OFDM Technique for Multi-carrier Modulation (MCM) Signaling

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Abstract

OFDM is novel multicarrier modulation (MCM) technique. It has strong advantage of being a generic transmission scheme whose actual characteristics can be widely customized to fulfill several requirements and constraints of an advanced communication system. It adopts wavelet packet function as carriers which have the characteristic of good orthogonality and time-frequency localization. It can be seen from both theoretical analysis and software simulation that multi-carrier modulation and demodulation technique based on wavelet packet transform has unique advantage and great potential in improving the performance of communication system.

This paper demonstrates the operation of a Wavelet Packet based multi-carrier modulation (WP-MCM) scheme. The wavelet packets are derived from multistage tree-structured paraunitary filter banks by choosing the right tree structure which would minimize the bit error between the desired and received signal for a particular channel condition. The performance of the system is simulated and analyzed for the AWGN channel. Through simulation results, we demonstrate the efficacy and the flexibility of the proposed wavelet packet based mechanism. The Bit Error rate (BER) performance is shown to be comparable, and even at times better, to conventional Fourier based OFDM. Comparison of different family of wavelets has been carried out and Meyer wavelet seems to be the most suitable wavelet through simulation results.

Keywords: OFDM, Wavelet Packet Multicarrier Modulation, AWGN, CDMA, WCDMA, Orthogonality, BER, Meyer Wavelet, SINR.

Introduction

Recently, intense interest is focused on modulation techniques which can provide broadband transmission over wireless channels for applications including wireless multimedia, wireless local loop, and future generation mobile communication systems such as CDMA, WCDMA, 3G.

While standard single carrier modulation techniques (PSK, QAM ...) take advantage of a flat (narrowband) channel, multicarrier modulation is a technique to deal with non-flat broadband channels. It splits up the channel into a large number of sub channels which all can be considered flat, so standard QAM or PSK can be used in each sub channel. Multi-carrier modulation (MCM) technology was firstly brought forward in the 1960s, which was used to modulate signals. Multi-carrier modulation (MCM) is a spectral efficient modulation scheme which transforms the single high-speed serial signal to multiple parallel low-speed signals with different carriers, and then combines these signals to one serial signal for the further transmission. By transmitting simultaneously *N* data symbols through *N* carriers the symbol rate is reduced to the one of the original symbol rate, and therefore the symbol duration is increased by N times. This leads to a transmission system which is robust against channel dispersions/fading, impulse noise and multipath interference. At the receiver port, it firstly demodulates the received signal to multiple low-speed signals with the help of the relevant carriers, and then transforms the multiple parallel low-speed signals to the high-speed original signal. The one-way symbol duration of the MCM is longer than that of the single-carrier modulation, which can effectively counteract the inter-symbol interference (ISI) and signal-to-interference-plus-noise-ration(SINR) caused by multipath transmission. MCM technique carries out the integral of numbers of symbol duration, which can effectively counteract pulse interference by dispersing effect of interference. Thereby, multi-carrier modulation technology is one effective high-speed transmission technology in wireless environment. Multicarrier modulation techniques, including orthogonal frequency division multiplex (OFDM) and wavelet packet division are among the promising techniques.

The Orthogonal Frequency Division Multiplexing (OFDM) is a MCM technique that is widely adopted and most commonly used today. In OFDM system, the modulation and demodulation can be implemented easily by means of IDFT and DFT operators. In such a system, however, the input data bits are actually truncated by **a** rectangular window and the envelope of the spectrum takes the forms of sinc (w) which create rather high sidelobes. This leads to rather high interference when the channel impairments can‘t be fully compensated. Time synchronization errors originating from misalignment of symbols at demodulator is a serious OFDM design consideration. This is because they cause Inter Symbol Interference (lSI) and Inter Carrier Interference (ICI) which severely degrade the OFDM performance. A lot of research energy has been expended to address this problem.

Wavelet transformation has recently emerged as a strong candidate for digital modulation. WPM was first proposed by Lindsey [1] in 1997 as an alternative to OFDM. The fundamental theories of OFDM and WPM have many similarities in their way of functioning and performance but there are some significant differences which give the two systems distinctive characteristics. OFDM makes use of

Fourier bases while WPMCM uses wavelet packet bases which are generated from a class of FIR filters called paraunitary filters. OFDM signals only overlap in the frequency domain while the wavelet packet signals overlap in both, time and frequency. Due to time overlap WPM systems cannot use cyclic prefix (CP) or any kind of guard interval (GI) that is commonly used in OFDM systems. OFDM utilizes CP to overcome interference caused by dispersive channels. The greatest motivation for pursuing WPM systems lies in the freedom they provide to communication systems designers. Unlike the Fourier bases which are static sines/cosines, WPM uses wavelets which offer flexibility and adaptation that can be tailored to satisfy an engineering demand. Different wavelets result in different subcarriers leading to different transmission characteristics [2].

In this paper we investigate the BER performance degradation of OFDM and WPMCM systems. Several well-known wavelets such as Haar, Symlets, discrete Meyer and Biorthogonal wavelets are applied and studied. To simplify the analysis the channel is taken to be additive white Gaussian noise (AWGN) and perfect frequency synchronization is assumed. The paper is organized as follows: theory on OFDM and MCM are given from section II-VII. The system block of Meyer based WPMCM is outlined in Section VIII.WPMCM transmitter, AWGN channel and WPMCM receiver is outlined in section IX, X and XI respectively. Finally section XII shows results obtained by computer simulations and is followed by section XIII which concludes the paper.

OFDM and Multicarrier Modulation

Recently, a worldwide convergence has occurred for the use of *Orthogonal Frequency Division multiplexing(*OFDM) as an emerging technology for high data rates. In particular, many wireless standards (Wi-max, IEEE802.11a, LTE, DVB) have adopted the OFDM technology as a mean to increase dramatically future wireless communications. OFDM is a particular form of Multi-carrier transmission and is suited for frequency selective channels and high data rates. This technique transforms a frequency-selective wide-band channel into a group of non-selective narrowband channels, which makes it robust against large delay spreads by preserving orthogonality in the frequency domain. Moreover, the ingenious introduction of cyclic redundancy at the transmitter reduces the complexity.

Multicarrier modulation splits the broadband channel into a large number of (narrowband) subchannels. The total bitstream is divided over these subchannels. These bits are modulated per subchannel onto a subcarrier with standard narrowband modulation techniques like PSK or QAM. The sum of all the modulated subcarriers forms the composite multicarrier signal that is sent over the channel.

When the subcarriers are orthogonal, the subchannels may overlap without interfering each other, resulting in a high spectral efficiency (compared to e.g. frequency division multiplexing, where all the subchannels are separated by guard bands to prevent interference). The generation of these subcarriers is done in the digital domain, so that only one global local oscillator is needed instead of one for each subcarrier. Normally the Fourier Transform is used. An IFFT multiplexes the different mapped subcarriers to a composite signal that is modulated onto the global carrier and sent over the channel. At the receiver, the signal is demodulated by the local oscillator; the sub channels are demapped by applying an FFT to the composite signal and taking a decision in each sub channel. Because of the orthogonality of the transform, the different sub channels do not interfere.

Modulation of a subcarrier is split into two processes: mapping the bits to the constellation of the modulation technique, followed by modulation onto the one global carrier after performing the transform, on all mapped symbols. The channel is of course not ideal. The signal suffers from ISI (inter symbol interference), SINR and ICI (inter carrier interference), which comes from the loss of orthogonality due to the channel effects. To replace the Fourier Transform by a transform that is less susceptible to all these channel effects, that can easily compensate for the resulting effects is the Wavelet Transform. Its longer basis functions allow more flexibility in the design of the waveforms used, and can offer a higher degree of sidelobe suppression. This is very important, since loss of orthogonality then results in less interference. Also narrowband interferers in the channel corrupt less subchannels, so less capacity is lost when such interferers are present [3].

Wavelet Vs. Wavelet Packet

Wavelet packet Transform offers a richer signal analysis than Wavelet Transform. Wavelet packet tree allows focusing on special parts in time-frequency domain in a more detailed way than is possible with ordinary wavelet transform [4].

A wavelet packet is a generalization of wavelets in that each octave frequency band of the wavelet spectrum is further subdivided into finer frequency bands by using the two-scale relations repeatedly. The translates of each of these wavelet packets form an orthogonal basis. We can decompose a signal into many wavelet packet components.

A signal maybe represented by a selected set of wavelet packets without using every wavelet packet for a given level of resolution. The good frequency characteristics and greater flexibility offered by wavelet packet transform make it an attractive choice for a high data rate transceiver in fading channel conditions.

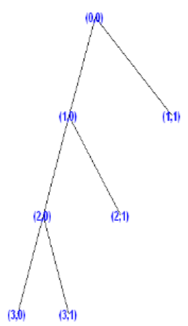

Figure 1: Wavelet tree

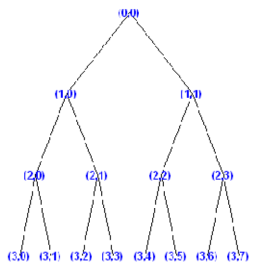

Figure 2: Wavelet packet tree

The WPT branch has a uniform frequency resolution.

Uniformity comes due to the same manner of decomposition in both low and high frequency components.

Comparing with Wavelet Transform, filter bank implementation of Discrete Wavelet Transform (DWT) performs iterative decomposition only on the low pass filter output. Thus we see non-uniformity in the frequency resolution of DWT. The output of each wavelet packet node corresponds to particular frequency band whereas outputs at wavelet packet nodes in the same level have evenly spaced frequency bands.

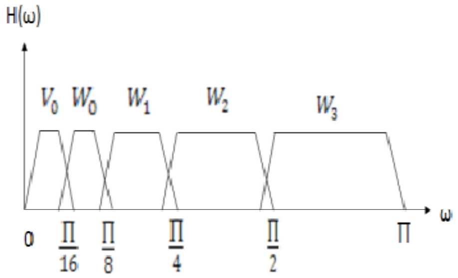

Figure 3: Frequency bands spanned by DWPT``

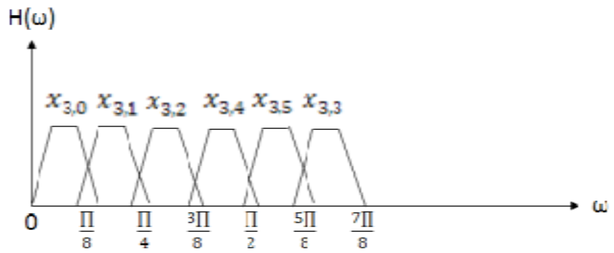

Figure 4: Frequency bands spanned by DWT

Generation of Wavelet Packet Bases

The subcarrier signal waveforms in traditional MCM implementations, such as OFDM, are sine/cosine basis functions. In WP-MCM the sub-carrier waveforms are derived from poly-channel tree structures built by cascading multiple two-channel filter banks. A two-channel filter bank consists of a set of four perfect reconstruction filters (two high pass and two low pass) which allow the decomposition and reconstruction of a signal without amplitude or phase or aliasing distortion . The two-channel filter bank has the property of splitting the signal into two lower resolution versions – namely the coarse (low pass) and the detail (high pass). When the decomposition into course and detail components is continued iteratively, it leads to the generation of wavelet packet bases. When the perfect reconstruction filters used satisfy an additional property known as paraunitary condition, they lead to wavelet packet bases with impulse responses that are mutually orthogonal to one-another and to their duals. The wavelet packet sub-carriers (to be used at the transmitter) are generated from the synthesis filters (*H'* and *G'*). The synthesis procedure at each level consists of binary interpolation (upsampling) by 2, filtering and recombination. And the wavelet packet duals (to be used at the receive analysis filters (*H* and *G*) through the analysis procedure which consists of filtering, decimation (down-sampling) by 2 and decomposition at each stage [5].

WPMCM, Wavelets and Filter Criteria

By adapting the filters one can conceive a WPMCM transceiver that best handles a system specification. The design of wavelets is bounded by multiple constraints. The constraints include properties such as orthogonality, compact support, symmetry, and smoothness and are usually stated in terms of the scaling filter $h[n]$ [6].

1) *Wavelet Existence and Compact Support*: This property ensures that the wavelet has a finite number of non-vanishing coefficients and the filters are of finite length. Wavelet existence imposes a single linear constraint on h[n]

$$\sum_{n=0}^{L-1} h[n] = \sqrt{2} \qquad (1)$$

2) *Paraunitary Condition*: The paraunitary condition is essential for many reasons. First, it is a prerequisite for generating orthonormal wavelets. Second, it automatically ensures perfect reconstruction of the decomposed signal i.e. the original signal can be reconstructed without amplitude or phase or aliasing distortion. To satisfy the paraunitary constraint the scaling filter coefficients have to be orthogonal at even shift.

$$\sum_{n=0}^{L-1} h[n]h[n-2m] = \delta[m]\begin{cases} 1 & if\ m=0 \\ 0 & otherwise \end{cases} \qquad (2)$$

3) *Flatness/K-Regularity*: This property is a rough measure of smoothness of the wavelet. The regularity condition requires that the wavelet be locally smooth and concentrated in both time and frequency domains. It is normally quantified by the number of times a wavelet is continuously differentiable. The simplest regularity condition is the *flatness* constraint which is stated on the low pass filter. A LPF is said to satisfy *K*th order flatness if its transfer function $H(\omega)$ contains K zeroes located at the Nyquist frequency

($\omega = \pi$). For any function $Q(\omega)$ with no poles or zeros at ($\omega = \pi$) this can be written as

$$H(\omega) = \left(\frac{1+e^{j\omega}}{2}\right)^k Q(\omega) \qquad (3)$$

Parameter K is called the regularity order and for a filter of length L its degree is limited by $1 \leq K \leq L/2$. In the time domain we can impose regularity condition.

$$\sum_{n=0}^{L-1} n^k (-1)^n h[n] = 0 \qquad for\ k = 0,1,\ldots,K-1 \qquad (4)$$

K-Regularity condition enforces K constraints on $h[n]$.

Choice of Wavelet Bases for WPMCM

The nature of the subcarrier signal waveforms greatly influence the performance of the MCM system and the wavelet basis and hence the filter pairs .In an ideal scenario the filter banks used to generate the wavelets have zero transition bands. Under such an ideal scenario the wavelet packet bases derived from a level-*i* decomposition have confined spectral footprints with bandwidth (1/2*i*) times that of the Nyquist frequency. However, available wavelet families are derived from filter banks that have a wide transition band and hence the resultant wavelet sub- carriers have a dispersed spectrum with footprints spilling into neighbouring regions. The wider the transition bandwidth the greater the dispersion of the carrier‘s spectral footprint and therefore the greater the difficulty in isolating those subcarriers that fall in the adjacent spectra. This greatly reduces the efficiency of the system. It is therefore important to design filter banks that have narrow transition bands. With regard to the applicability to WP-MCM systems, the desirable properties of the wavelet bases are: [5]

- They must be time-limited and smooth
- Must be well confined in frequency.
- The wavelet packet bases and their duals must be orthogonal (or at least linearly independent) to one another to enable perfect reconstruction.
- The carriers must be orthogonal (or at least linearly independent) to one another in order to have unique demodulation.
- Desirable wavelet functions have both compact support & symmetry with respect to the centre.
- Symmetric wavelet functions decay very fast.

Considering these requirements, among several available wavelets such as: Coiflets, Daubechies, Haar, Symlets, we have chosen the Meyer wavelet as it has proved to be the most suitable wavelet through simulation results that will be elaborated in further discussion. Let us see some properties of the Meyer wavelet:

- It is frequency band limited function whose Fourier transform is relatively smooth providing faster decay in time.
- It‘s scaling function has a compact support & is defined as

$$\phi(t) = \frac{\sin(\pi(1-\beta)t) + 4\beta t\cos(\pi(1+\beta)t)}{\pi(1-(4\beta t)^2)t} \quad (5)$$

where, ϕ (t) represents the scaling function and β represents the scaling factor. Usually β=1/3.It‘s wavelet function is given by

$$\psi(t) = \frac{\sin[2\pi(1-\beta)(t-1/2)]+8\beta(t-1/2)\cos[2\pi(1+\beta)(t-1/2)]}{\pi\{1-[8\beta(t-1/2)]^2\}(t-1/2)} \quad (6)$$

where Ψ(t) represents the wavelet function.

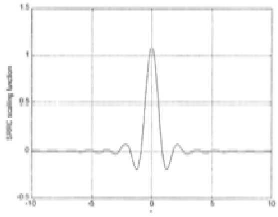

Figure 5 : Scaling function

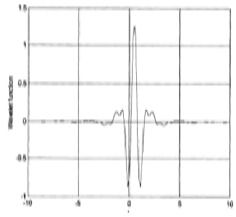

Figure 6 : Wavelet function

Perfect Reconstruction

An important issue in designing the multicarrier system is to obtain perfect reconstruction when the channel is not ideal. For perfect reconstruction in most Wavelet Packet Transform applications, the original signal can be synthesized by wavelet filter co-efficients. To actually implement the transform, one has to consider its end-effects. At the beginning and the end of a packet being sent, there is a sudden transition between no signal and signal-values creating unwanted high frequency peaks Also, implementing the Wavelet Transform comes down to performing convolutions which extend signal length (the number of non-zero signal-values). If we keep the extra values, and perform the inverse transform, we again introduce extra values at the edges. But we get perfect reconstruction and al1 the extra values at the edges are zero and can be discarded. In a way, these extra values can be seen as a small drawback and loss in performance [7].

In order to achieve the perfect reconstruction of original signal, certain wavelet conditions are to be satisfied out of which first condition says that the reconstruction is perfect and second says that it is aliasing free reconstruction. For perfect reconstruction the wavelet based transmultiplexer utilizes transmitting and receiving filter banks.

Wavelet Packet Based Modulation Scheme

The wavelet packet theory can be viewed as an extension of Fourier analysis. The basic idea of both transformations is the same: projecting an unknown signal on a set of known basis functions to obtain insights on the nature of the signal. Wavelet Packet modulation is an orthogonal multi-carrier modulation technique which is based on the wavelet packet transform. In the transmitter, a set of high speed input signals is converted into several low speed data streams by S/P (Serial to Parallel) conversion, all the sub-carriers are modulated by QAM or PSK. These wavelet packet sub-carriers (used at the transmitter end) are generated from the synthesis filters. Then by Inverse discrete wavelet packet transform (IDWPT), the wavelet packet modulation signal is obtained. At the receiver, by discrete wavelet packet transform (DWPT), QAM or PSK demodulation and P/S conversion, the original transmitted data can be obtained. And the wavelet packet duals (used at the receiver end) are obtained from the analysis filters given by equation:

$$S(n) = \sum_{u} \sum_{k=0}^{N} a_{u,k}\,\xi^{k}_{log_2(c)}(n-uN) \quad (7)$$

In equation (7), N denotes the number of subcarriers while *u* and *k* are the symbol and subcarrier indices, respectively. The constellation symbol modulating *k*th subcarrier in *u*th symbol is represented as *au, k*. The sub-index log2 (*N*) denotes the levels of decomposition required to generate *N* subcarriers.

Time and frequency limited wavelet packet bases ξ (t) can be derived by iterating discrete half-band high g[n] and low-pass h[n] filters, recursively defined as:

$$\xi_{l+1}^{2p}(t) = \sqrt{2}\sum_{n} h[n]\,\xi_{l}^{p}(t-2^{l}n) \qquad (8)$$

$$\xi_{l+1}^{2p+1}(t) = \sqrt{2}\sum_{n} g[n]\,\xi_{l}^{p}(t-2^{l}n)$$

In equation (8), l denotes the level in the tree structure, superscript p denotes the sub-carrier index at given tree depth and h[n]and g[n] represent the low pass and high pass analysis filters respectively [6].

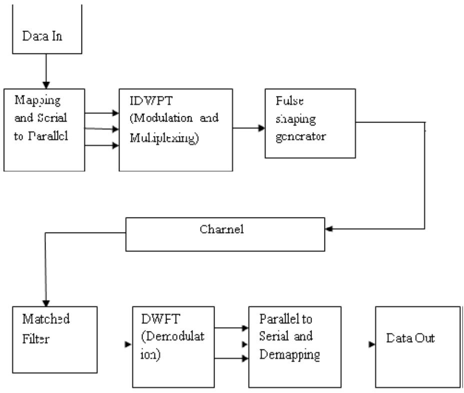

Figure 7: Block diagram of WPMCM

WPMCM Transmitter

WPMCM employs Inverse Discrete Wavelet Packet Transform (IDWPT) at the transmitter side. The IDWPT is implemented by wavelet packet synthesis filter bank which combines different parallel streams into a single signal. As shown in figure 8. the up sampling and downsampling operations by a factor 2 are represented by ↑2 and ↓2 respectively, while filter _g‘ stands for high-pass filter and filter _h‘ stands for low pass filter.

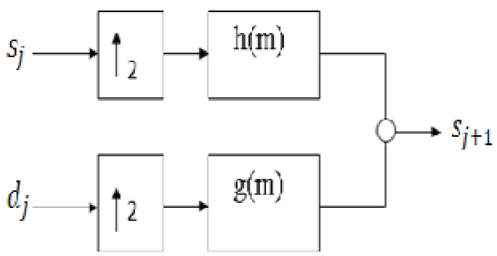

Figure 8: Synthesis or reconstruction of signal. The up arrow represents the interpolation by 2. h(m) and g(m) denote the frequency responses of the low and high pass reconstruction filters, respectively.

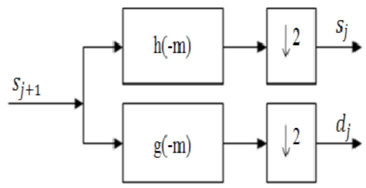

Figure 9: Analysis or decomposition of signal. The down arrow represents the downsampling by 2. h (-m) and g(-m) denote the frequency responses of the low and high pass decomposition filters, respectively

Because WPMCM transceivers are realized by an iterative method we can easily change the number of subcarriers and their bandwidth. By performing an addition alteration of two-channel filter bank at all outputs the subcarriers number is doubled or more generally the number of subcarriers is given by *N*=2*l*.

The subcarriers in WPMCM transceivers are completely determined by filters *H* and *G* and therefore by applying different set of filters we get different subcarriers which in turn lead to different transmission system characteristics. By just altering the filter coefficients the WPMCM transceivers are capable to achieve different values for bandwidth efficiency frequency concentration of subcarriers, low sensitivity to synchronization errors, low PAPR, etc. WPMCM signal in the discrete time domain can be expressed as:

$$X[n] = \sum_{u} a_{u,k} \sum_{k=0}^{N-1} \xi_{2\log N}^{k}(n-uN) \qquad (9)$$

Where k denotes the subcarrier index. u denotes the WPMCM symbol index. The constellation symbol modulating *k*th subcarrier in uth WPMCM symbol represented by [8].

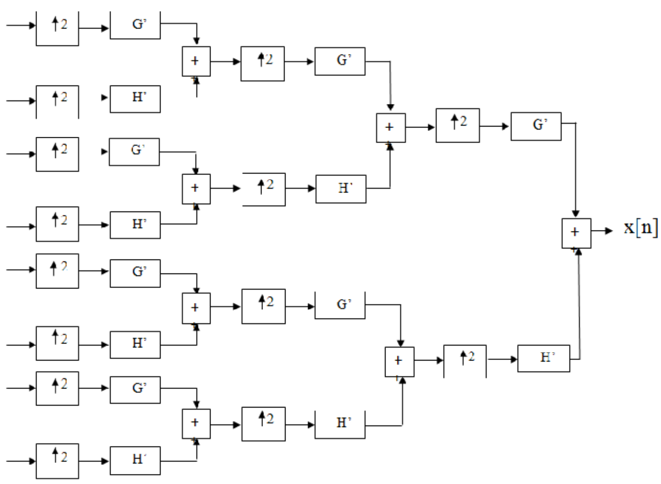

Figure 10: Synthesis using IDWPT where, G‘=low pass synthesis filter and H‘=high pass synthesis filter and x[n] =reconstructed signal

AWGN Channel

After implementing system and confirming that we get perfect reconstruction (with negligible round off errors), the first thing we studied was the behaviour when simple standard AWGN is present on the channel. This is expected to give exactly the same results as in the single carrier case, since the subcarriers should not interfere with each other .The bi-orthogonality of the basis function is clearly not suited here. If everything was orthogonal as in the FFT case, AWGN would stay AWGN on each subcarrier, and subcarriers would remain orthogonal, resulting in the same performance as in the single carrier case. The fact that the basic functions used to create the different waveforms in each sub-channel are not orthogonal to each other, causes the AWGN to become correlated within the sub-channel, which is of course no longer orthogonal . Also the basis functions are not orthogonal to basis functions in other sub-channels, which also translate in some kind of interference of the AWGN between different sub-channels.

This seems to be price to pay for using bi-orthogonal basis functions. Resistance against other channel impairments, like narrowband interference, should therefore offer more performance gain in order to consider wavelets as an alternative to the standard Fourier Transform.

WPMCM Reciever

WPMCM employs Discrete Wavelet Packet Transform (DWPT) at the receiver side. The composite signal is afterwards decomposed at the receiver using wavelet packets analysis filter bank or so called DWPT. The receiver demodulates the data by employing time reverse diversion of waveforms used by the transmitter. If we assume that the WPMCM transmitter and receiver are perfectly synchronized and channel is ideal, the detected data at the receiver is shown below.

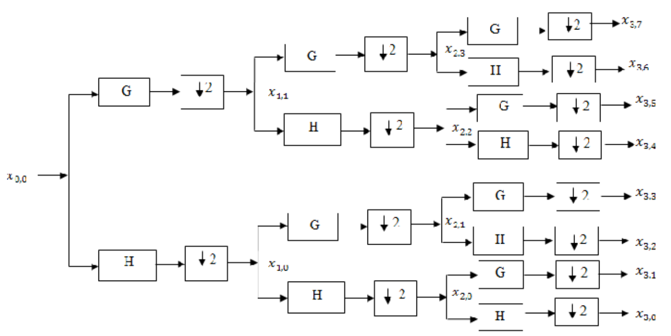

Figure 11: Recovery of data symbols using analysis filter bank. Analysis done using DWPT where G=low pass analysis filter H=high pass analysis filter

Simulation Results

The proposed system of the WPMCM system is shown in Fig.7.The simulation results of this system are obtained by using MATLAB version 7 R2009a. The comparison between WPMCM and single carrier modulation systems such as QAM, PSK and DPSK is shown in fig. 12, 13 and 14.The comparison between Meyer based WPMCM is compared with 4-OFDM, 16-OFDM and 32-OFDM over AWGN channel environment in fig.15, 16 and 17 respectively It can be clearly seen that the BER of WPMCM is lesser than that using OFDM over the same SNR.By comparing the BER for different wavelets such as Meyer wavelet, Haar wavelet, symlet wavelets, Meyer wavelet shows very less BER. we can conclude from the results shown in Fig. 18 that Meyer wavelet is most suitable wavelet than other orthogonal wavelets.

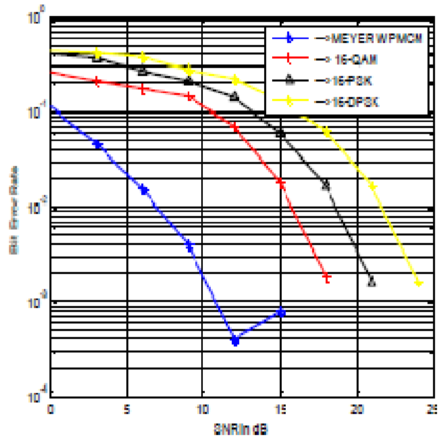

Figure 12: Bit Error Rate comparison between Meyer WPMCM (using 4- QAM), 16-QAM, 16-PSK and 16-DPSK

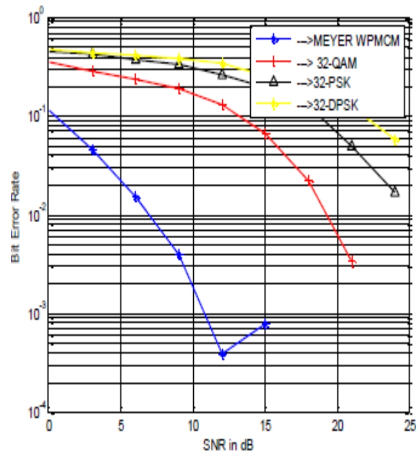

Figure 13: Bit Error Rate comparison between Meyer WPMCM (using 4- QAM), 64-QAM, 64-PSK and 64-DPSK

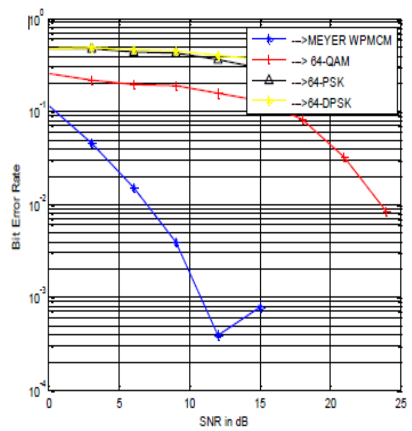

Figure 14: Rate comparison between Meyer WPMCM (using 4- QAM), 64-QAM, 64-PSK and 64-DPSK

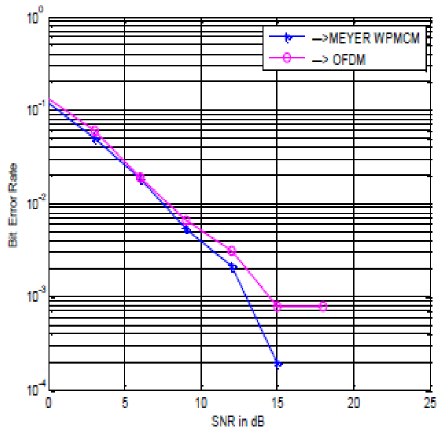

Figure 15: Bit Error Rate comparison between Meyer WPMCM (using 4- QAM) and OFDM (using 4-QAM)

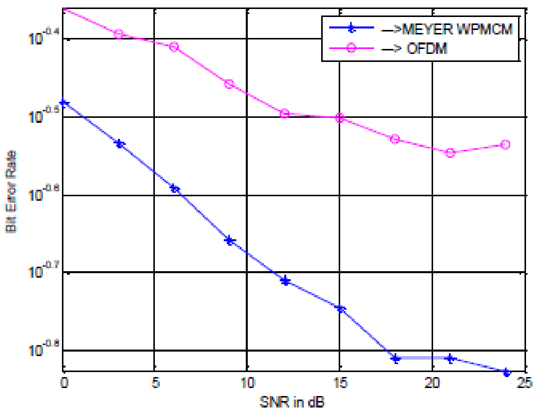

Figure 16: Bit Error Rate comparison between Meyer WPMCM (using 16- QAM) and OFDM (using 16-QAM)

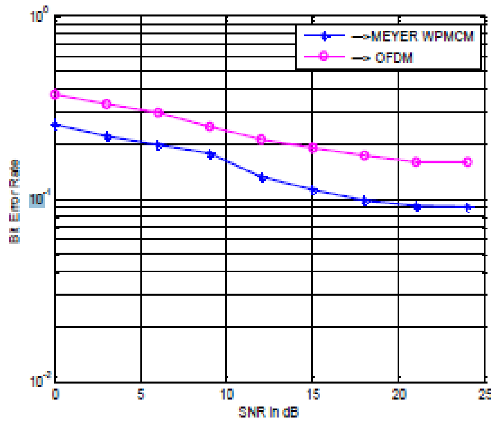

Figure 17: Bit Error Rate comparison between Meyer WPMCM (using 32- QAM) and OFDM (using 32-QAM)

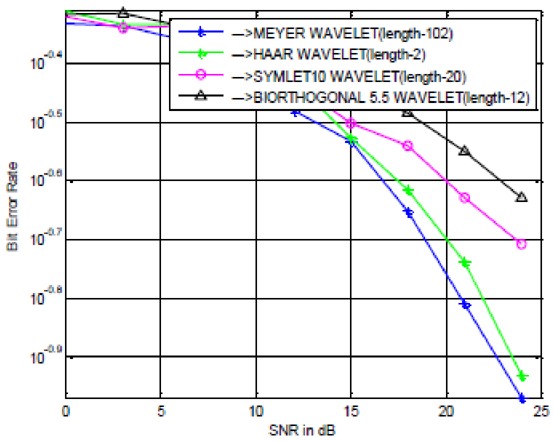

Figure 18: Bit Error Rate comparison between Meyer wavelet, Haar wavelet, Symlet wavelet and Biorthogonal wavelet (using 64-QAM)

Table II demonstrates the text transmission and reception.

Original text	**WPMCM**
SNR=12 db for WPCM. OFDM as well as 16 QAM	No of characters with errors Num=0 Rate of error, rt=0
OFDM	**16-QAM**
No of characters with errors Num=1 Rate of error, rt=0.0034	No of characters with errors Num=45 Rate of error, rt=0.1536

Conclusion and Future Scope

OFDM and WPMCM have recently emerged as strong candidates for multicarrier systems. WPMCM shares most of the characteristics of an orthogonal multi carrier system and in addition offers the advantage of flexibility and adaptation. The important points during simulation and discussion of the results are given below:

1. This paper presents an introduction to OFDM, WPMCM. WPMCM transmitter and receiver are described and the roles of main signal processing blocks are explained. After comparing WPMCM with various other transmission techniques like QAM, PSK, DPSK, OFDM, it can be inferred that WPMCM has a lower BER. Hence it proves to be a more promising modulation technique for future communication systems
2. The performance results of WPMCM lead us to conclude that this new modulation scheme is viable alternative to OFDM to be considered for today's communication systems. WPMCM remains nevertheless a strong competitor which offers a lot of flexibility and adaptability thanks to its simplicity and elegance.

These properties can make it suitable for the design and development of communication systems for the future (Cognitive Radio and 4G).Wavelet Packet Modulation with adaptive filter gives very good performance even under very low SNR conditions. These wavelet packets are more immune to inter symbol interference (ISI) and inter channel interference (ICI). By altering the design specifications a wavelet based system that is more robust against synchronization errors could be developed without compromising on spectral efficiency or receiver complexity. The design and development of new wavelets which handle timing offset is in itself a separate topic for discussion and a future topic for research.

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