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PERFORMANCE STUDY OF OFDM BASED ON IP-WT

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ABSTRACT

In this paper, a proposed model based on In-Place Wavelet Transform (IP-WT) was suggested to improve the performance of the Orthogonal Frequency Division Multiplexing (OFDM) under the Additive White Gaussian Noise (AWGN), and flat fading channel. The proposed model does not require additional arrays at each sweep such as in the ordered Haar wavelet transform; this ensures fast processing time with minimum memory size. The results extracted by a computer simulation and compared with the performance of the conventional model based on Fast Fourier Transform (FFT). As a result, it can be seen that the proposed technique has high performance improvement over the conventional OFDM system based FFT, where the Bit Error Rate (BER) is widely reduced under these models of channels.

INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a special technique of multicarrier modulation, where a single data stream is transmitted over a number of lower rate subcarriers. It is worth mentioning here that OFDM can be seen as either a modulation technique or a multiplexing technique. One of the main reasons to use OFDM is to increase the robustness against frequency selective fading and the narrowband interference. In a single carrier system, a single fade or interferer can cause the entire link to fail, but in a multicarrier system, only a small percentage of subcarriers will be affected. Error correcting coding can then be used to correct the few erroneous subcarriers. The first scheme for OFDM was proposed by Chang in 1966 [1] for dispersive fading channels. OFDM was standardized as the European Digital Audio Broadcasting (DAB) as well as Digital Video Broadcasting (DVB) scheme [2].

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It constituted also a credible proposal for the recent third-generation mobile radio standard competition in Europe; also OFDM was recently selected as the HIgh PERformance Local Area Network (HIPERLAN) transmission technique as well as becoming part of IEEE 802.11 WLAN standard [3].

In the OFDM system the bandwidth is divided into high narrow sub-bands in which the mobile channel can be considered no dispersive. Since no channel equalizer is required and instead of implementing a bank of sub-channel modems they can be conveniently implemented with the aid of Fast Fourier Transform (FFT) [3]. The employment of the Discrete Fourier Transform (DFT) to replace the banks of sinusoidal generators and the demodulators that had suggested by Weinstein and Ebert [4] in 1971, which significantly reduces the implementation complexity of OFDM modems, also they conceived the guard interval to avoid the Inter-Symbol Interference (ISI) and the Inter-Carrier Interference (ICI). This proposal opened a new era for OFDM.

In 2004 Zhang, et al [5] carried out research on DFT-OFDM and Discrete Wavelet Transform-OFDM (DWT-OFDM) on different transmission scenarios. The DFT based OFDM has currently drawn most attention in the area of wireless communication. To combat ISI, and ICI, cyclic prefix is inserted between DFT-OFDM symbols, and this will take up nearly 25 percent of bandwidth. To improve the bandwidth efficiency and ISI, ICI, DWT-OFDM was proposed. Salih M., et al [6] was proposed a new model for Multicarrier-Code Division Multiple Access (MC-CDMA) based on In-place Wavelet Transform (IP-WT), the ordered Haar wavelet transform requires additional arrays at each sweep, and it assumes that the whole sample is known at the start of the algorithm. In contrast, some applications require real-time processing as the signal proceeds, which precludes any knowledge of the whole sample, and some applications involve arrays so large that they do not allow sufficient space for additional arrays at each sweep. The two problems just described, lack of time or space, have a common solution in the In-Place Fast Haar Wavelet Transform [6, 7, and 8], which differs from the ordered Haar wavelet transform algorithm only in its indexing scheme.

HAAR WAVELET TRANSFORM

The wavelet transform is a mathematical transform similar to the commonly known Fourier transform. Wavelet analysis is a form of “multiresolution analysis”, which means that wavelet coefficients for a certain function contain both frequency and time-domain information. This fact makes wavelets useful for signal processing applications where knowledge of both frequency information and the location in time of that frequency information is useful. There are many different wavelet transforms, each based on different functions for low and high-pass transformation.

The low-pass wavelet coefficient is generated by averaging the two adjacent values, and the high-pass coefficient is generated by taking half of their difference. Fig. 1 shows the conversion for an 8-coefficient row. The inverse transform can be calculated from the wavelet coefficients very easily. Adding the corresponding average and difference coefficients and then subtracting these, leads to restoring the original two coefficients. fig.2 shows the inverse transform procedure.

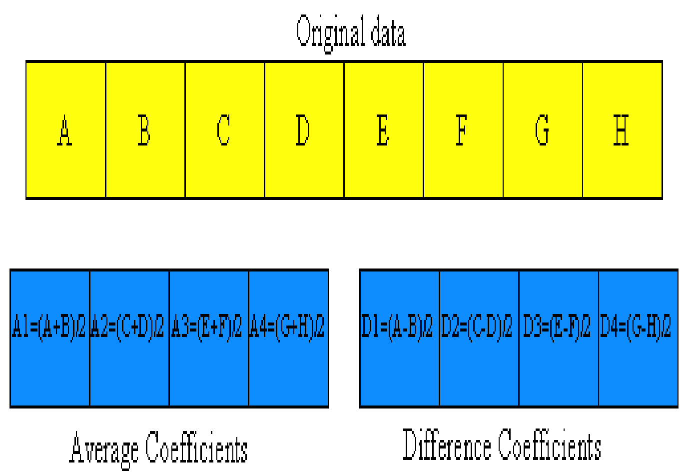

Fig. 1 Forward Haar transform for an 8-coefficient row.

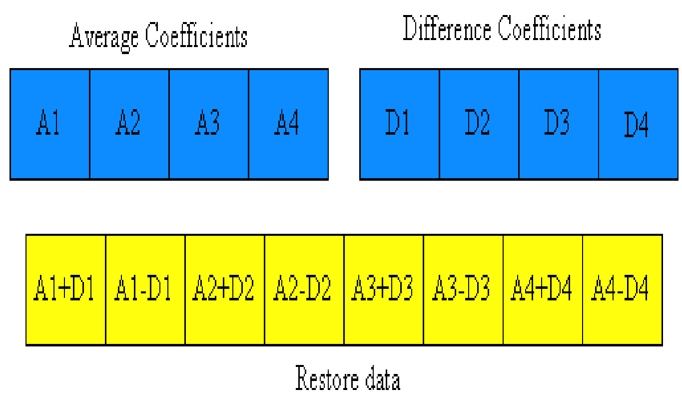

Fig. 2 Inverse Haar transform example.

The basic Haar transform expresses the approximating function $\tilde{f}$ with wavelets by replacing an adjacent pair of steps via one wider step and one wavelet. The wider step measures the average of the initial pair of steps, while the wavelet, formed by two alternating steps, measures the difference of the initial pair of steps. The shifted and dilated wavelet $\psi_{[u,w[}$ is defined by the midpoint v = (u + w) / 2 [8],

$$\psi_{[u,w[}(t) = \begin{cases} 1 & \text{if } u \le t < v \\ -1 & \text{if } v \le t < w \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

For all numbers u and w, the notation [u,w[represents the interval of all numbers form u included to w excluded,

$$[u,w[= \{t : u \le t < w\} \quad (2)$$

The sum and the difference of the narrower steps give a wider and a wavelet

$$\varphi_{[u,w[} = \varphi_{[u,v[} + \varphi_{[v,w[} \quad (3)$$

$$\psi_{[u,w[} = \varphi_{[u,v[} - \varphi_{[v,w[} \quad (4)$$

Adding and subtracting the last two equations yields the inverse relation, expressing the two narrower steps in terms of the wider step and the wavelet,

$$\frac{1}{2}\left(\varphi_{[u,w[} + \psi_{[u,w[}\right) = \varphi_{[u,v[} \quad (5)$$

$$\frac{1}{2}\left(\varphi_{[u,w[} - \psi_{[u,w[}\right) = \varphi_{[u,v[} \quad (6)$$

The basic Haar wavelet transform with the shifts and dilations are applied to all the consecutive pairs of measured signals.

In-Place Fast Haar Wavelet Transform

In this section the fundamental study of the In-Place Fast Haar Wavelet Transform (IP-WT) will be given. The basic Haar transform expresses the approximating function with wavelets by replacing an adjacent pair of steps via one wider step and one wavelet. The wider step measures the average of the initial pair of steps, while the wavelet, formed by two alternating steps, measures the difference of the initial pair of steps.

- *In-Place Basic Sweep*

For each pair $a_{2k}^{(n-[l-1])}$, $a_{2k+1}^{(n-[l-1])}$, instead of placing its results in two additional arrays, the

l^{th} sweep of the In-Place transform merely replaces the pair $a_{2k}^{(n-[l-1])}$, $a_{2k+1}^{(n-[l-1])}$ by the new entries $a_k^{(n-l)}$, $c_k^{(n-l)}$:

Initialization. Consider the pair $a_{2k}^{(n-[l-1])}$, $a_{2k+1}^{(n-[l-1])}$.

Calculation. Perform the basic transform

$$a_k^{(n-l)} = \frac{a_{2k}^{(n-[l-1])} + a_{2k+1}^{(n-[l-1])}}{2}, \quad (7)$$

$$c_k^{(n-l)} = \frac{a_{2k}^{(n-[l-1])} - a_{2k+1}^{(n-[l-1])}}{2}. \quad (8)$$

Replacement. Replace the initial pair $a_{2k}^{(n-[l-1])}$, $a_{2k+1}^{(n-[l-1])}$ by the transform $a_k^{(n-l)}$, $c_k^{(n-l)}$.

In-Place Fast Haar Wavelet Transform Analysis (IP-WT)

The In-Place basic sweep explained in the preceding subsection extends to a complete algorithm through mere record-keeping. The first few sweeps proceed as follows [8].

- *Initialization*

$$\vec{S}^{(n-1)} = \vec{S} = \left(S_0, S_1, S_2, \ldots\ldots\ldots, S_{2k}, S_{2k+1}, \ldots\ldots\ldots S_{2^n-2}, S_{2^n-1}\right) \quad (9)$$

  - *First Sweep*

$$\vec{S}^{(n-1)} = \left(\frac{S_0+S_1}{2}, \frac{S_0-S_1}{2}, \frac{S_2+S_3}{2}, \frac{S_2-S_3}{2}, \ldots\ldots\ldots\ldots, \frac{S_{2k}+S_{2k+1}}{2}, \frac{S_{2k}-S_{2k+1}}{2}, \ldots\ldots \ldots\ldots\ldots, \frac{S_{2^n-2}+S_{2^n-1}}{2}, \frac{S_{2^n-2}-S_{2^n-1}}{2}\right) \quad (10)$$

$$= \left(\mathbf{a}_0^{(n-1)}, c_0^{(n-1)}, \mathbf{a}_1^{(n-1)}, c_1^{(n-1)}, \mathbf{a}_2^{(n-1)}, c_2^{(n-1)}, \mathbf{a}_3^{(n-1)}, c_3^{(n-1)}, \ldots\ldots \ldots\ldots, \mathbf{a}_k^{(n-1)}, c_k^{(n-1)}, \ldots\ldots\ldots\ldots \mathbf{a}_{2^{n-1}-1}^{(n-1)}, c_{2^{n-1}-1}^{(n-1)}\right) \quad (11)$$

- *Second Sweep*

In the new array $\overset{\rightarrow(n-1)}{S}$, keep but skip over the wavelet coefficients $c_k^{(n-l)}$, and perform the basic sweep on the array $\mathbf{a}_k^{(n-1)}$ at its new location, now occupying every other entry in $\overset{\rightarrow(n-1)}{S}$:

$$\overset{\rightarrow(n-2)}{S} = \left(\frac{\mathbf{a}_0^{(n-1)}+\mathbf{a}_1^{(n-1)}}{2}, c_0^{(n-1)}, \frac{\mathbf{a}_0^{(n-1)}-\mathbf{a}_1^{(n-1)}}{2}, c_1^{(n-1)}, \frac{\mathbf{a}_2^{(n-1)}+\mathbf{a}_3^{(n-1)}}{2}, c_2^{(n-1)}, \frac{\mathbf{a}_2^{(n-1)}-\mathbf{a}_3^{(n-1)}}{2}, c_3^{(n-1)}, \ldots\ldots \frac{\mathbf{a}_{2^{n-1}-2}^{(n-1)}+\mathbf{a}_{2^{n-1}-1}^{(n-1)}}{2}, c_{2^{n-1}-2}^{(n-1)}, \frac{\mathbf{a}_{2^{n-1}-2}^{(n-1)}-\mathbf{a}_{2^{n-1}-1}^{(n-1)}}{2}, c_{2^{n-1}-1}^{(n-1)}\right) \quad (12)$$

$$= \left(\mathbf{a}_0^{(n-2)}, c_0^{(n-1)}, c_0^{(n-2)}, c_1^{(n-1)}, \mathbf{a}_1^{(n-2)}, c_2^{(n-1)}, c_1^{(n-2)}, c_3^{(n-1)}, \mathbf{a}_2^{(n-2)}, c_4^{(n-1)}, c_2^{(n-2)}, c_5^{(n-1)}, \ldots\ldots\ldots\ldots c_{2^{n-2}-1}^{(n-2)}, c_{2^{n-1}-1}^{(n-1)}\right) \quad (13)$$

In general, the In-Place lth sweep begins with an array

$$\overset{\rightarrow(n-[l-1])}{S} = \left(\mathbf{a}_0^{(n-[l-1])}, c_0^{(n-1)}, c_0^{(n-2)}, c_1^{(n-1)}, c_0^{(n-3)}, c_2^{(n-1)}, c_1^{(n-2)}, c_3^{(n-1)}, \ldots, c_{2^{n-2}-1}^{(n-2)}, c_{2^{n-1}-1}^{(n-1)}\right) \quad (14)$$

This contains the array

$$\overset{\rightarrow(n-[l-1])}{\mathbf{a}} = \left(\mathbf{a}_0^{(n-[l-1])}, \mathbf{a}_1^{(n-[l-1])}, \ldots\ldots\ldots, \mathbf{a}_{2^{n-(l-1)}-1}^{(n-[l-1])}\right) \quad (15)$$

At the locations $\mathbf{a}_k^{(n-[l-1])} = S_{2^{l-1}k}^{(n-[l-1])}$, in other words, at multiples of 2^{l-1} apart in $\overset{\rightarrow(n-[l-1])}{S}$, and which the lth sweep replaces by:

$$a_j^{(n-l)} = \frac{a_{2j}^{(n-[l-1])} + a_{2j+1}^{(n-[l-1])}}{2} = \frac{S_{2^{l-1}2j}^{(n-[l-1])} + a_{2^{l-1}(2j+1)}^{(n-[l-1])}}{2} \quad (16)$$

$$c_j^{(n-l)} = \frac{a_{2j}^{(n-[l-1])} + a_{2j+1}^{(n-[l-1])}}{2} = \frac{S_{2^{l-1}2j}^{(n-[l-1])} + a_{2^{l-1}(2j+1)}^{(n-[l-1])}}{2}, \quad (17)$$

$$S_{2^{l-1}2j}^{(n-l)} = a_j^{(n-l)}, \qquad S_{2^{l-1}(2j+1)}^{(n-l)} = c_j^{(n-l)} \quad (18)$$

So that the new array $\vec{a}^{(n-l)}$ occupies entries at multiples of 2^l apart in $\overset{\rightarrow(n-l)}{S}$, becomes $a_j^{(n-l)} = S_{2^{l-1}2j}^{(n-l)} = S_{2^l j}^{(n-l)}$.

2.3 In-Place Fast Inverse Haar Wavelet Transform Analysis (IP-IWT)

As described in the preceding section, the fast Haar wavelet transform neither alters nor diminishes the information contained in the initial array $\vec{S} = (S_0, S_1, \ldots\ldots\ldots, S_{2^n-1})$, because each basic transform

$$a_k^{(l)} = \frac{a_{2k}^{(n-1)} + a_{2k+1}^{(n-1)}}{2}, \quad c_k^{(l)} = \frac{a_{2k}^{(n-1)} - a_{2k+1}^{(n-1)}}{2} \quad (19)$$

admits an inverse transform:

$$a_{2k}^{(l-1)} = a_k^l + c_k^l, \quad a_{2k+1}^{(l-1)} = a_k^l - c_k^l. \quad (20)$$

Repeat the applications of the basic inverse transform just given, beginning with the wavelet coefficients

$$\overset{\rightarrow(0)}{S} = \left(a_0^{(n)}, c_0^{(1)}, \ldots\ldots\ldots\ldots, c_{2^n-1}^{(1)}\right),$$

Reconstruct the initial array

$$\overset{\rightarrow(n)}{S} = \vec{S} = \left(S_0, S_1 \ldots\ldots\ldots, S_{2^n-1}\right)$$

SIMULATION MODEL

The overall system of OFDM based on In-Place wavelet transform that is used in this simulation is shown in fig. 3. From this figure, it can be seen that the IFFT and the FFT in the conventional system are replaced by the In-Place Inverse Wavelet Transform (IP-IWT) and the In-Place Wavelet Transform (IP-WT) blocks. The processes of the S/P converter, the signal demapper and the insertion of training sequence are the same as in the OFDM system based FFT. After that the IP-IWT will be applied to the signal.

The main and important difference between OFDM based FFT and the OFDM based DWT or based IP-WT is that the OFDM model based wavelet transform will not add a cyclic prefix to the OFDM symbols. Therefore, the data rates in this system 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 through the channel. At the receiver, the S/P converts the OFDM symbol to parallel version, then, the IP-WT will be applied on the received symbols. Also the zero pads will be removed 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 OFDM based FFT.

The training sequence will be used to estimate the channel frequency response as follows [4, 8]:

$$H(k) = \frac{Received\ \ Training\ Sample(k)}{Transmitted\ \ Training\ Sample(k)} \quad (21)$$

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

$$Estmate.\ data = H^{-1}{}_{estimate}(k) * Received.data(k) \quad (22)$$

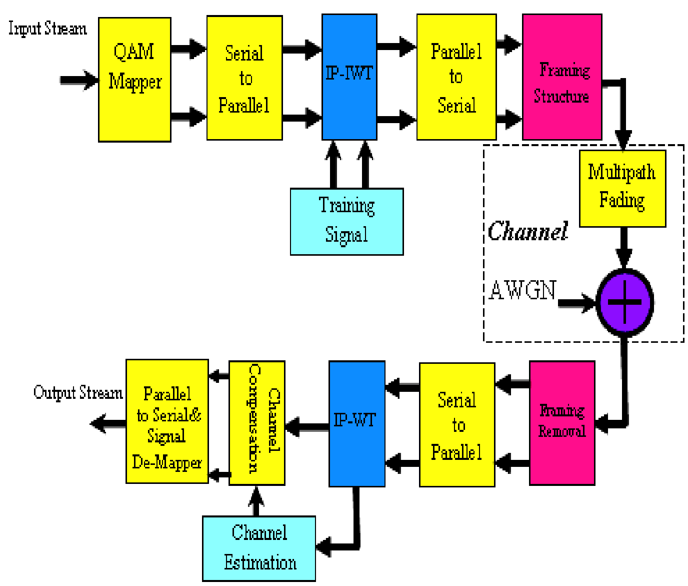

Fig. 3 Block diagram of OFDM system based on IP-WT.

SIMULATION RESULTS

In this section, the combination of conventional OFDM based FFT with the proposed OFDM based IP-WT will be studied, A simulation of the two systems has been made using MATLAB 7. And the BER performance of the two systems will be studied in different models of channels which are AWGN, AWGN+falt fading channel, and AWGN+frequency selective fading channel, with a bit rate of 5 Mbps, 32 subcarriers are used in this simulation, and 8-bit cyclic prefix was added to the OFDM symbols for the conventional system based FFT. The simulation parameters are given in table 1.

Table 1 Simulation Parameters

Modulation Type	QAM, 8 Point and 64 Point
Doppler frequency	5, 100 Hz
Number of sub-carriers	32
Number of bits per Symbol	32
Number of FFT points	32
Channel model	AWGN
	Flat fading+AWGN
	Frequency selective fading+AWGN

Performance of the Proposed System in AWGN Channel

The channel here is modeled as an Additive White Gaussian Noise for wide range of SNR from 0 dB to 40 dB, from Fig. 4, it is found that the proposed system does worked with SNR=19.5 dB at BER=10-4 and 8 constellation points, while in the traditional OFDM the bit error rate of 10-4 at SNR=38 dB, which means a gain of 18.5 dB was obtained by the proposed model. As the number of constellation mapping increased to 64 point, the BER was increased for both systems even the proposed model is less affected by this variation. The loss is about 8 dB for the proposed model while the BER is about 10-2 at SNR=40 dB for the conventional model.

Performance of the Proposed System in Selective Fading Channel

In this type of channel, the frequency components of the transmitted signal are affected by uncorrelated changes, where the parameters of the channel in this case corresponding to multipath, the two paths chosen are, the Line of Sight (LOS) and second path which is the reflected path. In selective fading channel many models can be taken into consideration to compare the BER performance of the systems, the influence of the attenuation, delay and maximum Doppler shift of the echo. Now, set the Doppler shift to 5 Hz, and 100 Hz. The path delay has been set to 1 sample and the path gain to -8 dB.

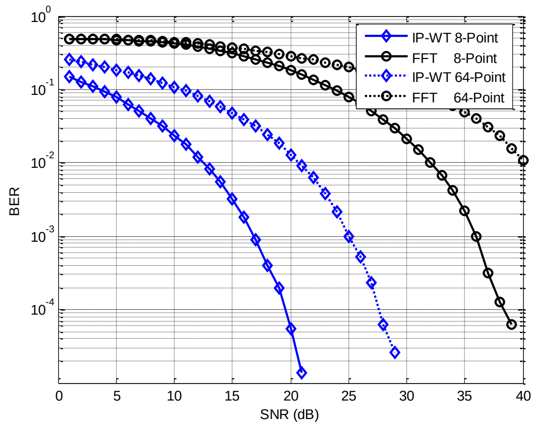

Fig. 4 BER performance of the proposed OFDM based IP-WT and the traditional model based FFT in AWGN channel.

It is seen that from Fig. 5 at Doppler frequency=5 Hz, the proposed model has better performance at the lower values of SNR. As the SNR increases for more than 20 dB, the BER will be constant for this model while it is reduces for the conventional model based FFT. As the number of constellation mapping increased to 64 point, the BER will increase for both systems.

Fig. 6 shows the performance of both systems as the Doppler frequency increased to 100 Hz. The proposed model has poor performance at the higher Doppler frequency, where its BER is approximately constant in all range of SNR. In general, both systems have poor performance in selective fading channel.

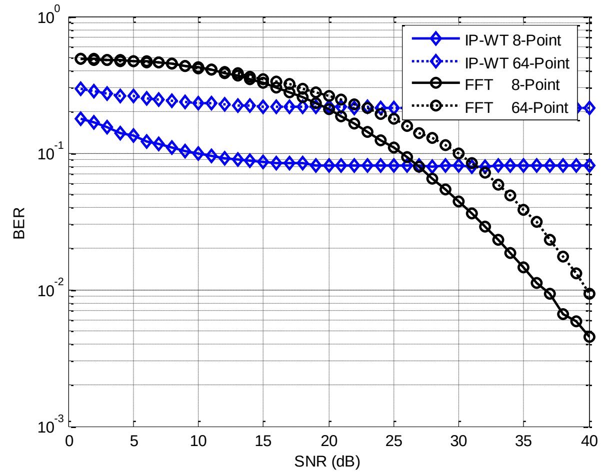

Fig. 5 Performance of the proposed and traditional OFDM in frequency selective fading channel (maximum Doppler shift=5 Hz, path gain=-8 dB, 1 sample delay).

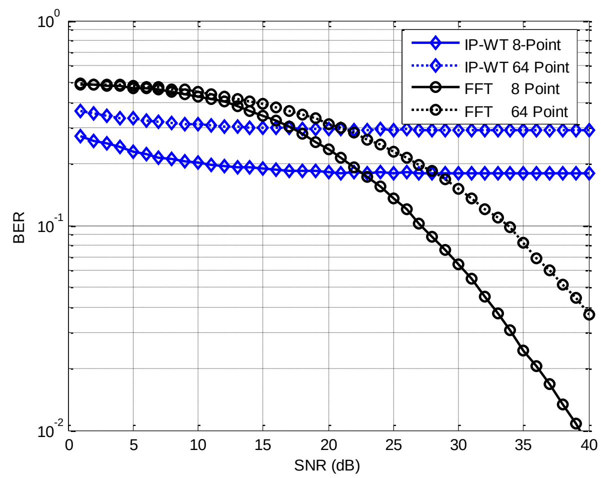

Fig. 6 Performance of the proposed and traditional OFDM in frequency selective fading channel (maximum Doppler shift=100 Hz, path gain=-8 dB, 1 sample delay).

Performance of the Proposed System in Flat Fading Channel

In this section, the performance of proposed and traditional models in flat fading channel will be shown under two values of Doppler frequencies as in the previous subsection, these are: 5 Hz, and 100 Hz. It can be seen from fig. 7 that there exists a wide difference in BER curves between the suggested and the traditional OFDM model, where the BER=10^{-4} at SNR=24.5 dB, while the traditional OFDM system was failed to work in this type of model of channel, it has high BER in all simulated SNR range. As the number of constellation point increases the losses for both models were also increases, in all cases the proposed model has better performance than the conventional one.

Fig. 8 shows the performance of these models as the Doppler frequency increases to 100 Hz. The BER for both models was increased; the proposed model based on IP-WT outperforms the conventional system in all range of SNR.

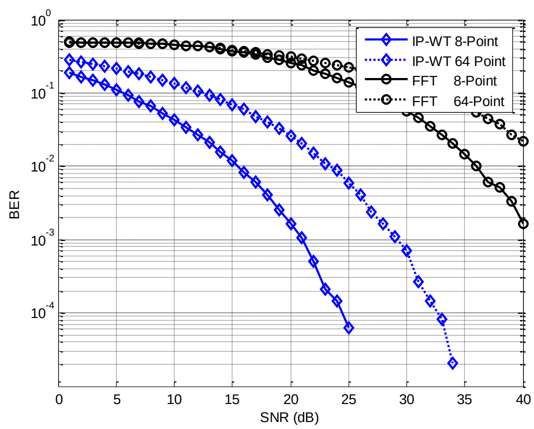

Fig. 7 Performance of the proposed and traditional OFDM in flat fading channel (maximum Doppler shift=5 Hz).

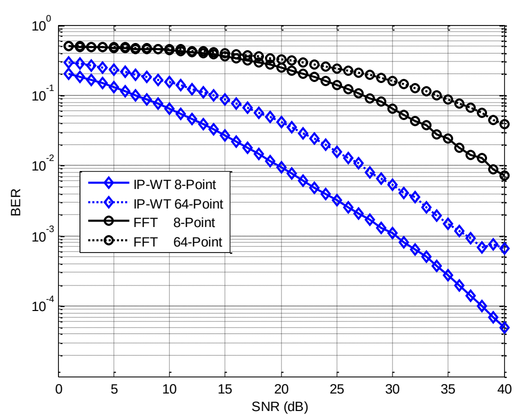

Fig. 8 Performance of the proposed and traditional OFDM in flat fading channel (maximum Doppler shift=100 Hz).

CONCLUSIONS

The simulation of the proposed and the conventional OFDM systems has been investigated. It has been shown that the new algorithm is widely active to work under the AWGN and flat fading channel characteristics. The proposed and the conventional models have poor performance in selective fading channel. The suggested model can be considered as an alternative technique to the conventional system where it requires minimum memory size at each sweep; this ensures a fast processing time relative to the ordered Haar wavelet transform.

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دراسة أداء مازج تقسيمات التردد المتعامدة بالاعتماد على في-مكان لتحويل الويفليت

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الخلاصة

في هذا البحث تم اقتراح نموذج لتحسين أداء مازج تقسيمات التردد المتعامدة(OFDM) تحت تأثير قناة الضوضاء الابيض التراكمية لكاوز (AWGN) وقناة الخبو المنبسط. ان النموذج المقترح لايحتاج الى مصفوفة إضافية عند كل مستوى من مرحلة معالجة للإشارة مثلما يحتاجه تحويل الويفليت المرتب؛ وبالتالي فان سرعة المعالجة ستزداد وبأقل حجم للذاكرة. تم مقارنة النتائج مع اداء النموذج الاعتيادي المعتمد على تحويل الفوري السريع (FFT) بالاعتماد على في– مكان لتحويل الويفليت (IP-WT). النتائج بينت ان النموذج المقترح قد اعطى تحسن عالي بالاداء نسبة الى النموذج الاعتيادي ، حيث انقل بشكل كبير تحت تأثير تلك النماذج من القنوات.