyadic wavelet bases, the scaling space v_j and the wavelet spaces $w_{i,j}$ are defined as [9, 10]

$$v_j = Span\{\varphi(2^j t - n)\} \qquad (6)$$

$$w_{i,j} = Span\{\psi_i(2^j t - n)\}, \quad i = 1,2\,. \qquad (7)$$

Following the multiresolution framework, the signal spaces can be nested: $v_0 \subset v_1, w_{1,0} \subset v_1, w_{2,0} \subset v_1$. It follows that φ, ψ_1, ψ_2 satisfy the scaling and wavelet equations as

$$\varphi(t) = \sqrt{2}\sum_n h_0(n)\varphi(2t-n) \qquad (8)$$

$$\psi_i(t) = \sqrt{2}\sum_n h_i(n)\varphi(2t-n)\ , \quad i = 1,2. \qquad (9)$$

The low pass function $\varphi(t)$ and the high pass $\psi_1(t), \psi_2(t)$ are defined through these equations by the low-pass filter $h_0(n)$ and the two high-pass filters $h_1(n)$ and $h_2(n)$[9].

Framelet Based UWB System :

In this system, the Framelet transform will be used instead of the FFT. The incoming data are modulated by QPSK modulator then pass through serial to parallel converter, then the parallel sub-channels obtained are synthesized to a single channel by inverse Framelet transform and the resulting signal is transmitted through the channel. At the receiver, the whole process is reversed to recover the transmitted data. Figure (3) shows the block diagram of the proposed system. Inverse Framelet Transform (IFT) can be used as modulating each input channel with a framelet carrier at the transmitter, while the direct transform in the receiver can be used as a demodulating the received signal by a set of framelet at the receiver. Figure (4) shows the simulation flow chart for this system.

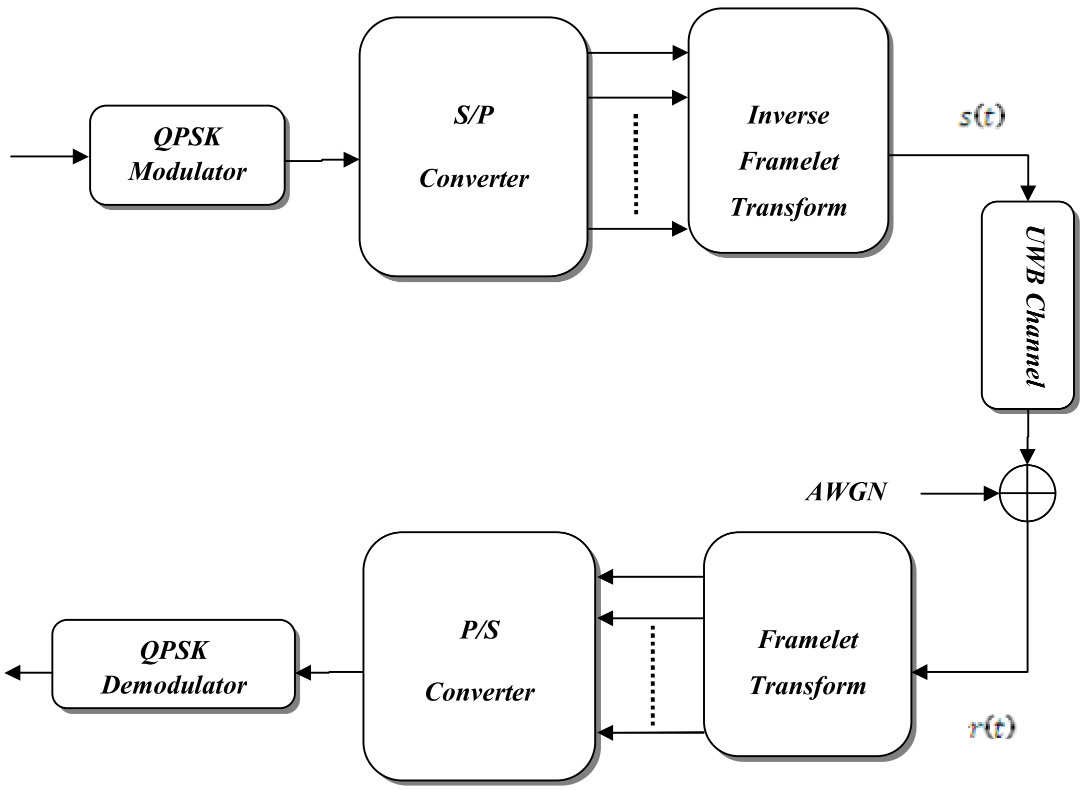

Fig. (3) Block diagram of the proposed Framelet based OFDM system for UWB channel

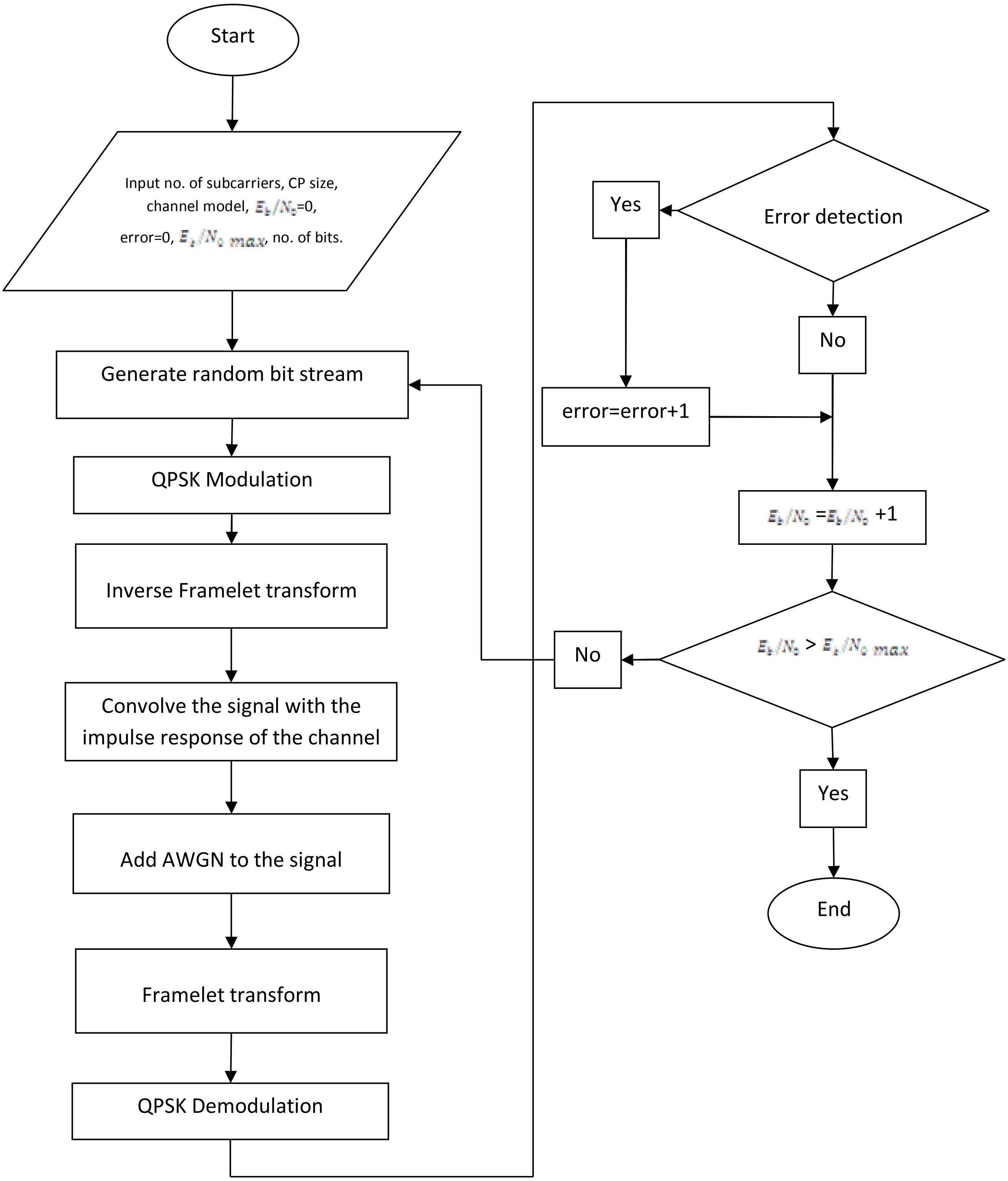

Fig. (4) Simulation flowchart.

Performance of UWB System in Multipath Channel :

In this section the systems FFT-UWB, DWT-UWB, Discrete Wavelet Packet Transform (DWPT)-UWB and Framelet-UWB) are compared in multipath channel environment in terms of BER versus E_b/N_0 in UWB Channel Model 1 (CM1), CM2, CM3 and CM4.

CM1 describes a LOS (line of sight) scenario with a separation between transmitter (T_X) and receiver (R_X) of less than 4m. CM2 describes the same range, but for a non-LOS situation. CM3 describes a non-LOS scenario for distances between T_X and R_X 4-10m. Finally, scenario 4 describes an environment with strong delay dispersion, resulting in a delay spread of 25ns. The detailed description of these scenarios is given in [11].

Due to the fact that wavelet and framelet OFDM symbols overlapped in time, cyclic prefix can't be inserted between two OFDM symbols.

For this reason, a complicated time domain equalizer should be used in order to reduce the effect of ISI. Table (1) shows the simulation parameters, while figures (5-8) show the bit error rate (BER) vs. energy per bit to noise power spectral density (E_b/N_0) for the four channel model.

Table (1). Simulation parameters used in this paper.

	FFT-UWB	DWT-UWB	DWPT-UWB	Framelet-UWB
Modulation	**QPSK**			
Number of subcarriers	**128**			
Cyclic Prefix	**Yes**	**No**	**No**	**No**
Equalizer	**4-Tap MMSE Equalizer**			
Channel	**CM1, CM2, CM3, CM4**			
Data rate	**480 Mbps**			
Channel spacing	**528 MHz**			

In Figure (5) for CM1, Framelet-UWB reaches BER of 10^{-5} at $E_b/N_0 = 11\ dB$ while DWPT-UWB, DWT-UWB and FFT-UWB reach BER of 10^{-5} at E_b/N_0 equal to $12\ dB$, $12.5\ dB$ and $15\ dB$ respectively. This is attributed to the fact that the subcarrier element used in framelet system is more robust in multipath channels than the other systems due to its longer symbol time, so it can reduce the effect of the inter symbol interference (ISI) on the system performance.

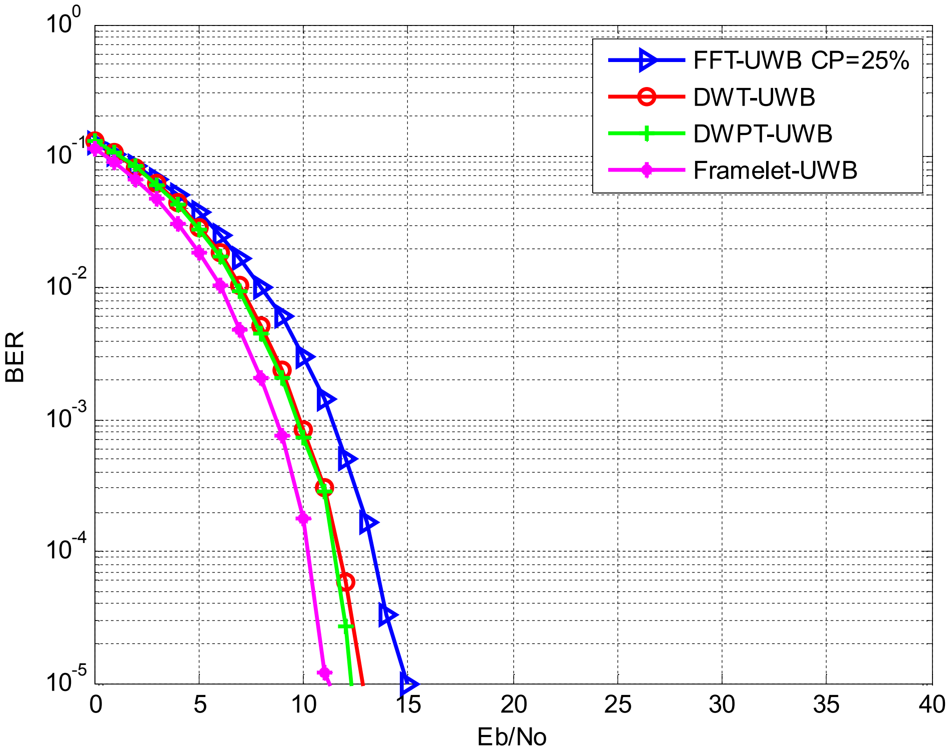

Fig. (5) BER performance of different UWB systems in CM1.

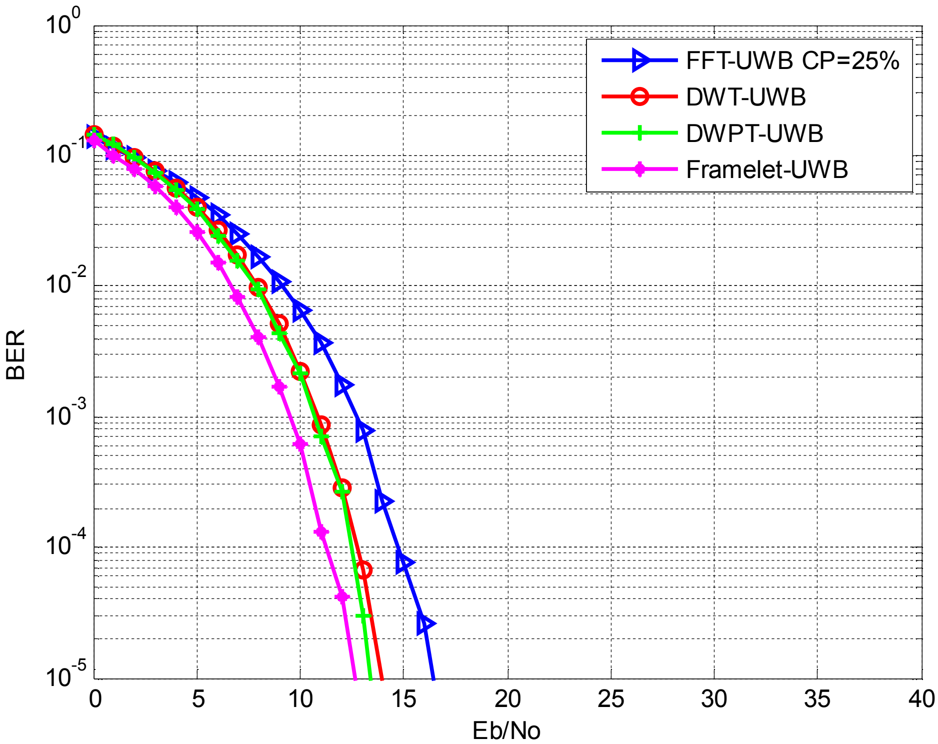

Fig. (6) BER performance of different UWB systems in CM2.

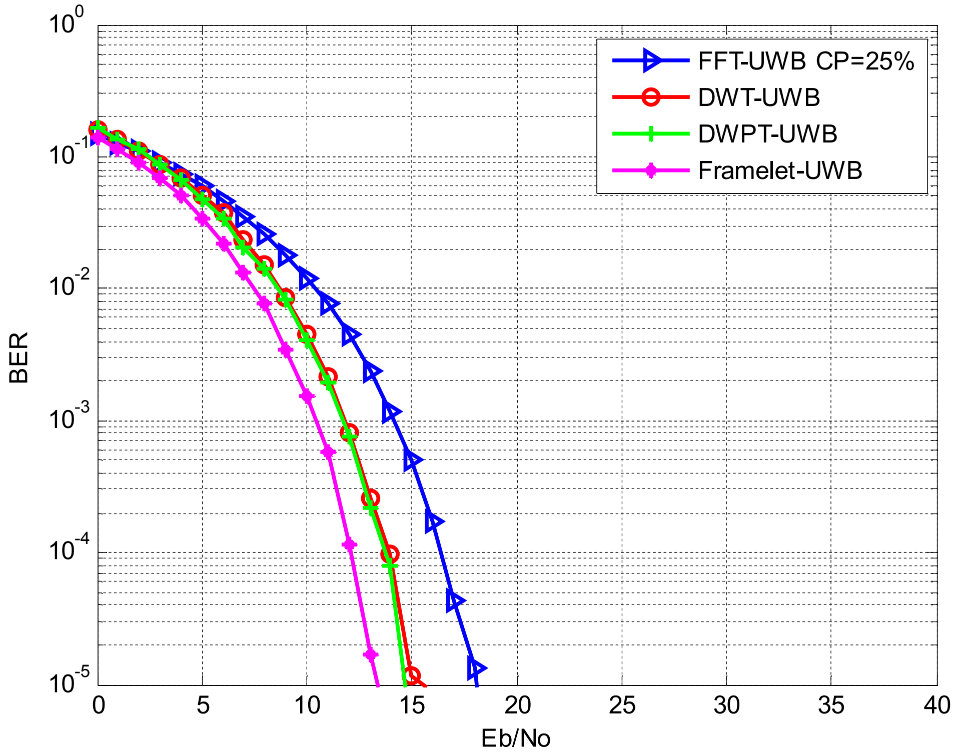

Fig. (7) BER performance of different UWB systems in CM3.

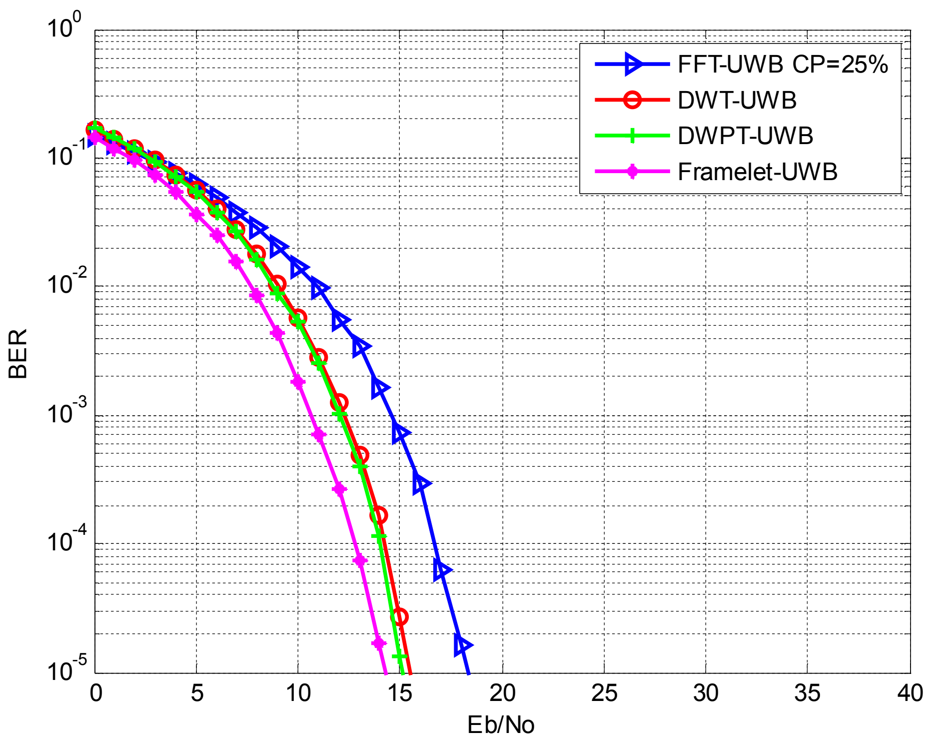

Fig. (8) BER performance of different UWB systems in CM4.

On the other hand, in Figure (6) for CM2, Framelet-UWB needs an $E_b/N_0 = 12.7\ dB$ to reaches BER of 10^{-5} while DWPT-UWB, DWT-UWB and FFT-UWB reach BER of 10^{-5} at E_b/N_0 equal to $13.2\ dB$, $13.8\ dB$ and $16.5\ dB$ respectively.

While in Figure (7) for CM3, Framelet-UWB reaches BER of 10^{-5} at $E_b/N_0 = 13.2\ dB$ while DWPT-UWB, DWT-UWB and FFT-UWB reach BER of 10^{-5} at E_b/N_0 equal to $15\ dB$, $15.7\ dB$ and $18\ dB$ respectively.

Finally, in Figure (8) for CM4, Framelet-UWB reaches BER of 10^{-5} at $E_b/N_0 = 14.2\ dB$ while DWPT-UWB, DWT-UWB and FFT-UWB reach BER of 10^{-5} at E_b/N_0 equal to $15.2\ dB$, $15.7\ dB$ and $18.2\ dB$ respectively.

In summary, it has been seen that DWT-UWB, DWPT-UWB and Framelet-UWB outperform the FFT-UWB when an efficient equalizer is used. Moreover, Framelet-UWB outperforms all the other systems.

MULTIPLE ACCESS USING CDMA :

Multiband OFDM approach for UWB uses frequency hopping between different sub-bands for multiple access of different users, an alternative approach is created by assigning a different spreading code to every user as in the system proposed by [7], similar to multicarrier CDMA.

If four users are considered, a different code for every user is assigned with code length=4. Walsh-Hadamard spreading code is used for its realized orthogonality. Figures (9-12) show BER performance of framelet-UWB system in CM1-4 with different number of users accessing the channel instantaneously.

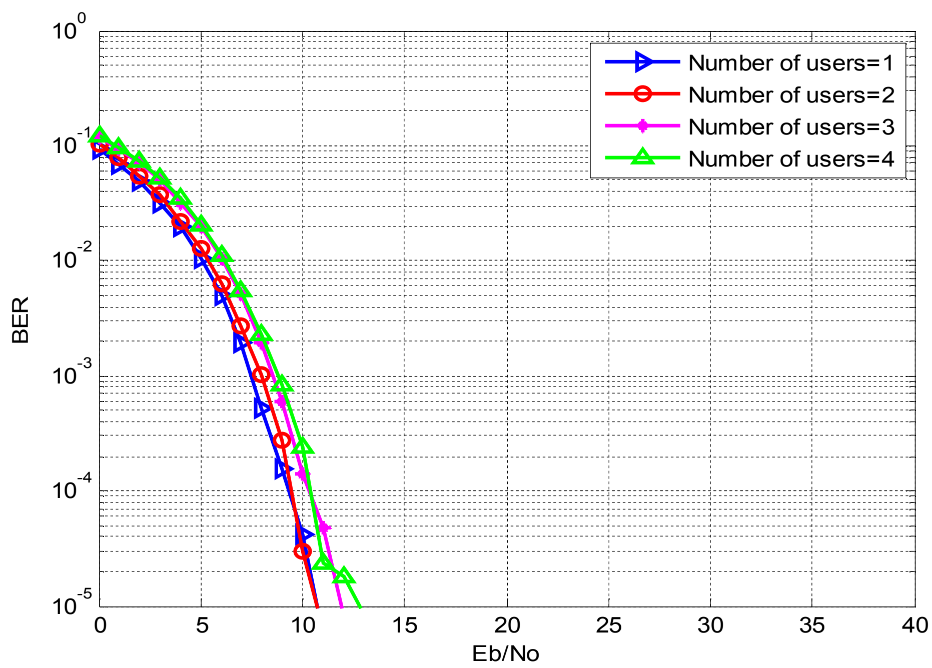

Fig. (9) BER performance of Framelet UWB system using DS-CDMA for channel accessing with variable number of users in CM1.

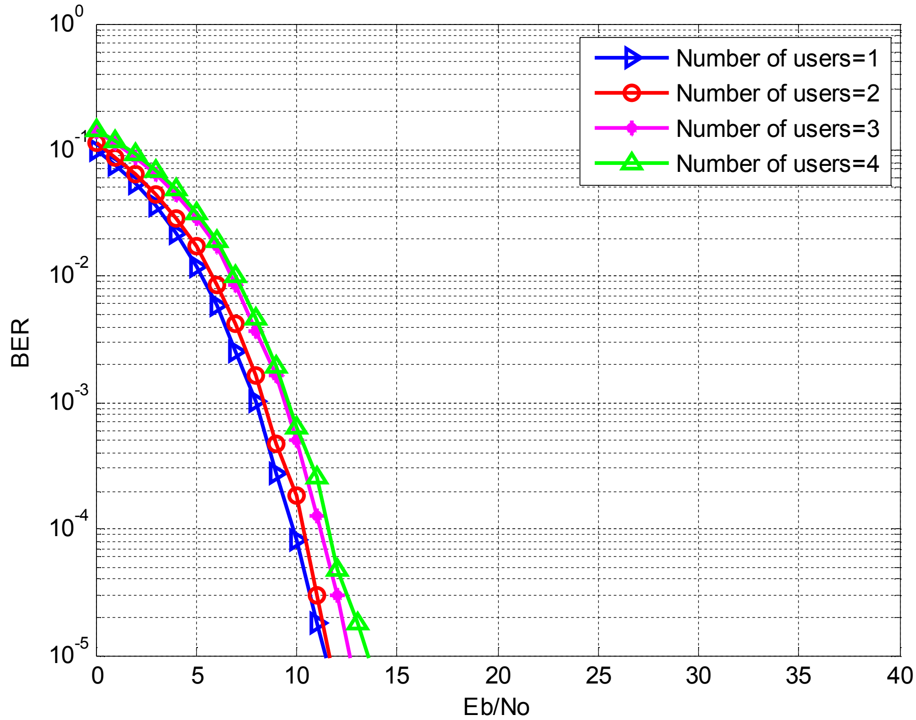

Fig. (10) BER performance of Framelet UWB system using DS-CDMA for channel accessing with variable number of users in CM2.

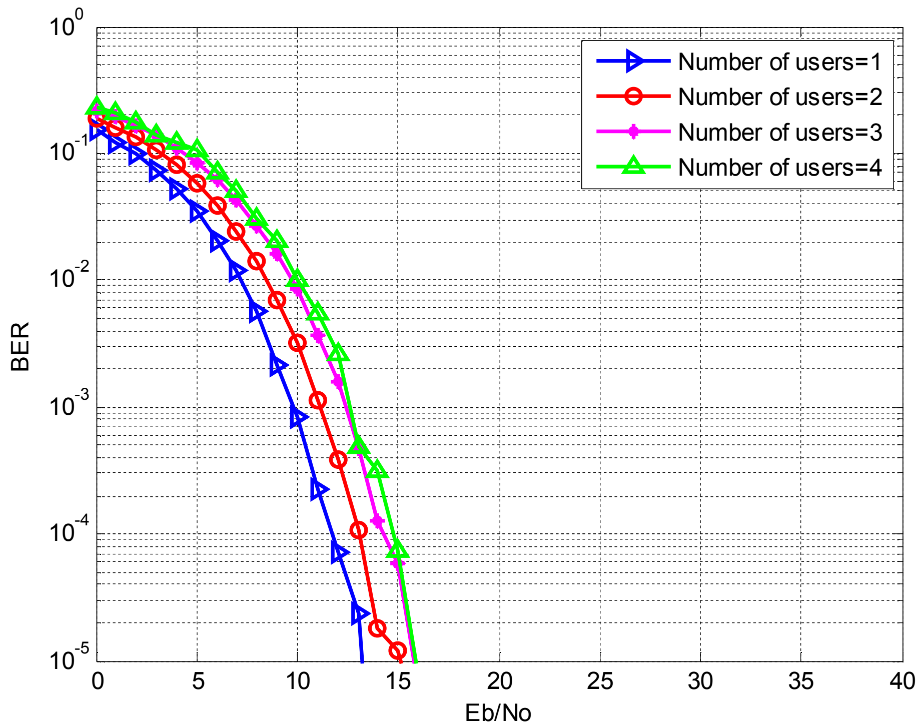

Fig. (11) BER performance of Framelet UWB system using DS-CDMA for channel accessing with variable number of users in CM3.

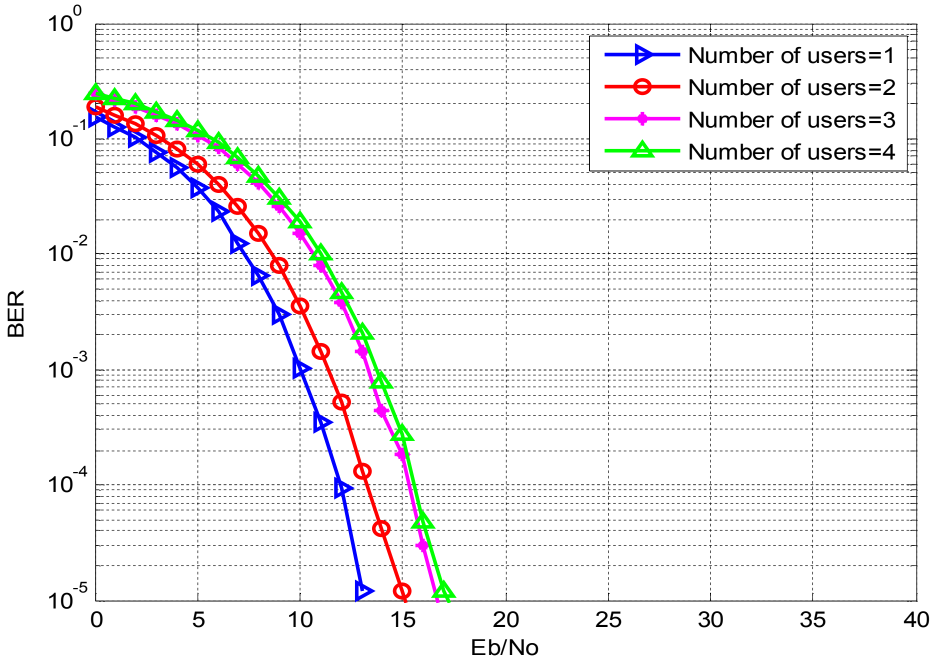

Fig. (12) BER performance of Framelet UWB system using DS-CDMA for channel accessing with variable number of users in CM4.

The bandwidth of a single user in OFDM-UWB system is approximately 500-MHz, so if Walsh-Hadamard code with length equal to 4 is used (the spreading factor=4), then four users with a 2-GHz bandwidth is used. It is worth to note that the data rate is preserved the same as the case without using spreading codes.

In figure (9) for CM1, a BER of 10^{-5} can be achieved at $E_b/N_0 = 10.8\, dB$ for single user accessing the channel, while an $E_b/N_0 = 13\ dB$ is required to achieve the same BER when four users are accessing the channel instantaneously. This requires $2.2\ dB$ more power than single user case.

While in figure (10) for CM2, a BER of 10^{-5} can be achieved at $E_b/N_0 = 11.5\, dB$ for single user accessing the channel. On the other hand, an $E_b/N_0 = 13.8\, dB$ is required to achieve the same BER when four users are accessing the channel instantaneously. This requires $2.3\ dB$ more power than single user case.

On the other hand, in figure (11) for CM3, a BER of 10^{-5} can be achieved at $E_b/N_0 = 13\ dB$ for single user accessing the channel. Also an $E_b/N_0 = 15.6\, dB$ is required to achieve the same BER when four users are accessing the channel instantaneously. That needs $2.6\ dB$ more power than single user case.

Finally, in figure (12) for CM4, an $E_b/N_0 = 13.1\ dB$ is required to achieve a BER of 10^{-5} for single user accessing the channel, while an $E_b/N_0 = 17\ dB$ is required to achieve the same BER when four users are accessing the channel instantaneously. This requires $4\ dB$ more power than single user case.

Based on the previous results, it can be concluded that as the number of users accessing the channel instantaneously increases, the BER performance is slightly degraded. This indicates that interference or a crosstalk between users occurs. Since orthogonal codes are used for spreading, there must be no interference between different users in an ideal or AWGN channel because the cross correlation between different codes is zero. However, in multipath channels, the situation completely differs. Spread spectrum with orthogonal codes is susceptible to multipath environment. In addition, multipath in the channel typically compromises the orthogonality of the codes, leading to medium access interference. For CM1, this degradation in performance is small, while for more severe multipath channel, e.g. CM2, CM3, and CM4 the degradation becomes more and more significant, indicating an increase in the cross-talk level between different users.

Conclusions:

This paper has studied the Framelet based UWB system and compared it with other existing systems. The Framelet transform was used instead of the fast Fourier transform in the conventional system. Framelet UWB system can't employ a cyclic prefix to deal with ISI, so these systems need more complex equalizer to improve its performance. Also it has been seen that Framelet-UWB system has better performance than FFT-OFDM when equalizer is used. Finally, it has been proved using Matlab software package that the Framelet based UWB system gives the best performance among DWT-UWB and DWPT-UWB.

References :

1- X. Shen, M. Guizani, R. C. Qiu, and T. Le-Ngoc, ”*Ultra-Wideband Wireless Communications and Networks*”, John Wiley, 2006.

2- C. Snow, L. Lampe, and R. Schober, ”*Performance Analysis and Enhancement of Multiband OFDM for UWB Communications*”, IEEE Transactions on Wireless Communications, Vol. 6, No. 6, June 2007, pp. 2182-2193.

3- G. Wornell, ”*Emerging Applications of Multirate Signal Processing and Wavelets in Digital Communications*”, *Proceedings of the IEEE*, Vol. 84, No. 4, April 1996, pp. 586-603.

4- M. Oltean and M. Naforniţă, ”*Wavelet OFDM Performance in Frequency Selective Fading Channels”*, 8th International Conference on Communications, 2010, pp. 343-346.

5- An Li, W. Shieh, and R. S. Tucker, ”*Wavelet Packet Transform-Based OFDM for Optical Communications*”, Light Wave Technology Journal, Vol. 28, No 24, December 2010.

6- S. Maki, E. Okamoto, Y. Iwanami, ”*Performance Improvement of Haar Based Wavelet Packet Modulation in Multipath Fading Environment*”, *ISCIT 2007*, October 2007, Sidney, Australia.

7-H. Harada, M. Hernandez and R. Kohno, ”*Multiband and Multicarrier Wavelet Packet Multiplexing for UWB Transmissions*”, Proceedings of the IEEE international conference on ultra-wideband, Vol. 3, 2008, pp. 39-42.

8-Z. Q. Abdulkareem, ”*Framelet-Based OFDM System*”, M.Sc. Thesis, University of Technology, 2011.

9-Selesnick, I. W. and L. Sendur, ”*Iterated Oversampled Filter Banks and Wavelet Frames*”, In: Wavelet Applications in Signal and Image Processing VIII, San Diego. Proceedings of SPIE, Vol. 4119, 2000.

10- R. Jiao and B. Lin, ”*A Digital Image Watermarking Method Based on Tight Framelet*”, International Conference on Web Information Systems and Mining, Vol. 2, 2010, pp. 49-52.

11- J. R. Foerster, M. Pendergrass and A. F. Molisch, ”*A Channel Model for Ultra-Wideband Indoor Communication*”, IEEE Wireless Communications, Vol. 10, No. 6, pp. 14–21, Dec. 2003