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A Survey on OFDM Systems based on Wavelets

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Abstract— The orthogonal frequency division multiplexing is used in wireless communication due to high data rate. OFDM are robustness against multi-path fading, frequency selective fading, and narrow band interference. Wavelet analysis has strong advantages over fourier transform and also allows time-frequency domain operation with flexibility. Wavelet is applied in various fields of wireless communication systems including OFDM. In this paper, various wavelet based OFDM algorithms presented, such as OFDM System using Wavelet Packet OFDM, Complex Wavelet Packet Modulation, Complex Wavelet Transform, Haar Wavelet-Based BPSK OFDM System and Wavelet Transform in MIMO-OFDM Systems.

Index Terms— OFDM, Wavelet, Haar Wavelet, Complex Wavelet Transform.

1 Introduction

Orthogonal Frequency Division Multiplexing (OFDM) introduced in the year 1960, based on the multicarrier modulation techniques used in high frequency range for military application. In the year 1971, the basic idea created based on Discrete Fourier Transform (DFT) for the implementation of OFDM and removing the requirement for banks in the analog subcarrier oscillators [1]. It is very useful for an easy implement of OFDM and Fast Fourier Transform (FFT) with an efficient development of DFT. The implementations of orthogonal frequency division multiplexing suggested, along with Digital Signal Processing (DSP) and FFT algorithms. The development of OFDM is cost effective due to integrated circuits. At the early stage of OFDM system, the digital signal processing is not allowed to use broadly. After 1980s, the OFDM system used for commercial purpose, which is used in digital audio broadcasting systems [2]

OFDM system is one of the most useful technologies for the present and future wireless communications. The data bits are encoded to multiple sub-carriers using multicarrier modulation technologies when being sent simultaneously [3]. The each sub carrier in an OFDM system is modulated with amplitude and phase using the data bits. There are various modulation techniques used, such as Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation (QAM), 8-QAM, 16-QAM, 64-QAM, etc., when merge different subcarriers, a composite time-domain signal is obtained using Fast Fourier Transform (FFT) and Inverse FFT (IFFT) operations[1]. The design of a communications system is one of the problems, when a wireless link is to deal with multi-path fading due to a significant degradation in terms of both the data rate and reliability of the link. Eventhough the Wireless Communication Systems like OFDM can reveal efficient bandwidth it makes deteriorate effect on performance by multi-path fading channels. Forever, to enhance the performance there is a need in development to recognize the system in addition a well organized channel estimation and equalization methods [5]. Enormous standards adopt OFDM modulation methods due to the construction of OFDM receiver conflict channel delay spreads by fairly straightforward signal processing [6,7].

Flat and time-invariant channel maintain orthogonality property over a radio channel signal transmission but in case of Doppler spread and consequent time variations in channel distort the property of OFDM sub-carrier waveforms [1]. The relevant sub-carrier casing Inter Symbol Interference (ISI) in addition with unlike sub-carriers casing Inter Carrier Interference (ICI) will have self-interference occur along with successive symbols in the dispersive channel. This is avoided in time-invariant frequency-selective channel [8].

The conventional orthogonal frequency division multiplexing / Quadrature amplitude modulation systems are hearty for multipath channels because of the frequently prefixed guard intervals that inserted between subsequent symbols to remove the ISI. However, guard interval decreases the spectral efficiency of the orthogonal frequency division multiplexing system [9]. There are many approaches of wavelet based orthogonal frequency division multiplexing and no need to use the guard interval [9-15]. From the observation the OFDM, system using haar orthonormal wavelets are capable of removing the ISI and ICI.

There are many researchers have involved the use of wavelet based to swap fourier transform based OFDM and wavelet based OFDM has more advantages than fourier transform based OFDM. A few researchers have done comparisons

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between discrete multitone (DMT) and discrete wavelet multitone (DWMT) systems [16],[17],[18],[19].

The orthogonal frequency division multiplexing is a very great deal of concentration and effective in the frequency selective channel. The OFDM system offers higher data rates due to the advantage of Digital Signal Processing (DSP) and RF technologies. This is very good option for service providers with wire-line carriers [20].

2 Wavelet Packet OFDM Synchronization

In wavelet packet approach [21], the signal is implied using a recursive filter-bank for a sequence of length 8. The transmitter obtains each data symbol of the time domain sequence, upsample and filters them. The obtained odd sequences are added to the even sequences obtained, and then they upsampled and filtered. This process continuous until the obtained sequence is equal to the time sequence length. In this case, the time/frequency representation leads to a more complex structure than the earlier methods. The receiver part computes the decomposition to convert the data back in the frequency domain. The received OFDM symbol then filtered, and each filter output is downsampled and filtered again until 1-symbol sequences obtained. These sequences are then concatenated to form the original time sequence.

For synchronization, wavelet Packets does not need Cyclic Prefix, leading to an improved symbol rate. The filter bank concept brings some typical advantages for implementation in systems such as FPGAs and it is also possible to vary the OFDM symbol length which allows adding or removing a filter. In Wavelet Packet OFDM [29], a particular rapport between each coefficient and the transmitted sequence can be outlined (e.g. (9), where a[n] be the original symbols and b[n] the received coded symbols, n = 0, . . .N −1, with N the frame size). From this observation it is possible to build a Maximum Likehood (ML) function that allows synchronization using few symbols, and before the DWT. For example the ML function can be taken as the squared difference sum between the received symbol and the synchronization data, yielding (10) for a synchronization using the first two data (thus a[0] and a[1] are fixed and known), with K an arbitrary value representing the detection sensitivity. The simple relationship thus allows a fast and efficient synchronization. But robustness and efficient data rate will form a trade-off and ML algorithm automatically takes into account the non-integer offsets. Then the average BER and resulting offset values calculated for each offset. The frame size taken is 256 symbols and the interpolation made using upsampling and FIR filtering on 8 points. The Signal to Noise Ratio taken is 20 dB over an additive White Gaussian Noise (AWGN) channel. The symbols are coded using QAM-16 modulation.

In [21] for each SNR value, ten randomly chosen offsets applied and the sequences are chosen randomly for the first set of results, there will be a coupling between two values of two successive sequences. Thus, an error is not identified always. Finally the probability of false offset identification increases with the offset raises the hitch of synchronization, which is previously a problem for classical Fourier OFDM, but has greater impact in wavelets domain. The synchronization problem is well resolved, and the robustness is acceptable in traditional environment but it has to be enhanced**.**

3 Complex Wavelet Packet Modulation (CWPM) in OFDM

In [22], two filter banks are used in Complex Wavelet Packet Modulation (CWPM) system. One of the filter bank at the transmitter side adopts Inverse Discrete Wavelet Packet Transform (IDWPT) and the other one at the receiver side performs Discrete Wavelet Packet Transform (DWPT). The two inputs of "MAKE CMPLX" block are N-dimensional real vectors. The real elements of the *ith* vector of two input will form *ith* complex element of an N-dimensional complex output vector. Two IDWPT blocks, one block for real and another for imaginary symbols where the inverse wavelet transform get the input as DQPSK complex symbols. The transmitted signal $x[n]$ is obtained by combining the outputs of two IDWPT together in complex form. Finally, the individual N waveforms $\varphi j[k]$ modulated with DQPSK symbols are summed to obtain the transmitted signal. The transmitted signal discrete representation created by IDWPT as the time shifted sum of N waveforms which insert information about data symbol. Finally, the transmitted symbols $a_{k,j}$, $b_{k,j}$ recovered by DWPT at the receiver side by utilizing the orthogonal property in analysis formula. The CWPM system has performance better than the conventional OFDM but similar to the performance of WPM.

4 OFDM System using Complex Wavelet Transform

In [23], the Subcarriers are generated and identified using Fourier Transform (FT) in Conventional Orthogonal Frequency Division Multiplexing (OFDM). This can be done using an Inverse FFT / FFT has the hitch that it adopts rectangular window, which produces high side lobes. The subcarrier modulation has employed with the pulse shaping function to extend them to infinity in the frequency domain. This causes high interference and the performance levels are also degraded. Dual Tree Complex Wavelet Transform (DTCWT) used instead of Fast Fourier Transform (FFT) in wavelet based OFDM to limit the interference and also improve performance level. The use of DTCWT also reduces Peak-to-Average Power Ratio (PAPR) in OFDM system which surpasses the Wavelet Packet Transform (WPT) and FFT/

IFFT.

In digital image processing the Complex Wavelet Transform (CWT) is widely used. Kingsbury [24-28], provided the actual explanation of DTCWT in image processing. Two real DWTs adopted in DTCWT where the real part of the transform will be upper one and the lower one confers the imaginary part.

DTCWT basis function based Inverse DTWCT (IDTWCT) used for multiplexing in Complex Wavelet Modulation (CWM). The spectral efficiency of wavelet modulation is high since out-of-band energy is low and their consideration to Inter Carrier Interference (ICI) is also low. The Filter Bank (FB) construction arrangement flexibility in wavelet modulation can putrefy time frequency plane. The resolution in FFT based OFDM system will be only in frequency domain while that of WT based OFDM system has both in frequency and time domains. Even in tone/impulse interference the wavelet modulation obtains good performance due to inherent flexibility.

The result given under this section compare the PAPR in OFDM based on DTCWT, with that for conventional OFDM, and WPM. To be able to make a fair comparison, the same simulation parameters are used. The simulation parameters are as follows: Modulation type is 16-QAM; 64 subcarriers; Daubechies-1 (DAUB-1) wavelet packet base; PAPR threshold level is 2dB; shaping filter is Raised Cosine (α=0.01, upsamler = 5)

The results show that this new scheme gives about 2dB improvement in PAPR reduction over the conventional OFDM and WPM systems. From the results, the conventional OFDM and WPM systems have produced same results in PAPR reduction.

5 Haar Wavelet-Based BPSK OFDM System

In [29], Haar Wavelet Transform based BPSK OFDM system have been adopted. The sequence of data symbols are decomposed after mapping of binary to complex shows one part of the data symbols are zeros and the other part of the data symbols are either $\sqrt{2}$ or $-\sqrt{2}$. As compare to FFT-OFDM the PAPR reduced by 3dB in case of Haar wavelet based OFDM system. Then the robustness of the system checked with the traditional OFDM system which uses a decoding algorithm for the improvement and derived the bit error rate (BER) performance using unbalanced QPSK modulation. The BER performance shows a better result for the proposed work than the conventional OFDM over different channels.

6 Wavelet Transform in MIMO-OFDM System

In [30], OFDM technology combined with wavelet transform to remove the worst multipath fading channel characteristics. Many versions of RF carriers transmitted with the wavelet transform techniques so that fading condition in one carrier frequency will not affect the rest other frequencies when deep fading is applied. The result also shows a satisfactory BER performance with low SNR value. If SNR = 4dB, BER will be in the order of 10-6 using two transmitting antennas and two receiving antenna which means that this system will be efficient for heavy packet transmission corresponding to voice, video, or multimedia communication systems.

7 Wavelet in Multiuser OFDM with MIMO

In [31], Wavelet based on OFDM system with beam former and MIMO configuration is projected. The proposed method is a multiuser environment of interfering users, where the user will have more number of antennas to communicate with a base station equipped with more number of antennas. A beamforming technique proposed in this paper is based on Signal-to-leakage ratio maximization to examine the multiuser system. The number of antennas used either at base station or receiver side without any limitation produces better performance in WOFDM than the traditional FFT based OFDM.

8 Conclusion

OFDM is one of the techniques in wireless communication systems, which is used for high speed data transfer. In OFDM, the use of wavelet has improved the system performance and made it robustness against multi-path fading, frequency selective fading, and narrow band interference. In this paper, a study of various wavelet techniques used in OFDM such as Wavelet Packet OFDM, Complex Wavelet Packet Modulation, Complex Wavelet Transform, Haar Wavelet-Based BPSK OFDM System and Wavelet Transform in MIMO-OFDM Systems are presented and also the complexity of the system is analyzed. Thus the Haar Wavelet-Based BPSK OFDM is better in Performance and the complexity is less while compared with other techniques. Further the BPSK OFDM can replaced by MQAM and MPSK modulation techniques can be used to obtain better performance than the earlier.

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