Wavelet Based Multicarrier Modulation Schemes

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ABSTRACT
Recent developments in the field of wireless communication lead to demand for high data rate and efficient spectrum utilization. Selection of suitable modulation scheme plays an important role for data rate of communication systems and its spectral efficiency. In this paper, Orthogonal Frequency Division Multiplexing (OFDM), Constant Envelope OFDM (CE-OFDM), DFTS-OFDM and Filter Bank Multi Carrier (FBMC) are discussed. Wavelet based OFDM and FBMC are simulated in Matlab and results are compared with conventional FFT/IFFT based multicarrier modulation schemes. The system performance is evaluated using Bit Error Rate (BER) Versus Signal to Noise Ratio (SNR). The Wavelet Packet Transform (WPT) based Multicarrier Modulation Schemes (MCM) outperforms compared to conventional FFT and IFFT based MCM schemes.

KEYWORDS
Multicarrier modulations, Cognitive Radio (CR), WPT, OFDM, PAPR, BER, SNR, FBMC, CE-OFDM, DFTS-OFDM.

I. INTRODUCTION

The basic idea of CR in white space is to establish an opportunistic communication system in a given frequency spectrum which remains hidden from the primary systems. The opportunistic system scans the unused bands in the spectra which could be used for transmission. Naturally, there are many difficulties in doing this which have to be overcome such as spectrum sensing, spectrum management and spectrum allocation. The most prominent parameter is the selection of the applied modulation scheme so that need of huge data rate will be completed and also the efficient spectrum utilization will be carried out. In this paper brief overview and a comparison of the most desirable modulation schemes for white space applications are given. Four possible multicarrier modulation schemes are discussed here: Orthogonal Frequency Division Multiplexing (OFDM), DFT-Spread OFDM (DFTS-OFDM), Constant Envelope OFDM (CE-OFDM) and Filter Bank Multicarrier (FBMC). Each of these techniques has different sensitivity to the various impairments. The comparisons will be performed via spectral density functions and bit error rates (BER) [1].

Orthogonal Frequency Division Multiplexing (OFDM) is often preferred in wideband wireless communication systems because of its advantages discussed in [3]. Although OFDM has many advantages it also has some drawbacks: it is highly sensitive to nonlinear distortion, synchronization errors, moderate adjacent channel leakage and high peak to average power ratio (PAPR) [3]. Due to these phenomena several multicarrier schemes have been proposed which could compete with OFDM. Here three of the most promising alternatives are selected for investigation: Constant Envelope OFDM which has a major drawback of high PAPR value [4], DFT-Spread OFDM having slightly lower PAPR as compare to CE OFDM but data rate will be reduced by half [5], and the Filter Bank Multicarrier which has best spectral utilization with no data rate loss [6], [7].

Finally two of the most popular multicarrier modulation schemes are selected at random and are simulated to evaluate their performance parameters, one of which is wavelet based orthogonal frequency division multiplexing and other is filter bank multicarrier. Simulation results are compared with conventional FFT/IFFT based modulation schemes which shows that wavelet based multicarrier modulation schemes are far superior to that of their conventional counterparts.

This paper is organized in several sections as follows. In Section I introduction of whole idea is elaborated. Section II discusses the four modulation schemes mentioned above along with their advantages and disadvantages. To increase the system efficiency and to achieve other benefits given in [3], section III is introduced which uses DWT instead of conventional Fourier transform. Finally in section IV simulation results are shown and in section V conclusion is drawn.

II. CONVENTIONAL SYSTEMS

This paper deals with the three fundamental modulation schemes which are mainly used for cognitive radio in white spaces. Each scheme has its own advantages and disadvantages over other schemes. Detailed discussion of the above modulation schemes is given in upcoming section.

OFDM:

Cognitive Radio has been proposed as a promising technology to improve spectrum utilization. Highly flexible OFDM system is considered to be a good candidate for the Cognitive Radio baseband processing where individual carriers can be switched off for frequencies occupied by a licensed user. The block diagram of an OFDM transmitter is as shown in Figure 1.

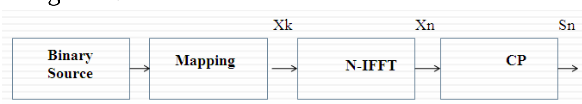

Figure 1: OFDM Transmitter [1].

The popularity of the system lies in the fact that the modulation and demodulation can be performed simply by using Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) respectively. The time domain samples of an OFDM symbol can be calculated using an N point IFFT as,

$$x_n = \sum_{k=0}^{N-1} e^{\frac{j2\pi nk}{N}} \quad \ldots\ldots\ldots\ldots (1)$$

Where, X_k is the complex modulation data for the subcarrier with index k. Then, prior to transmission, a Cyclic Prefix (CP) is added to each symbol. With the use of the CP the inter symbol interference can be overcome, but it reduces the effective data rate of the system.

CE-OFDM:

Objective of the CE-OFDM is to solve the problem of high PAPR values in OFDM signal. Constant envelope OFDM (CE-OFDM) transforms the OFDM signal, by way of phase modulation, to a signal designed for efficient power amplification [4]. The complex modulation symbols are aligned in a complex conjugated manner to achieve a real valued IFFT output as depicted in Figure 2.

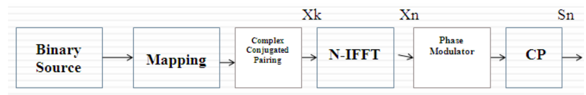

Figure 2: CE - OFDM Transmitter [1].

In CE-OFDM, the OFDM signal is embedded within the phase of a constant envelope carrier signal. The resulting CE-OFDM waveform alleviates the PAPR problem. The use of low modulation indices was deemed necessary to limit phase wrapping and the associated performance loss. Phase modulation is applied to the real-valued time domain signal and the CP is added to form the transmitted signal. The transmitted symbol s_n' before adding the CP can be expressed as:

$$S'_n = e^{j2\pi m x_n} \, , \quad \ldots\ldots\ldots (2)$$

Where, n = 0,1……. N-1 and m is the modulation index of the phase modulator and x_n is defined in (1) but with the restriction of $X_k = X^*_{N-K.}$

A noticeable disadvantage is that the complex conjugated pairing reduces the data rate by a factor of two. Then the phase modulator can be driven by this real valued signal that results in a constant envelope output signal. The power spectrum density (PSD) of the transmitted signal will be determined by the modulation index m of the phase modulator [1].

DFTS-OFDM:

In case of DFTS-OFDM systems [5], the complex modulation data set is pre processed, the complex modulation values which will be transmitted are grouped and a DFT is applied as shown in Figure3.

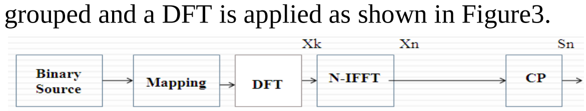

Figure 3: DFTS - OFDM Transmitter [1].

Then the output of the DFT is used to modulate the subcarriers. This technique can be also considered as a single carrier modulation scheme, where the frequency spreading is applied through all subcarriers. The result is a slightly lower PAPR value compared to OFDM transmission [1].

FBMC:

FBMC systems [6], [7] use a specially designed filter bank structure. First the complex modulation values are spread over several carriers and filtered by a prototype filter. This implies the necessity of a larger FFT to construct the transmission signal as shown in Figure 4.

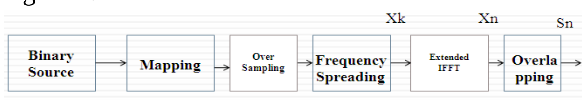

Figure 4: FBMC Transmitter [1].

Due to the advantageous properties of the prototype filter bank, the spectral band efficiency will be more efficient than the OFDM signal. With the use of an offset-QAM modulation, where the real and imaginary data values are offset by half symbol duration, no data rate loss will occur. Prior to transmission the symbols are overlapped in such a way that they can be separated at the receiver due to the fact that the filter bank is designed to fulfill the Nyquist criterion to minimize the inter-symbol interference [1].

Although the symbols duration is longer compared to OFDM symbols and they overlap, no data rate loss will occur. The other advantage of FBMC is that no CP has to be used to compensate the channel-induced inter-symbol interference. However, more complex signal processing has to be applied, and the channel equalization in the receiver chain will be more complex than in case of other schemes. With the use of a so called polyphase filter bank [7] the previously mentioned signal processing requirement can be reduced.

III. SYSTEM DESCRIPTION

Wavelet packet transform can be used instead of conventional Fourier transform, since Fourier transform involves large number of mathematical calculations and very high computational complexities. Key advantage of using wavelet instead of Fourier transform is its robustness against inter carrier interference (ICI).The performance of wavelet packet modulation (WPM) systems using several well known wavelets in the presence of timing offset is compared with OFDM. As a future work it will propose to design wavelet and scaling filters that would minimize the interference energy from timing error. Some key advantages of wavelet transform are configurable transform size, noise and interference suppression, robustness against ISI and ICI.

System description

At the transmitter the data stream X = (x[1], x[2], x[3], …, x[n], …, x[N],) is first converted from serial to parallel sequences S_k and then modulated with *M*-array inverse wavelet packet transform (IWPT). Figures 5 show the wavelet packet based MCM transmitter operating Mallat's fast algorithm [8].

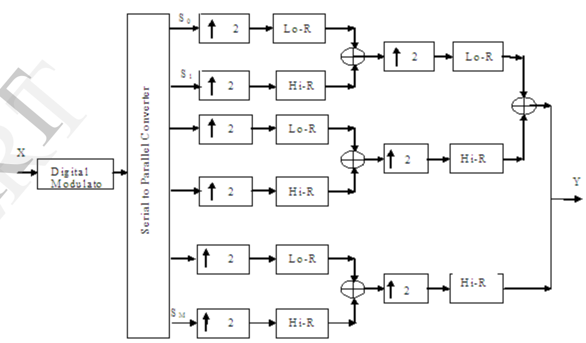

Figure 5: Wavelet Packet Based MCM Transmitter

The transmitted signal Y is composed of successive K symbols, as the sum of *M* amplitude modulated waveforms by Φ_K. It can be expressed using matrix notations as:

$$Y= \sum_k S_k \Phi_k \qquad .... (3)$$

Where Y= (y[1], y[2], y[3], …, y[n], …, y[N],) is transmitted signal, S_k= (s_0[k], s_1[k], s_2[k], s_M[k], s_{M-1}[k],) is constellation encoded K^{th} data symbol, and Φ_K is the waveforms matrix which $\Phi_m[n]$ are mutually orthogonal to reduce the symbol errors, i.e. $\Phi_m[n] * \Phi_m[n] = \Phi$ [i-j], Where * indicates a convolution operation and,Φ represents the Dirac function.

The relationship between the number of iterations *J* and the number of carrier waveforms *M* is given by $M= 2^J$.

IV. SIMULATION RESULT

OFDM in the time domain is equivalent to a sum of modulated sinusoidal carriers that are each windowed in time with a rectangular window function. This window defines the boundary of each OFDM symbol, and determines the frequency response of the generated OFDM signal. Figure 6 shows an example time waveform for a single carrier OFDM transmission.

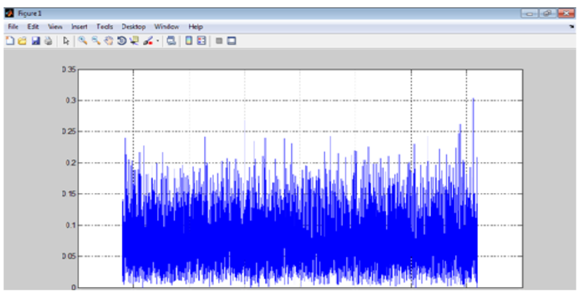

Figure 6: OFDM Signal.

Figure 7 shows the spectrum of a 52 subcarrier OFDM signal (same as HiperLAN2, or IEEE802.11a) with no band-pass limiting.

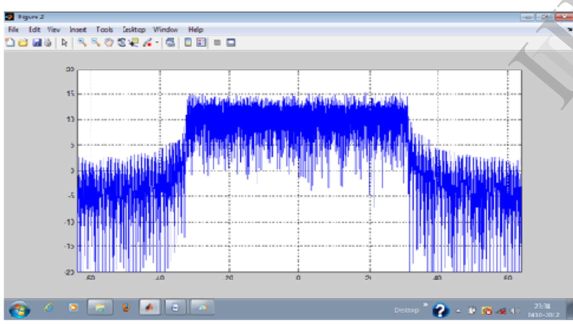

Figure 7: OFDM Spectrum.

The out of band components only fall off slowly due to the sincroll off of each subcarrier. The system performances are compared via the bit error rate as a function of signal to noise ratio (SNR).The values of SNR are computed as follows,

$$SNR_{dB} = 10 \log_{10}(E_b/N_0) \quad \ldots\ldots (4)$$

Where E_b is being bit energy and $N_0$is noise variance.

A simulation result of BER Vs SNR for wavelet based OFDM, FBMC and conventional FFT/IFFT based OFDM is shown in the figure 8. It is clearly seen that FBMC performs well as compared to others.

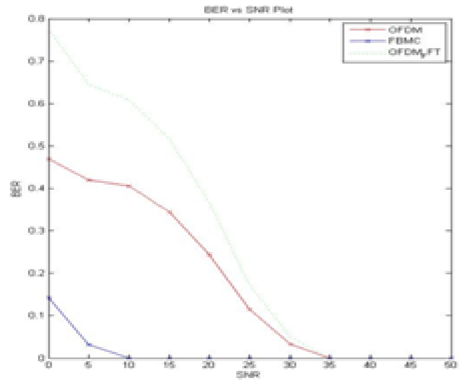

Figure 8: BER versus SNR for FFT OFDM, Wavelet Based OFDM and FBMC.

Bit error rate for wavelet OFDM at SNR value equals to 0 dB is 0.47 whereas for same SNR it is approximately 0.12 for wavelet FBMC. Hence as long as talking about BER Vs SNR, FBMC is far superior to OFDM as one always expect ideally 0 BER at lower SNR. For FBMC, the value of BER becomes zero at SNR equals to 10 dB, whereas it requires the SNR equals to 30 dB for OFDM.

Further if the comparison is made between conventional FFT based OFDM and wavelet based OFDM, it is clearly observed from the figure 5.6 that at 0 dB SNR, values of BER for FFT based OFDM and wavelet based OFDM are 0.78 and 0.47 respectively.

V. CONCLUSION

The analysis of four possible choices for the modulation scheme for cognitive radios in white space has been carried out. In this paper wavelet packet based multicarrier modulation scheme are recommended for high speed applications. It investigates the BER performance of WPMCM under AWGN channel model and wavelet families. BER improvement is achieved by WPMCM as compared to the conventional OFDM. The simulation result shows that wavelet based filter bank multicarrier modulation scheme outperforms compared to OFDM.

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