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Performance Evaluation of Dual Tree Complex Wavelet Packet Modulation (Dt-Cwpm) System over Multipath Rayleigh Fading Channel

Dr. Hikmat N. Abdullah
Engineering College, University of Al-Mustansiryah /Baghdad
Email: hikmat.abdullah@ieee.org
Dr. Majid A. Alwan
Engineering College, University of Basrah /Basrah
Fadhil S. Hasan
Engineering College, University of Al-Mustansiryah /Baghdad

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ABSTRACT

The effectiveness of Dual Tree Complex Wavelet Packet Modulation (DT-CWPM) with DQPSK modulation is investigated for communication over flat and frequency selective Rayleigh fading channel. The simulation results show that the performance of the proposed DT-CWPM system is better than that of Orthogonal Frequency Division Multiplexing (OFDM) and other types of Multicarrier Modulation (Slantlet based OFDM and FRAT-OFDM)for the same environment. The comparison of complementary cumulative distribution function (CCDF) of the peak to average power ratio (PAPR) between different types of multicarrier modulation is also achieved.

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), Dual Tree-Complex Wavelet Packet Modulation (DT-CWPM), FRAT- OFDM, Slantlet based OFDM, Hilbert transform, Rayleigh Fading channel.

تقييم أداءِ منظومة تضمين حزمة المويجة المركبة ذات الشجرة الثنائية (DT-CWPM) عبر قناة االتوهين ريلي المتعدد المسارات

الخلاصة

في هذا البحث تم التحقق من فعالية منظومة تضمين حزمة المويجة المركبة ذات الشجرة الثنائية (DT-CWPM) مع أستخدام تقنية التضمين (DQPSK) للانصال عبر قناتي رايلي ذات التوهين المسوّى وذات التوهين الانتقائي . أثبتت نتائج البحث أن المنظومة المقترحة تعطي نتائج أفضل من منظومات التضمين المتعدد الناقلة كمنظومة التعدد ألتقسيمي الترددي المتعامد (OFDM) ومنظومة(Slantlet based OFDM) ومنظومة (FRAT based OFDM) لظروف الإرسال نفسها. ولقد تم مقارنة دالة التوزيع التراكمية المتممة (CCDF) لنسبة القدرة العظمى الى المعدل (PAPR) لانواع مختلفة من منظومات التضمين المتعدد الناقلة.

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2412-0758/University of Technology-Iraq, Baghdad, Iraq
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الكلمات المرشدة: منظومة التعدد التقسيمي الترددي المتعامد (OFDM) , منظومة تضمين حزمة المويجة المركبة ذات الشجرة الثنائية (DT-CWPM), FRAT-OFDM , Slantlet based OFDM, تحويل Hilbert, قناة التوهين Rayleigh.

INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) has emerged as an efficient multicarrier modulation (MCM) schemes for wireless, frequency selective, communication channels. OFDM splits a high rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of overlapped subcarriers. These subcarriers are modulated with subcarriers spacing, which are selected such that modulated subcarriers are orthogonal over symbol duration. Increasing symbol duration will result in lower rate parallel subcarriers. This decreases the relative amount of dispersion in time caused by multipath delay spread. Intersymbol interference (ISI) is eliminated almost completely by introducing a guard time in every OFDM symbol. In guard time, the OFDM symbol is cyclically extended to combat the frequency selective of the channel and to avoid intercarrier interference (ICI) [1].

In recent years different types of multicarrier modulation are produced, Slantlet based OFDM [2], Finite Radon Transform (FRAT) based OFDM [3,4], Wavelet based OFDM [5,6,7,8], and Dual Tree-Complex Wavelet Transform (DT-CWT) [9,10]. The dual-tree wavelet decomposition has been introduced by N. Kingsbury [11]. This transform is based on a combination of classical wavelet decompositions. It has been further investigated by I. Selesnick [12]. The standard real dual-tree decomposition is 2 times redundant and is nearly shift-invariant. The dual-tree transform is interesting for several reasons: good directional analysis, low redundancy, improved shift-invariance property, simplicity of implementation, reduced computational cost. In this paper, the performance of Dual Tree Complex Wavelet Packet transform is evaluated over multipath fading channel and compared with different types of multicarrier modulation systems.

THE DUAL-TREE COMPLEX WAVELET PACKET TRANSFORM (DT-CWPT)

The dual tree complex wavelet packet transform (DT-CWPT) employs two real discrete wavelet packet transforms (DWPT), the upper part of the filter bank gives the real part of the transform while the lower one gives the imaginary part. This transform uses the two pairs of the filters. The first pair: $h_0(n)$ and $h_1(n)$ are the lowpass/highpass filter pair for the upper filter bank respectively. The second pair: $g_0(n)$ and $g_1(n)$ are the lowpass/highpass filter pair for the lower filter bank respectively. Using the first pair of filters, the sequence of wavelet function $\psi(t)$ and scaling function $\phi(t)$ are defined as follows [10]:

$$\begin{aligned} \psi_h(t) &= \sqrt{2}\sum_n h_1(n)\,\phi_h(2t-n) \\ \phi_h(t) &= \sqrt{2}\sum_n h_0(n)\,\phi_h(2t-n) \end{aligned} \qquad \ldots (1)$$

The wavelet function $\psi_g(t)$ and the scaling function $\phi_g(t)$ are defined similarly but with filters $g_0(n)$ and $g_1(n)$. The two real wavelets associated with each of

the two real transform are $\psi_h(t)$ and $\psi_g(t)$. To satisfy the perfect reconstruction conditions, the filters are designed so that the complex wavelet $\psi(t) = \psi_h(t) + j\psi_g(t)$ is approximately analytic. Equivalently, they are designed so that $\psi_g(t)$ is approximately the Hilbert transform of $\psi_h(t)$.

$$\psi_g(t) = H\{\psi_h(t)\} \qquad \ldots (2)$$

The analysis (decomposition or demodulation) and the synthesis (reconstruction or modulation) filter banks used to implement the DT-CWPT and their inverses are illustrated in Figure (1) and Figure (2) respectively. The inverse of DT-CWPT is as simple as the forward transform. To invert the transform, the real part and the imaginary part are each inverted. Upsampling is performed at the transmitter before entering the filter of its stage, and downsampling is held at the receiver after each data passed a filter of its stage.From these figures, it is seen that the filters for the first dual tree stage should be different from the filters for the remaining stages [13].

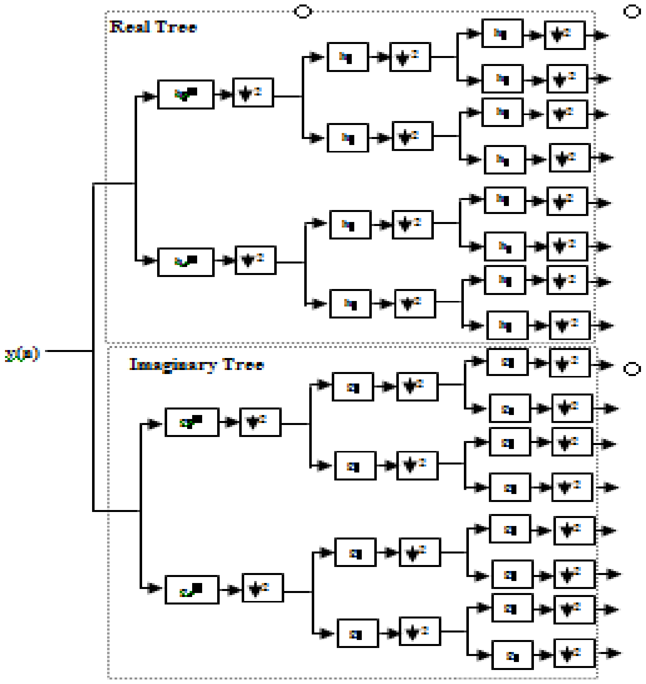


Figure (1) The DT-CWPT three levels Demodulation filter bank.

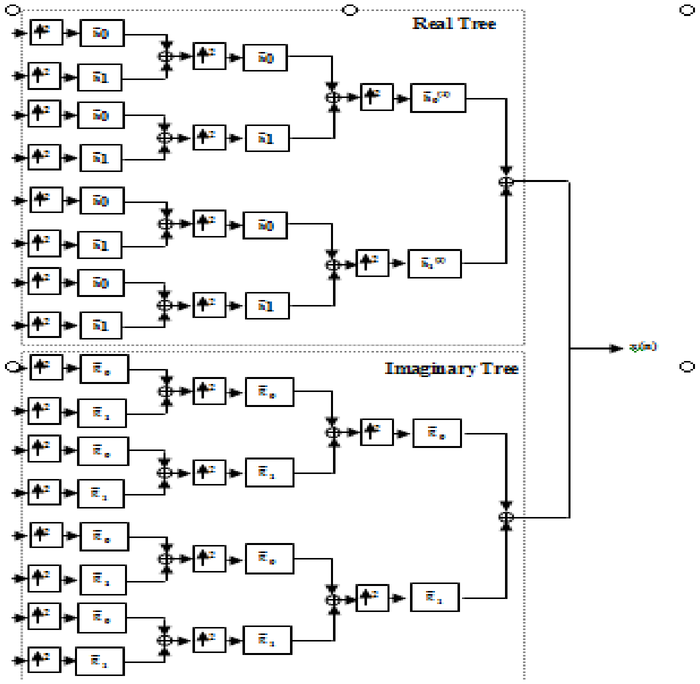


Figure (2) The DT-CWPT three level Modulation Filter bank.

All filters should be designed so that the resulting aliasing are exactly cancelled out. This condition leads to the construction of perfectly reconstruction (PR) filter bank, which is called quadrature mirror filter (QMF). In the QMF case, the filters of the real part are specified in terms of a single lowpass filter, $h_0(i)$, and the others are time reversal. These are:

$$\begin{aligned} h_1(i) &= (-1)^i h_0(L_o - 1 - i) \\ \tilde{h}_0(i) &= h_0(L_o - 1 - i) \qquad \dots (3) \\ \tilde{h}_1(i) &= -(-1)^i h_o(i) \end{aligned}$$

Similarly for the filters of imaginary part are specified in terms of a single lowpass filter, $g_0(i)$ and the others are time reversal. These are:

$$\begin{aligned} g_1(i) &= (-1)^i g_0(L_o - 1 - i) \\ \tilde{g}_0(i) &= g_0(L_o - 1 - i) \qquad \dots (4) \\ \tilde{g}_1(i) &= -(-1)^i g_o(i) \end{aligned}$$

where L_o is the length of the filter and $0 \le i \le L_o - 1$

THE HALF SAMPLE DELAY CONDITION

The two low pass filters should satisfy a very simple property: one of them should be approximately a half-sample shift of the other [10]:

$$g_0(n) \approx h_0(n - 0.5) \Rightarrow \psi_g(t) \approx H\{\psi_h(t)\} \qquad \dots (5)$$

Since $g_0(n)$ and $h_0(n)$ are defined only on the integers, this statement is somewhat informal. However, we can make the statement rigorous using Fourier transform. In [12] it was shown that, if $H_0(w)$ and $G_0(w)$ are lowpass filters with .

$$G_0(w) = H_0(w)\, e^{-j(\frac{w}{2})} \qquad for\,|w| < \pi \qquad \dots (6)$$

then the corresponding wavelets from a Hilbert transform pair:

$$\Psi_g(w) = \begin{cases} -j\Psi_h(w), & w > 0 \\ j\Psi_h(w), & w < 0 \end{cases} \qquad \dots \ (7)$$

where $\Psi(w)$ is the Fourier transform of $\psi(t)$.

FILTER DESIGN FOR THE DT-CWPT

There are various approaches to the design of filters for the DT-CWPT, such as linear-phase biorthogonal method, quarter shift method, and common factor method. These filters are satisfied the following desired properties [10]:

1- Approximately half-sample delay property.
2- Perfect reconstruction (PR) (orthogonal or biorthogonal).
3- Finite support (FIR filters).
4- Vanishing moments/good stop-band.
5- Linear phase filters.

Selesnick in [12] design simple algorithm solution depends on an all pass filter having a flat delay response. The design procedure allows for an arbitrary number

of zero wavelet moments to be specified. The design procedure yields filter $h_0(n)$ and $g_0(n)$ of minimal length of 2(L+K), where L is the degree of fractional delay and K is the number of zeros at z=-1. Different sets of filters are designed based on

K and L for DT-CWPM system as shown in Table.1. In this table, the specifications of six filters are given. For instance, Filter1 uses K=3 and L=1 with filter length of 8 for the first stage of filter bank while it uses K=3 and L=3 with filter length of 12 for the remaining stage of filter bank.

Table (1) Designed filter based on K and L for DT-CWPM system.

First stage			**Remaining stages**			**Name of filter**
K	**L**	**Length of filter**	**K**	**L**	**Length of filter**	
3	1	8	3	3	12	Filter1

2	1	6	3	3	12	Filter2
2	1	6	3	1	8	Filter3
3	3	12	5	4	18	Filter4
5	4	18	3	3	12	Filter5
3	3	12	3	1	8	Filter6

PEAK AVERAGE POWER RATIO (PAPR) DISTRIBUATION

One Problem with multicarrier modulation system that is often referred as the major drawback of multicarrier transmission is its large fluctuation of the signal envelope which is usually measured by parameter called PAPR. The system must be designed to operate perfectly in linear or operation region at power level below maximum power available, due to the distortion in peak which could cause undesirable spectrum that affects the adjacent channel.

A wavelet based OFDM signal, like the OFDM signal, is the sum of much information bearing subcarrier which is statistically independent. DT-CWPM is implemented with complex wavelet bases derived from a Hilbert transform pairs [12]. The PAPR of discrete time signal, x (n), is given as [14]:

$$PAPR=\frac{\max_n(|x(n)|^2)}{E(|x(n)|^2)} \qquad \ldots\ (8)$$

Where E (.) denotes ensemble average calculated over the duration of DT-CWPM symbols.

The Complementary Cumulative Distribution Function (CCDF) of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques. The CCDF of the PAPR denotes the probability that the PAPR of data block exceeds a given certain value, and is expressed as follows [14]:

$$CCDF\ (PAPR0)=Pr\ \{PAPR>PAPR0 \qquad \ldots\ (9)$$

From Central limit theorem it follows that for a large value of subcarriers N, the real and imaginary component of the multicarrier signal are modeled as a zero mean Gaussian distribution random variable with variance σ^2. The amplitude of the OFDM signal therefore has a Rayleigh distribution and its power distribution becomes a central chi-square distribution with two degrees of freedom and zero mean [14]. The CCDF of the PAPR can be calculated as:

$$\Pr(\mathrm{PAPR} \le \mathrm{PAPR0}) = 1 - \left(1 - e^{-\mathrm{PAPR0}}\right)^{N} \qquad \ldots\ (10)$$

The distribution obtained by the conventional analysis, however, does not fit those of the PAPR of the OFDM signals obtained by computer simula

tions, even for very large N. In [15], Van Nee and Prasad gave an empirical approximation:

$$\mathrm{CCDF}(\mathrm{PAPR0}) = 1 - \left(1 - e^{-\mathrm{PAPR0}}\right)^{\alpha N} \qquad \ldots\ (11)$$

Where α is a parameter determined by computer simulation to be 2.8.

Dual Tree Complex Wavelet Packet Modulation (DT-CWPM)

A functional block diagram of DT-CWPM system is shown in Figure (3). At the transmitter an inverse DT-CWPT (IDT-CWPT) block is used. At the receiver side a DT-CWPT is used. Data to be transmitted are typically in the form of a serial data stream. The stream binary bits are modulated using DQPSK modulation, and then passed through a serial to parallel (S/P) converter. This stream is modulated through an IDT-CWPT. IDT-CWPT works in a similar fashion to an IFFT; it takes the input DQPSK complex symbols and output them as complex subcarriers symbols. The transmitted signal is constructed as the sum of N waveforms $\varphi_h[i,k]$ and $\varphi_g[i,k]$ individually modulated with the DQPSK symbols as follows:

$$x[n] = \sum_{k} \left(\sum_{i=0}^{N-1} a_{k,i}\ \varphi_h(i, n - kN) + j \sum_{i=0}^{N-1} b_{k,i}\ \varphi_g(i, n - kN) \right) \qquad \ldots(12)$$

where $a_{k,i}$, $b_{k,i}$ are a real and imaginary constellation encoded kth data symbol modulating the ith wavelet packet basis function respectively. Then, the signal is passed through Multipath fading channel and AWGN. At the receiver, the signal is converted to parallel symbols by S/P converter and DT-CWPT is taken to them. Finally the symbols are demodulated by DQPSK demodulation to reconstruct the receiver bit streams.

Figure (3) Block diagram of DT-CWPM transceiver.

SIMULATION RESULTS

The simulation results of DT-CWPM systems are obtained by using MATLAB version 7.12 (R2011a). These results are compared with OFDM, SLANTLET, FRAT-OFDM and WPM systems over different channel models, the AWGN channel, the flat Rayleigh fading channel, and the frequency selective Rayleigh fading channel. OFDM is cyclically extended with guard sample 0.25N . Table (2) shows the parameters used in DT-CWPM system.

Table (2) Simulation parameters.

Modulation Type	DQPSK
Number of subcarriers	128
Doppler spread factor (fdTs)	0.0025, 0.0075, 0.015
Path delay	[0 8*Ts]
Path gain	[0 -8] dB
Channel model	AWGN
	Flat fading+AWGN
	Frequency selective fading+AWGN

AWGN CHANNEL RESULTS

Figure (4) shows the performance of DT-CWPM system in AWGN channel. The performance is compared with OFDM, WPM (Haar, db4, db5 and db6), Slantlet-OFDM and FRAT-OFDM systems. The type of complex wavelet is filter2. From this figure, it is seen that the performance of DT-CWPM system is better than OFDM, FRAT-OFDM and Slantlet-OFDM. For WPM system, the performance comparison is difficult since WPM system depends on filter types and filter length. DT-CWPM is better than WPM system for Daubechies with L_o<12. WPM with db6 (L_o=12) gives SNR gain about 0.5 dB greater than DT-CWPM for BER equals 10^{-3}.

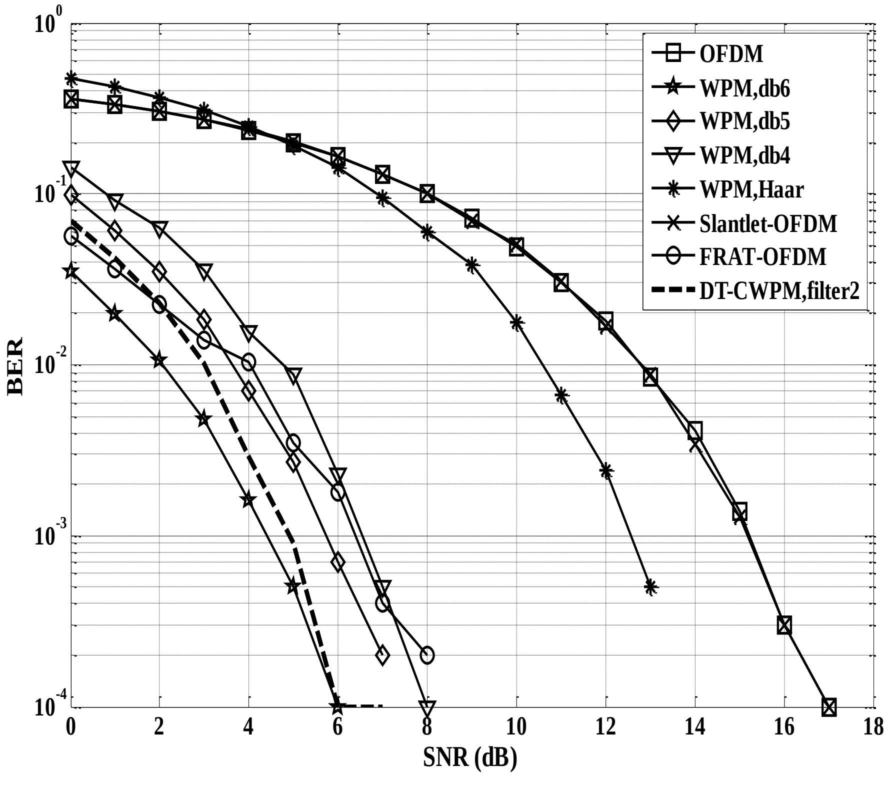


Figure (4) BER performance of MCM in AWGN channel.

FLAT FADING CHANNEL

The performance of DT-CWPM over flat Rayleigh fading channel is shown in Figures (5) through (7) for Doppler spread factor fdTs=0.0025,0.0075, and 0.015 respectively. From these figures, it is seen that DT-CWPM performance is better than OFDM, FRAT-OFDM and Slantlet-OFDM. Also, it is better than WPM system that has L_o<12. When Doppler spread factor is increased the WPM with db6 appears better performance than DT-CWPM system.

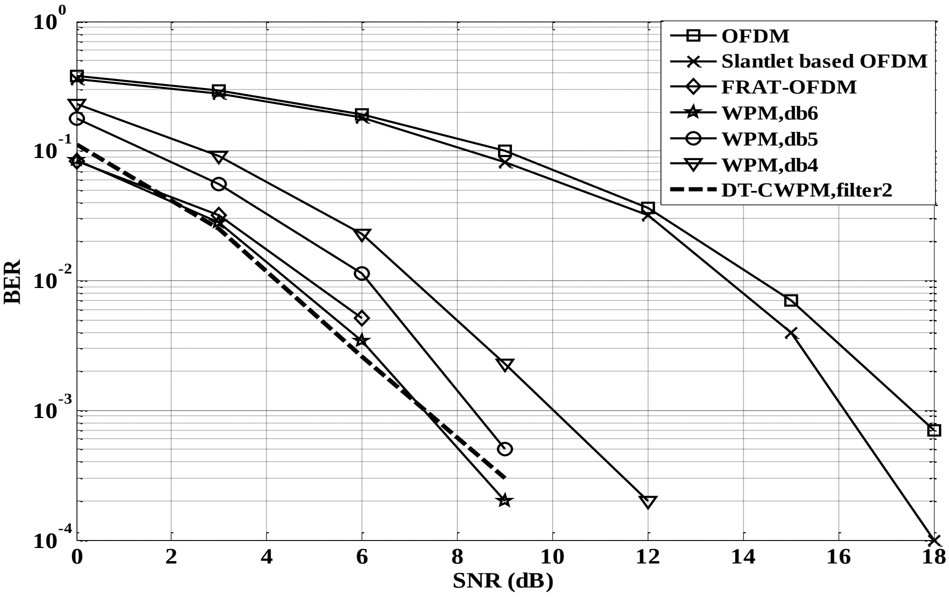


Figure (5) BER performance of MCM systems in Flat fading channel at Doppler spread factor fdTs=0.0025.

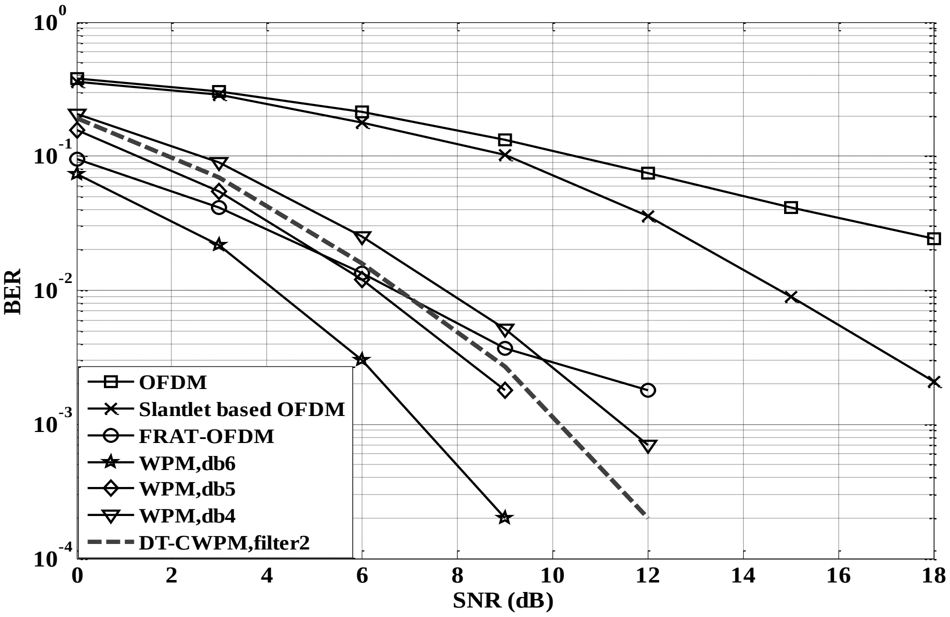


Figure (6) BER performance of MCM systems in Flat fading

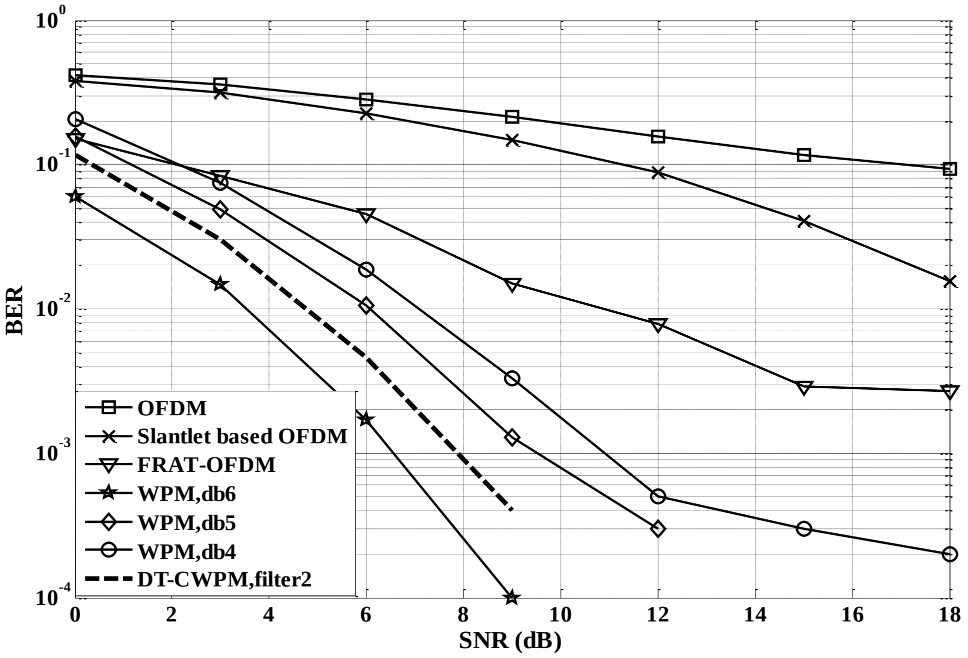


Figure (7) BER performance of MCM systems in Flat fading channel at Doppler spread factor fdTs=0.015.

SELECTIVE RAYLEIGH FADING CHANNEL

The performance of DT-CWPM over selective Rayleigh fading channel is shown in Figures (8) through (10) for Doppler spread factor fdTs=0.0025, 0.0075, and 0.015 respectively. From these figures, it is seen that DT-CWPM performance is better than OFDM, FRAT-OFDM and Slantlet-OFDM. Also, it is better than WPM system that has $L_o<10$. At low Doppler spread factor, the performance of DT-CWPM system is closed to WPM system with db5. However, when Doppler spread factor is increased; the performance of DT-CWPM system becomes better than WPM system with db5. Also, WPM system with db6 appears better performance than DT-CWPM system. Figure (11) shows the performance of DT-CWPM system over frequency selective fading channel with fdTs=0.015 for different types of complex filters. From this figure, it is shown that there are no rules about change of filters as Daubechies, i.e. as Daubechies increase the length of filter increases BER performance. This rule is not shown in complex Hilbert filter. Therefore, be careful in choosing filter types. Also, There is no rule about changing K or L in filter design.

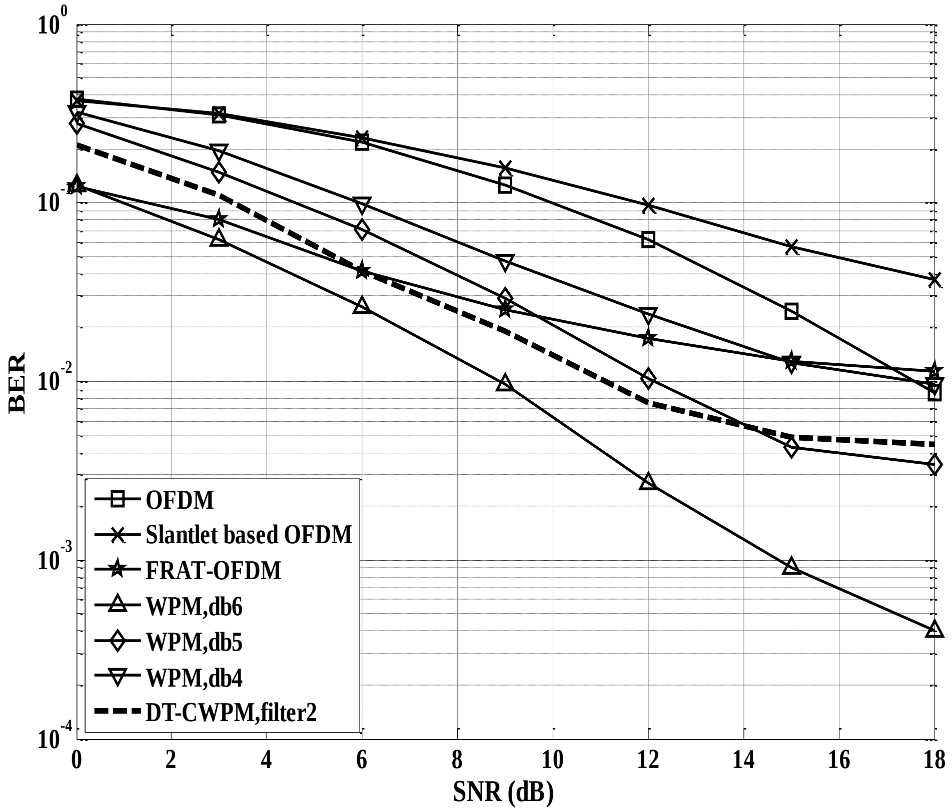


Figure (8) BER performance of MCM systems in Selective fading channel at Doppler spread factor fdTs=0.0025.

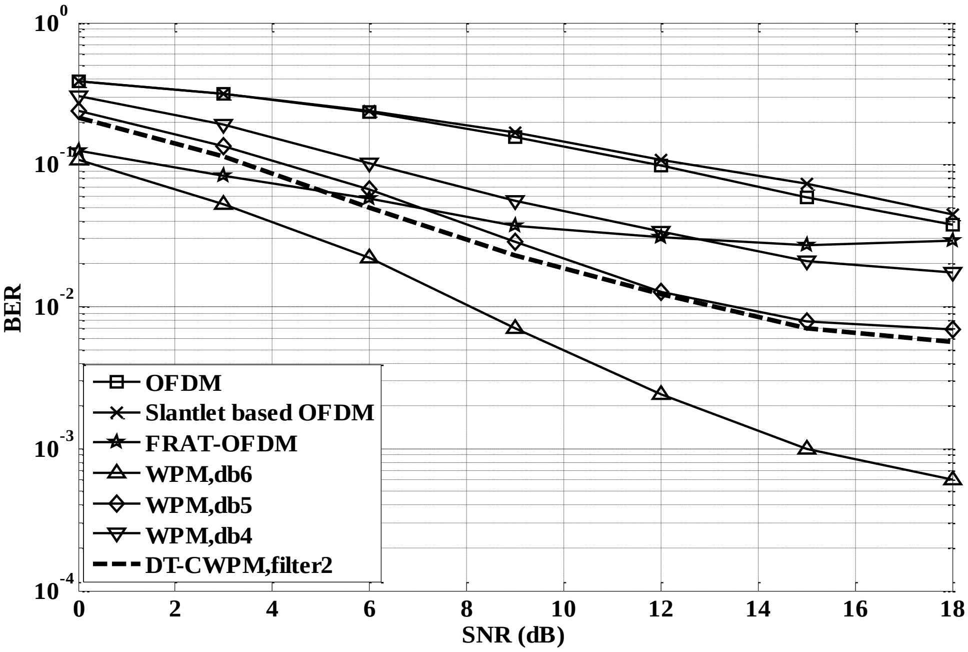
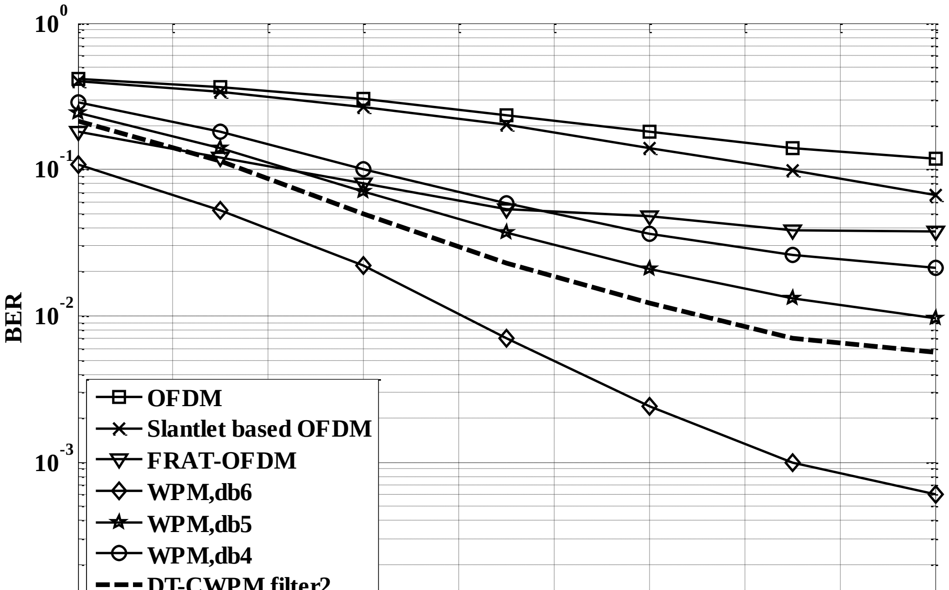


Figure (9) BER performance of MCM systems in Selective fading channel at Doppler spread factor fdTs=0.0075



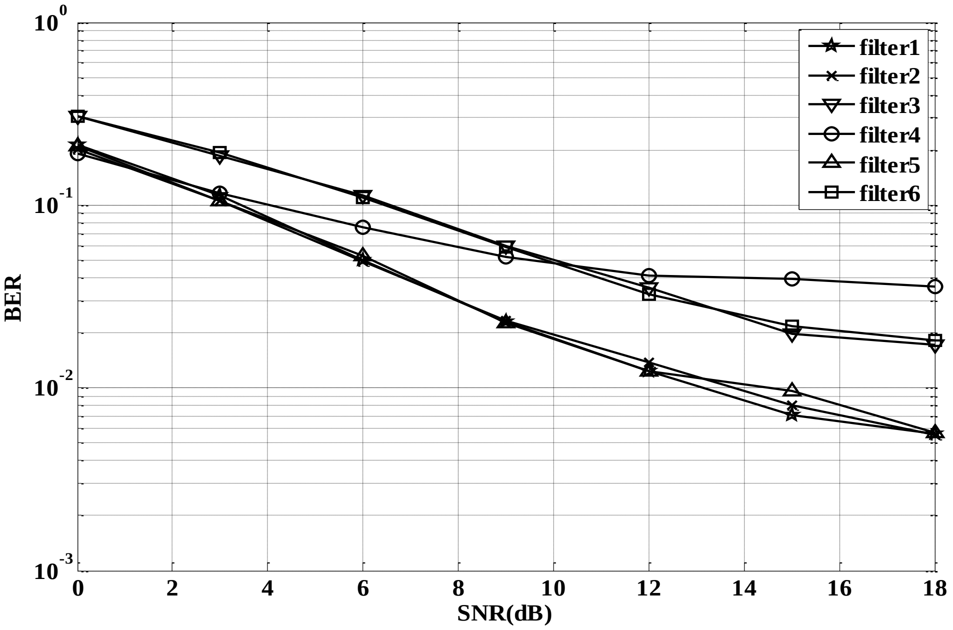


Figure (11) BER performance of DT-CWPM systems in selective fading channel at Doppler spread factor fdTs=0.015 for different filter types.

PAPR RESULTS

Figure (12) shows the CCDF of the PAPR of DT-CWPM system compared with OFDM and WPM systems for N=128. Figure (13) shows CCDF of the PAPR of DT-CWPM system for different types of filter. It can be seen that from these figures the PAPR of DT-CWPM is greater than OFDM by about 4.5dB when CCDF=0.01 when filter2 is used, and PAPR of DT-CWPM is smaller than WPM by about 1 dB when CCDF=0.01. Also, the filter length affected the PAPR values; therefore, the choice of filter is taken in carefully without effecting the BER performance.

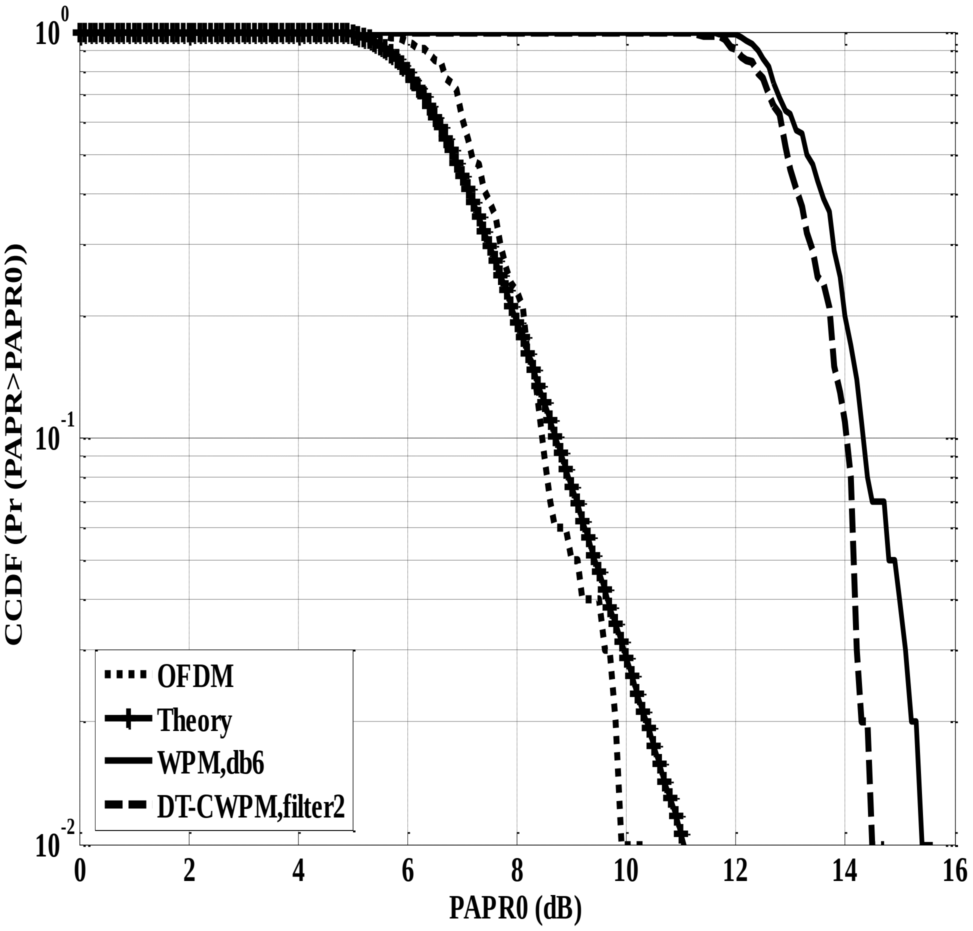


Figure (12) CCDF of the PAPR of DT-CWPM compared with OFDM and WPM signals for N=128.

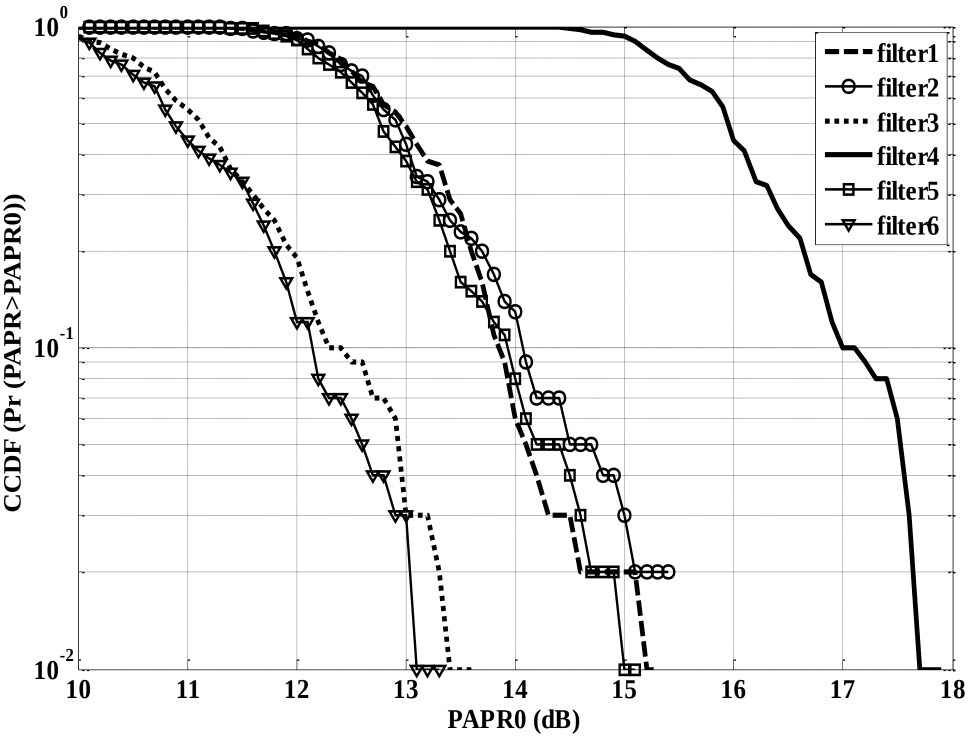


Figure (13) CCDF of the PAPR of DT-CWPM, for different types of filter.

CONCLUSIONS

In this paper the DT-CWPM system is presented as an efficient new multicarrier modulation system. Comparing the BER performance of this system with other multicarrier modulation systems in multipath Rayleigh fading channel has showed that its performance is better than OFDM, FRAT-OFDM and Slantlet-OFDM for different Doppler spread factors. DT-CWPM performance is better than WPM when length of Daubechies filter is less than 12. For filter lengths equal or exceeds 12, the performance of WPM becomes better. The PAPR for DT-CWPM system is better than that of WPM system. However, the problem of dealing with high values of PAPR is still a challenge in the proposed system

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