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A Review on wavelet transform as a substitute to cyclic prefix removal in FFT in OFDM

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Abstract

The performance and versatility of wireless communication effected by allocated spectrum for communication. The utility of spectrum depends on modulation technique and allocation process. In conventional OFDM modulation technique uses cyclic prefix (guard band) for prevention of interference in carrier signal. From that process waste some valuable bandwidth using cyclic prefix. Now in these day wavelet transform function replace FFT process for removal of cyclic prefix and improve the efficiency of bandwidth. Wavelet transform work in two different modes one is details (high filter) and another one is approximation (lower filter). The combination of low filter and high filter in form of wavelet transform and remove the cyclic prefix in OFDM modulation system. In this paper, we study of wavelet transform function such as DCT, WPT and IWPT instead of FFT.

Keywords: OFDM, FFT, Wavelet Transform.

Introduction

Now adays, wavelet transform function play an important role in field of communication, time series data analysis and image processing. In this section, we use to discuss the uses of wavelet transform function in OFDM modulation technique for wireless communication. However, such alternative methods have not been foreseen as of major interest and therefore have received little attention [4]. With the current demand for high performance in wireless communication systems, we are entitled to wonder about the possible improvement that wavelet-based modulation could exhibit compared to OFDM systems. The major advantage of wavelet transform function is its flexibility. This feature makes it eminently suitable for future generation of communication systems. With the rapid increasing need for enhanced performance, communication systems can no longer be designed for average performance while assuming channel conditions. In lieu of, new generation systems have to be designed to dynamically take advantage of the instantaneous propagation conditions [11]. This situation has led to the study of flexible and reconfigurable systems capable of optimizing performance according to the current channel response. Wavelet theory has been foreseen by several authors as a better platform on which to build multicarrier waveform bases. The dyadic division of the bandwidth, though being the key point for compression techniques, is not well suited for multicarrier communication. Wavelet packet bases therefore appear to be a more logical choice for building orthogonal waveform sets usable in communication. In their review on the use of orthogonal transmultiplexers in communications, the relation between filter banks and transmultiplexer theory and predict that wavelet has a role to play in future communication systems[12]. Lindsey and Dill were among the first to propose wavelet packet modulation. The theoretical foundation of this orthogonal multicarrier modulation technique and its interesting possibility of leading to an arbitrary time-frequency plane tiling are underlined [8]. Moreover, wavelet is placed into a multitone communication framework including alternative orthogonal bases such as M-band wavelet modulation (MWM) and multiscale modulation (MSM). Alternative methods are to use wavelet transforms replacing IFFT and FFT [14]. By using these transforms, the spectral containment of the channels is better since they are not using CP. They can be considered as Discrete Wavelet Transform OFDM (DWT-OFDM) or Wavelet Packet Transform OFDM (WPT-OFDM). Both transform employs Low Pass Filter (LPF) and High Pass Filter (HPF) operating as Quadrature Mirror Filters satisfying perfect reconstruction and orthonormal bases properties. The transform uses filter coefficients as detail and approximate in HPF and LPF respectively [15]. The approximated coefficients is sometimes referred to as scaling coefficients, whereas, the detailed is referred to wavelet coefficients. Sometimes these two filters can be called sub-band coding since the signals are divided into sub-signals of low and high frequencies respectively. In section II, we discuss wavelet transform related work. In section III we discuss conclusion of transform application in communication.

Related Work

The wavelet packet forming block can be simulated using the following MATLAB command T = wptree (2, 3, xx, vv). The purpose for this command is to create the wavelet packet tree T to be processed for the reconstruction block of the WPT. The first parameter 2 is the order number depending on the input vector signal xx[6]. The second parameter is the number of level which is depending on the size of xx and wv is the wavelet family. Furthering process to this, the MATLAB code X_K = wprec (T, wv) is invoked. The input signals of WPT block has to be a wavelet packet tree, otherwise, the signal cannot be processed for transmission. At the front end of the receiver, the signals U_K is received by the system and processed by the WP forming block. For this purpose, the same command as in the transmitter is invoked[12]. The same parameters have to be used to minimize the BER errors. After the WP tree is formed then the WPT reconstruction is used before the data is processed by the QAM demodulator. An example of the signals that are processed by this block model is shown in Fig.1.

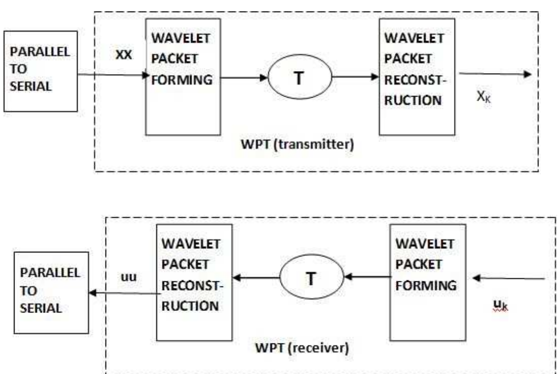

Figure 1. Inverse and Forward Wavelet Packet Transform WPT-OFDM model.

The simplified block diagram of the multicarrier communication system studied in this article is shown in Figure 1. The transmitted signal in the discrete domain, x[k], is composed of successive modulated symbols, each of which is constructed as the sum of M waveforms 'm[k] individually amplitude modulated. It can be expressed in the discrete domain as:

$$x[K] = \sum_s \sum_{m=0}^{M-1} a_{s,m}\, \varphi_m[k - sM] \text{……………..(1)}$$

Where $a_{s,m}$ is a constellation encoded s^{th} data symbol modulating the m^{th} waveform. Denoting T the sampling period, the interval [0, LT − 1] is the only period where $\varphi_m[k]$ is non-null for any m Є 2 {0...M − 1}. In an AWGN channel, the lowest probability of erroneous symbol decision is achieved if the waveforms φ_m [k] are mutually orthogonal, i.e.

$$(\varphi_m[K]\varphi_n[k]) = \delta[m-n], \text{……………………(2)}$$

Where $\langle , . , \rangle$ represents a convolution operation and _[i] = 1 if i = 0, and 0 otherwise.

In OFDM, the discrete functions $\varphi_m[k]$ are the well-known M complex basis functions w[t]exp $(j2\pi \frac{m}{M} kT)$ limited in the time domain by the window function w[t]. The corresponding sine-shaped waveforms are equally spaced in the frequency domain, each having a bandwidth of $\frac{2\pi}{M}$ and are usually grouped in pairs of similar central frequency and modulated by a complex QAM encoded symbol. In WPM, the subcarrier waveforms are obtained through the WPT. Exactly as for ODFM, the *inverse* transform is used to build the transmitted symbol while the *forward* one allows retrieving the data symbol transmitted. Since wavelet theory has part of its origin in filter bank theory [14], the processing of a signal through WPT is usually referred as decomposition (i.e. into wavelet packet coefficients), while the reverse operation is called reconstruction (i.e. from wavelet packet coefficients) or synthesis. WPT that can be defined through a set of FIR filters. Though it would be possible to use other wavelets as well, those cannot be implemented by Mallat's fast algorithm and hence their high complexity makes them ill-suited for mobile communication. The synthesis discrete wavelet packet transforms constructs a signal as the sum

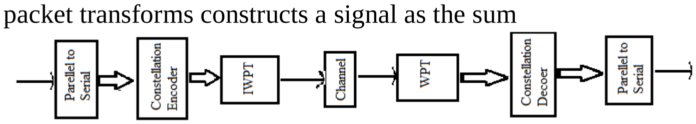

Figure 2. Wavelet packet modulation functional block diagram

of M = 2^J waveforms. Those waveforms can be built by J successive iterations each consisting of filtering and upsampling operations. Noting $\langle , . , \rangle$ the convolution operation, the algorithm can be written as:[9]

$$\begin{cases} \varphi_{j,2m}[k] = \langle h_{lo}^{rec}[k], \varphi_{j-1,m}[k/2] \rangle \\ \varphi_{j,2m+1}[k] = \langle h_{lo}^{rec}[k], \varphi_{j-1,m}[k/2] \rangle \end{cases} \text{………………..(3)}$$

With $\varphi_{0,m}[k] = \begin{cases} 1 & for\ k = 1 \\ 0 & otherwise \end{cases} \quad \forall m$

where j is the iteration index, 1 ≤ j ≤ J and m the waveform index 0 ≤ m ≤ M − 1. Using usual notation in discrete signal processing, $\varphi_{j,m}[k/2]$ denotes the upsampled-by-two version of $\varphi_{j,m}[k/2]$. For the decomposition, the reverse operations are performed, leading to the complementary set of elementary blocks constituting the wavelet packet transform depicted in Figure 2. In orthogonal wavelet systems, the scaling filter h_{lo}^{rec} and dilatation filter h_{hi}^{rec} form a quadrature mirror filter pair. Hence knowledge of the scaling filter and wavelet tree depth is sufficient to design the wavelet transform [15]. It is also interesting to notice that for orthogonal WPT, the inverse transform (analysis) makes use of waveforms that are time-reversed versions of the forward ones. In communication theory, this is equivalent to using a matched filter to detect the original transmitted waveform.

A particularity of the waveforms constructed through the WPT is that they are longer than the transform size. Hence, WPM belongs to the family of overlapped transforms, the beginning of a new symbol being transmitted before the previous one(s) ends[11].

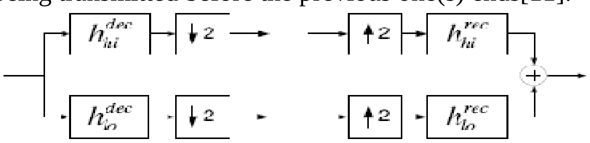

Figure 3. Wavelet packet elementary block decomposition and reconstruction

The waveforms being M shift orthogonal, the inter-symbol orthogonality is maintained despite this overlap of consecutive symbols. This allows taking advantage of increased frequency domain localization provided by longer waveforms while avoiding system capacity loss that normally results from time domain spreading. The waveforms length can be derived from a detailed analysis of the tree algorithm [16]. Explicitly, the wavelet filter of length L_0 generates M waveforms of length

$\boldsymbol{L = (M-1)(L_0-1)+1}$.................................(4)

In Daubechie's wavelet family [17] for instance, the length Lo is equal to twice the wavelet vanishing order N. For the order 2 Daubechie wavelet, L is equal to 4, and thus a 32 subcarrier WPT is composed of waveforms of length 94. This is therefore about three times longer than the corresponding OFDM symbol, assuming no cyclic prefix is used. The construction of a wavelet packet basis is entirely defined by the wavelet scaling filter; hence its selection is critical. This filter solely determines the specific characteristics of the transform [12]. In multicarrier systems, the primary characteristic of the waveform composing the multiplex signal is out-of-band energy. Though in an AWGN channel this level of out-of-band energy has no effect on the system performance thanks to the orthogonality condition, this is the most important source of interference when propagation through the channel causes the Orthogonality of the transmitted signal to be lost. A waveform with higher frequency domain localization can be obtained with longer time support [13]. On the other hand, it is interesting to use waveforms of short duration to ensure that the symbol duration is far shorter than the channel coherence time. Similarly, short waveforms require less memory, limit the modulation-demodulation delay and require less computation. Those two requirements, corresponding to good localization both in time and frequency domain, cannot be chosen independently. In fact, it has been shown that in the case of wavelets, the bandwidth-duration product is constant [17]. This is usually referred to as the uncertainty principle.

Full Name	Abbreviated Name	Vanishing Order	Length L_0
Haar	haar	1	2
Daubechie [17]	Db *N*	N	2N
Symlets	Sym *N*	N	2N
Coiflet	Coif *N*	N	2N
Discrete Meyr	dmey	–	62

Table i. Summary of wavelet family characteristics.

We limit our performance analysis to WPT based on widely used wavelets such as those given in [17]. While there are numerous alternative wavelet families that could be used as well, a comparative study would deserve a separate publication by itself. As previously mentioned, we are essentially interested in wavelets leading to fast transforms through the tree algorithm. The primary wavelet family we have been using in our research is the one from Daubechie [17], since it presents wavelets with the shortest duration. Furthermore, their localization in the frequency domain can be adequately adjusted by selecting their vanishing order, as it is illustrated by two of the curves plotted in Figure 4. The label *dbN* is used in the rest of this article to refer to WPT based on Daubechie wavelet of vanishing order N.

Conclusion

We have analysed in this paper about the working of wavelet transform function for multicarrier communication systems.Comparison between these new schemes and OFDM have been used for carrier signal. At some points, we have discussed in detail the MATLAB commands regarding the DWT-OFDM models and also provided detail about perfect reconstruction properties and orthonormal base. Finally, it is important to underline that wavelet theory is still developing. Since the use of wavelet packets in telecommunications has been mainly studied by communications engineers, an important potential for improvements is possible if some of the specific issues are addressed from a mathematical point-of-view.

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