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On the Simulation of BER Performances for Transform Schemes Used in OFDM

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ABSTRACT
Due to many special characteristics of OFDM it has been widely applied in various applications. Besides exponential transforms some other transforms like DCT and Wavelet can also be used in OFDM. Since last decade DCT is going to be a good alternative as it is a real transform hence less complex. In very recent scenario telecommunication industry has been attracted towards the wavelets. Wavelet applications are finding a way in which their performances match the current system for example in communication system. In this paper Computer simulation using MATLAB 7.0 has been used to analyze the performance of FFT, DCT and WPT OFDM in terms of bit error rate. All the simulations have been done using AWGN and Rayleigh channel. Along with it mapping schemes used in these simulations are BPSK, QPSK and Pi/4 DQPSK.

Keywords
Fast Fourier Transform (FFT), Discrete Cosine Transform (DCT), Wavelet Packet Transform (WPT), Orthogonal Frequency Division Multiplexing (OFDM).

1. INTRODUCTION
OFDM is one of the multicarrier modulation techniques which are used in wire line digital communication systems and wireless network standards. All such type of systems comes under the category of FFT- OFDM. These types of transforms use exponential function set as orthogonal basis [1]. In OFDM general signaling like BPSK, QPSK, QAM and Pi/4 DQPSK is performed on raw data then further processing is done by inverse Fast Fourier transform (IFFT) [2]. At the receiver side Fast Fourier Transform (FFT) is used to get back the original data. The prime requirement to construct baseband multicarrier signals is orthogonal basis functions. But, exponential functions set are not only the orthogonal basis. A set of co- sinusoidal functions can also be a substitute to implement these types of schemes. Discrete Cosine Transform (DCT) is this type of scheme [1].

Bandwidth efficiency is a major factor which motivates to use DCT in MCM [3]. 1-D signaling format can be applied here as DCT is real transform besides that it can also be applied in complex valued (2D) modulation format in OFDM. Energy compaction property is one of the prime importance’s which make its suitability for OFDM system due to less ICI Coefficients [4] [5].

Prediction of the channel impulse response length is difficult in wireless and besides it if length of channel is so high that insertion of cyclic prefix makes the system performance loss severe then overall system degrades badly. This problem can be overcome if Fourier transform can be replaced by such a transform that is less susceptible to channel effects [6] [7]. Longer basis function for wavelet transform provides more flexibility in design of waveform used and provides high degree of side lobe suppression [7].

Two properties of wavelets namely, Orthonormality [8][9][10] and perfect reconstruction [11][12][13], makes it a suitable candidate for OFDM. FFT- OFDM signals only overlap in frequency domain while WPT- OFDM overlaps in both time and frequency. Cyclic Prefix (inserted in time domain) being an essential part of FFT-OFDM to avoid ISI cannot be included in wavelet based OFDM; overload due to it can be decreased [14] [15]. Wavelet based OFDM reshapes the multicarrier transmission concept, by using wavelet carriers instead of OFDM’s complex exponentials. DFTs have sines and cosines as its basis function so transients and edges in time domain cannot be localized while DWPT use irregular wave shapes of finite length which allows analyzing sharp variation and local features of signal [16].

Fourier analysis is breaking of signals into sine waves of various frequencies; wavelet analysis is breaking of signals into shifted and scaled versions of original wavelet. Unlike Fourier bases which are static sines and cosines WPMCM offers flexibility and adaptation that can be tailored to satisfy an engineering demand [15]. Flexibility is the feature of wavelets which makes it highly suitable for future generation of communication systems. This feature together with a modular implementation complexity makes WPM a potential candidate for building highly flexible modulation schemes. The greatest motivation for pursuing WPM systems lies in the freedom they provide to communication systems designers [15]. A wavelet based systems having robustness against synchronization errors can be developed without compromising on spectral efficiency or receiver complexity by modifying the design specification [15].

FFT- OFDM of programmable size is not feasible due to fixed no. of subcarriers defined at design time. While in WPT-OFDM it can be made configurable without any additional complexity [17].

This paper is organized as follows: In section II OFDM system model is described in brief. This includes FFT-OFDM, WPT- OFDM, and DCT- OFDM. Section III describes mapping schemes used in this paper. In Section IV performance is analyzed and simulation results are presented. The last section includes Conclusion remarks. We in this paper have compared performance of DFT- OFDM, DWPT-OFDM and DCT- OFDM transceiver in AWGN and Rayleigh fading channel.

2. OFDM SYSTEM MODEL
2.1 FFT-OFDM
Figure 1 describes simulation block diagram of OFDM system. Transmitter section includes input bit stream being converted into Parallel N different sub channels by serial to

parallel converter. These lower data rate signals over sub channels have bit or symbol period longer which makes it more robust against multipath time delay effects. The system can be made by increasing the number of subcarriers over a wider bandwidth. This means higher frequencies can be used with fewer multipath effects. This can be more advantageous in today's communication where concept of mobility is more important, transmitter or receiver or both are moving and undergoing different environment conditions.

These parallel streams of data are mapped on constellation using any one of the digital mapping schemes either conventional or non-conventional. Then an N-point IFFT is applied to transform the frequency domain incoming symbols into the time domain signal. This transformation maps the data points onto orthogonal subcarriers. The IFFT outputs are presented by following equation:

$$X_{k}(n) = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} X_{m(i)} \exp\left(j2\pi\, i \,\frac{n}{N}\right)$$

$X_{k\ (n)}$ sequence is in discrete time domain and $X_{m(i)}$ are complex nos. in discrete frequency domain.

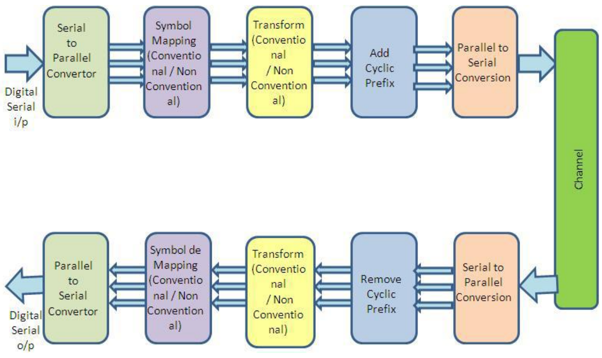

Fig. 1 Simulation Diagram of OFDM System

A cyclic prefix is added to the signal in the digital domain after the IFFT operation to avoid inter-block interference (IBI). Contaminants like noise, multipath etc. added to data while data is transmitted through channel. In broadband communication channel may be either wired or wireless. In wireless systems, changes in physical environment (like both relative movement between transmitter and receiver and moving scatters in the surrounding space) cause the channel to fade. There are various types of fading characteristics like Rayleigh and Rician fading.

To recover the original information, in the OFDM receiver the reverse process of transmitter is performed. The cyclic prefix is removed and an N point FFT operation in performed on the resulting signal to recover the data in frequency domain. The output of FFT in frequency domain can be expressed as:

$$X_{m(i)} = \sum_{n=0}^{N-1} X_{k(n)} \exp\left(-j2\pi i \frac{n}{N}\right)$$

Advantage of this system is its very low computational complexity and implementation cost. Limitation is wasted bandwidth and reduced data throughput due to CP insertion.

2.2 WPT-OFDM

Filters used for FFT based OFDM suffers from poor frequency response due to rectangular window used as pulse shaping filter. FFT-OFDM transceiver is being replaced by spectrally efficient wavelet based transceiver. Good frequency characteristic and greater flexibility offered by wavelet packet transform makes it an attractive choice for high data rate OFDM transceiver in fading channel conditions. Unique time fequency localization features of wavelets can be useful to improve SNR performance of communication system. The coefficients of wavelet packet filter banks are computed with an algorithm that performs iterations of two channel filter bank decomposition or reconstruction. Wavelet packets are defined recursively in [15]. Perfect reconstruction is the main feature of wavelet which enables it to reconstruct the decomposed signal into original signal without detritions.

In WPM the no. of iterations determine number of terminals, in turn, determine no. of subcarriers. During each iteration, inverse discrete wavelet packet transformation (IDWPT) up samples two signals and filters one with HPF and other with LPF. The outputs of these branches are then subsequently added [16]. The transmitted signal for WPM is given by

$$S = \sum_{p=0}^{N-1} \sum_{l=0}^{\infty} a_p\,(l) \emptyset_{k,p}^{syn}(m - lN)$$

Where $a_p(l)$ are complex data symbols of different parallel streams p, while $\emptyset_{k,p}^{syn}$ denotes synthesis wavelet packet function for pth subchannel and N is the no. of subcarriers. On the receiver side discrete wavelet packet transformation (DWPT) is performed to bring the signals back to their original domain. In an iteration of DWPT the input signal is filtered by HPF and LPF; decomposing original signal into two parts. Each of the decomposed parts is then sampled by two, satisfying the nyquist rule [15].

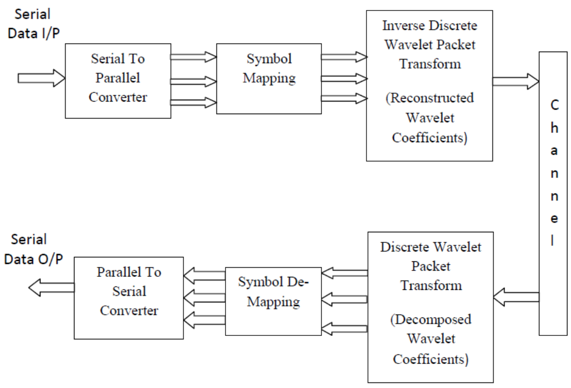

Fig. 2: Simulation Diagram for IDWPT and WPT Transceiver

2.3 DCT-OFDM

Baseband multicarrier signals are usually constructed using orthogonal basis functions. Discrete Cosine Transform, Discrete Sine transform etc. are some of the alternative methods besides complex exponential functions. In DCT most of the energy is contained in a small number of components. Detailed study of DCT- OFDM can be done in [18] and references therein.

In the OFDM system transmitter section includes IDCT which can be represented as [18]

$$x_i = \sqrt{\frac{2}{N_s}} \sum_{n=0}^{N_s-1} d_n\ \beta_n \cos\left(\frac{\pi n(2i+1)}{2N_s}\right)$$

$i = 0, 1, \dots, Ns\text{-}1$

At the receiver side DCT operation is performed that can be represented as

$$d_n = \sqrt{\frac{2}{N_s}}\,\beta_n \sum_{i=0}^{N_s-1} x_i \cos\left(\frac{\pi n(2i+1)}{2N_s}\right)$$

In fact, cyclic shift properties similar to DFT were extended to a wide variety of sinusoidal transforms in References [19, 20]. Cyclic shift properties can be derived for other transforms by applying some kind of symmetric extension.

The inverse operation is done by N × N DCT matrix at the receiver which is orthogonal to $N/2 \times N$ IDCT matrix involving the symmetric extension and so recovers the original transmitted symbol sequence.

Table I shows the comparative analysis on the features and properties of various transform schemes included in OFDM.

Table I. Comparison of various transform schemes used with OFDM

Parameter	DFT	DCT	WPT
Subcarrier	210	210	256
Transform Bin size	1024	1024	-
Transmitted data length	64000	128000	16384
Symmetric extension	Not required	Required	Not required
Cyclic Prefix	Required	Required	Not required
Pulse shaping	Required	Required	In built
Transform	Complex valued	Real valued	Real/complex valued
Complexity in implementation	Less	Less	Complex
Reconfigurable transceiver	No	No	Yes
Energy compaction	No	Yes	Yes
Time-frequency Resolution	Fixed	Fixed	Dynamic

3. MAPPING SCHEMES

Conventional or non- conventional like BPSK, QPSK, DQPSK, Pi/4 DQPSK and many other can be used as modulation technique. The detailed description about this is in [21] and references within. Multipath scenario occurs in short distance communication where the carrier frequency offset and doppler spread are the critical factors to be considered. System complexity is also one of the major factors while choosing the proper modulation technique.

QPSK is a multilevel modulation technique and is most often used since it does not suffer from BER degradation while bandwidth efficiency is increased. Other MPSK schemes suffer from BER degradation at the cost of bandwidth efficiency. Compared to BPSK, it is more spectrally efficient but requires more complex receiver.

Adversary effects of fading channel can be reduced by applying differential demodulation, this property is useful for mobile communications. The π /4 DQPSK is a form of differentially encoded QPSK. It has been widely used in digital cellular telephone system in U.S and Japan. This mapping scheme is discussed in [21] and the references in this.

Because of its simplicity BPSK is appropriate for low-cost passive transmitters, and is used in RFID standards such as ISO/IEC 14443 which has been adopted for biometric passports, credit cards such as American Express's Pay, and many other applications. IEEE 802.15.4 (the wireless standard used by ZigBee) also relies on PSK. IEEE 802.15.4 allows the use of two frequency bands: 868–915 MHz using BPSK and at 2.4 GHz using OQPSK [22].

4. NUMERICAL RESULTS

The performance of FFT based OFDM, DCT- OFDM and wavelet packet based OFDM has been analyzed with the help of computer simulations. Software used for computer simulation is MATLAB 7.0. A communication system has been designed with BPSK, QPSK, and Pi/4 DQPSK mapping schemes and 64 (50) orthogonal subcarriers in WPT (FFT). FFT- OFDM makes use of cyclic prefix of length $1/4^{th}$ of FFT bin size but WPT- OFDM does not use any kind of CP. NO other circuitry has been used for simulation. Parameters chosen for FFT- OFDM and WPT- OFDM are given in Table II.

Table II. Parameters for Simulation

Parameters	Values
No: of bits to be processed	symbol per carrier × bit per symbol × number of subcarriers
SNR	1 : 30 dB
IFFT/IDCT bin size	1024
WPT terminal node	256/256
Symbols per subcarrier DCT/FFT WPT	 50 64
No. of subcarrier (FFT, DCT)	210
Bits per symbol	2/4
Cyclic prefix	0.25 × FFT/IDCT bin size
Channel	AWGN , Rayleigh channel
Modulation technique used	BPSK,QPSK and π/4 DQPSK
Doppler Spread	0 Hz, 10 Hz

4.1 AWGN Channel

In the figure below performance comparison of transform schemes FFT, DCT and WPT has been shown along with the various combination of mapping schemes of BPSK, QPSK and Pi/4 DQPSK. In all the combination of transform and mapping schemes DCT and WPT based OFDM give far better performances than FFT based OFDM. Although DCT and WPT gives same performance yet some features of WPT-OFDM like no CP inclusion, time and frequency localization and flexibility for the designer makes it a more suitable candidate than DCT- OFDM. Along with that for making subcarriers orthogonal symmetric extension has to be done in DCT-OFDM so additional circuitry and data overload is required.

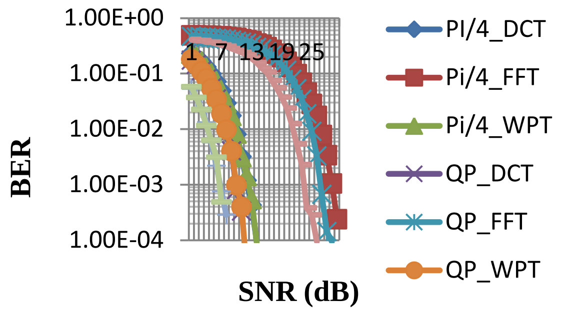

Fig. 3: BER Performance of Different Transform Schemes with different Mapping Schemes over AWGN Channel

4.2 Rayleigh Channel

While not considering any relative movement performance in terms of BER in multipath scenario has been shown in figure 4.

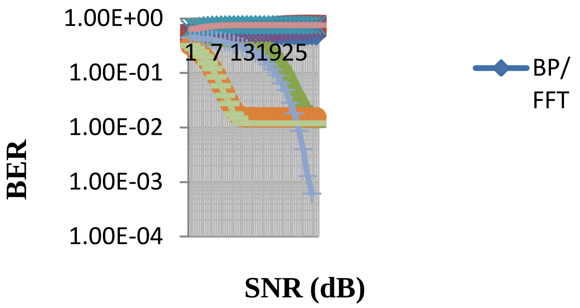

Fig. 4: BER Performance of Different Transform Schemes with different Mapping Schemes over Multipath Channel with no relative movement

In this case BER performance is better for Pi/4 DCT and Pi/4 WPT in comparison of all other combinations of transform and mapping scheme.

From Figure 5 it can be observed that Performance degrades measurably in mobility environment. In comparison of DCT, WPT and FFT based OFDM systems DCT outperforms the other two schemes; especially DCT with pi/4 DQPSK gives a very good performance improvement. In WPT packets are formed with equal energy distribution. So in multipath mobility environment its performance can degrade because energy requirement in mobility scenario may be different at different positions. That is the reason that WPT-OFDM does not give any performance improvement with any of the mapping scheme while applied in mobility conditions. While observing the performance of all OFDM systems mentioned above in combination of pi/4 DQPSK it can be observed from Figure 6 that this combination gives better performance in comparison of other mapping schemes used in this paper.

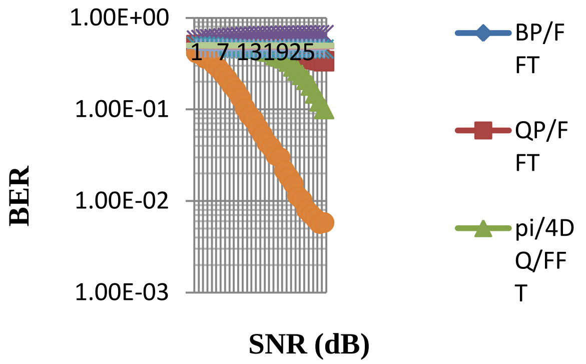

Fig. 5: BER Performance of Different Transform Schemes with different Mapping Schemes over Multipath Channel under mobility conditions

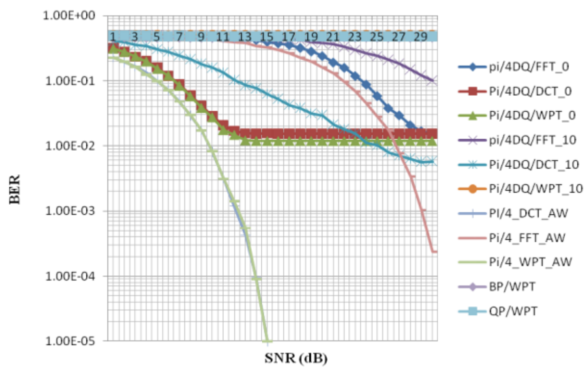

Fig. 6: BER Performance of Different Transform Schemes with Pi/4 DQPSK Mapping Schemes over AWGN and Rayleigh Channel

5. CONCLUSION

In Rayleigh channel environment with no Doppler effect the performance of the system is same as that with AWGN channel. Basic WPT based OFDM system does not improve the performance in combination of any of mapping scheme. Reason behind this is that in this uniform bandwidth allocation is there, so bandwidth utilization is not proper which not the case in others is. By increasing the no. of decomposition levels performance of system degrades. This system can work with less no. of data subcarriers only. For higher levels some modification like complex WPT can be used.

6. REFERENCES

[1] Peng Tan, Norman C. Beaulieu "A Comparison of DCT-Based OFDM and DFT-Based OFDM in Frequency Offset and Fading Channels", IEEE Transaction on communications, VOL. 54, NO. 11, November 2006.

[2] A.Bahai and B. Saltzberg, "Multi-Carrier Digital Communications, Theory and Applications of OFDM", Kluwer, 1999.

[3] J. Tan and G. L. Stüber, "Constant envelope multi-carrier modulation," in *Proc. IEEE MILCOM*, 2002, vol. 1, pp. 607–611.

[4] A. V. Oppenheim, R. W. Schafer, and J. R. Buck, *Discrete-Time Signal Processing*, 2nd ed. Englewood Cliffs, NJ: Prentice-Hall, 1998.

[5] K. R. Rao and P. Yip, *Discrete Cosine Transform*. New York: Academic, 1990.

[6] Khaizuran Abdullah, Amin Z. Sadik, and Zahir M. Hussain, "On the DWT- and WPT- OFDM versus FFT-OFDM",

[7] Swati Sharma and Sanjeev Kumar, "BER Performance Evaluation of FFT-OFDM and DWT- OFDM", International Journal of Network and Mobile Technologies, VOL 2 / ISSUE 2 / MAY 2011, pp. 110-116.

[8] J.Oliver, R. Shantha Selva Kumari, V.Sadasivam, "Wavelets For Improving Spectral Efficiency In A Digital Comm. System" International Conference on Computational Intelligence and Multimedia Applications (ICCIMA'05)

[9] W. Jones,"A unified approach to orthogonally multiplexed communication using wavelet bases and digital filter banks," Ph.D.dissertation, Ohio Univ, Athens, Aug 1994.

[10] Fred Daneshgaran and Marina Mondin, "Bandwidth efficient modulation with wavelets", IEEE Electronic letters, Vol.30 No.15, pp. 1200-1202, July 1994.

[11] Saber.I.Hassouna, Ehab.F.Badran, Darwish.A.Mohamed and Shawki Shaaban, "Wavelet Packet Modulation for Multi-carrier CDMA Communications", 24th NATIONAL RADIO SCIENCE CONFERENCE (NRSC 2007) March 13-15, 2007, pp 1-8.

[12] Sanjit K. Mitra "Digital Signal Processing: A Computer-Based Approach" third.edition. Mc Graw hill, 2006

[13] Khaizuran Abdullah and Zahir M. Hussain, "Studies on DWT-OFDM and FFT-OFDM Systems", INT. CONF.ON COMM., COMPUTER AND POWER (ICCCP'09) MUSCAT, FEBRUARY 15-18, 2009, pp. 382- 386.

[14] Haitham J. Taha, M. F. M. Salleh, "Performance Comparison of Wavelet Packet Transform (WPT) and FFT OFDM System Based on QAM Modulation Parameters in Fading Channels",WSEAS TRANSACTIONS on COMMUNICATIONS, Issue 8,Volume 9, August 2010, pp., 453- 462.

[15] H. Nikookar and M.K.Lakshmanan, "COMPARISON OF SENSITIVITY OF OFDM ANDWAVELET PACKET MODULATION TO TIME SYNCHRONIZATION ERROR", IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'08).

[16] M. K. LAKSHMANAN and H. NIKOOKAR, "A Review of Wavelets for Digital Wireless Communication", Wireless Personal Communications, 2006 vol. 37, pp. 387–420.

[17] Antony Jamin, Petri Mahonen, "Wavelet Packet Modulation for wireless Communication", Wireless Communication and Mobile Computing Journal, March 2005, vol. 5, Issue 2, pp. 1-18.

[18] Shilpi Gupta, Chhaya Mehta, U.D. Dalal, "Performance Analysis of OFDM Using Non- Conventional Transform and Non-Conventional Mapping Schemes over Rayleigh Channel", Journal of Communication Engineering and System, vol. 2, Issue1, April 2012, pp. 13-20.

[19] Mandyam G. D., "Interspersed Sinusoidal Transforms for OFDM Systems", IEEE 2004, pp., 1025- 1029.

[20] Martucci S. A., "Symmetric Convolution and the discrete sine and cosine transform", IEEE Trans. Signal Process., Vol. 2, no. 5,pp. 1038- 1051, May 1994.

[21] R. Parmar, Shilpi Gupta, and Dr. (Mrs.) U. D. Dalal, "Comparison of BER Performances For Conventional and Non-Conventional Mapping Schemes Used in OFDM", International Conference on World Academy of Science, Engineering and Technology, Issue 79, July 2011,pp. 733-736.

[22] Xiong Fuqin, Digital Modulation Techniques. London: Artech House, 2000, 2nd Edition, ch.4, pp. 170 -176.