Out of Band Reduction in Cognitive OFDM Systems

Aswathy S. Kootummel  
Department of ECE, SriGuru Institute of Technology, Coimbatore, Tamil Nadu, India  
K. Kavitha  
Department of ECE, SriGuru Institute of Technology, Coimbatore, Tamil Nadu, India  
R. Sarankumar  
Department of ECE, SriGuru Institute of Technology, Coimbatore, Tamil Nadu, India

Abstract:  
Orthogonal Frequency Division Multiplexing is a special case of multicarrier transmission where a single data stream is transmitted over a number of lower rate subcarriers. This kind of parallel transmission achieves high throughput and better transmission quality. One of the problems associated with this high data rate multiplexing technique is formation of sidelobes. Here we discuss about a new window called soft window that decay the sidelobes in a faster rate. Orthogonality is achieved if the integral of product of two signals result in zero output. Hence, OFDM gives a faster rate of transmission with high spectral efficiency.

Key words: Orthogonal Frequency Division Multiplexing, soft window, sidelobes, Orthogonality, OFDM

1. Introduction

Wireless communication is one of the most vibrant areas in the communication field today. The idea of OFDM is to split the bandwidth into a number of orthogonal subbands inorder to transmit the symbols using subcarriers in parallel. Analogous to carriers used in usual modulation techniques, subcarriers are used in OFDM, since a subcarrier each is used in each of the split subbands. OFDM can be referred to as multicarrier, multitone and Fourier Transform. One of the main reason to use OFDM is to increase robustness against frequency-selective fading or narrowband interference. In a single-carrier system, a single fade or interferer can cause the entire link to fail, but in a multi-carrier system, only a small percentage of the subcarriers will be affected. There are a few problems associated with this high data rate modulation system like PAPR, formation of sidelobes etc., formation of sidelobes being one of the critical problems.

In this paper, we discuss about a shaping soft window that decays the sidelobes in a faster rate. It is more efficient than the conventional Raised Cosine window, since it achieves the same performance as that of Raised Cosine window, which is 100% with 90% overhead savings. Soft window has the characteristics of functions with vestigial symmetry which forces null derivatives at the extremes of the window. Conventional OFDM used rectangular windowing which led to spectral spreading and as a result interference to symbols working at adjacent channels. So as a solution to the problem, we introduce soft window. Several techniques have already been proposed for reducing out of band radiation, the simplest among them being low pass filtering of transmit signal using a higher order digital filter. Other techniques that have been proposed include insertion of cancellation carriers, subcarrier weighting, insertion of cancellation carriers, adaptive symbol transition, subcarrier weighting, windowing and so on. All the techniques except spectral precoding and windowing are resort to optimization methods leading to high computational overhead. Spectral precoding uses a data independent matrix and requires matrix operations at both transmitter and receiver leading to considerable computational complexity in implementation. On the contrary, windowing is simpler and computationally efficient but signal is extended in time domain resulting in poor spectrum efficiency. Soft window is designed based on characteristics of functions with vestigial symmetry that has null derivatives at the extremes. Vestigial symmetry is an odd symmetry about 1/T where T is the time period.

2. System Model

The side-lobe of OFDM transmission is decayed faster than conventional raised-cosine windowing by the use of soft window. By using the vestigial symmetry and enforcing several null derivatives at the extremes of the window, it is possible to control the fast out-of-band decay. Results show that by using a lower roll-off factor (10%) the proposed window can achieve the same performance of raised-cosine (100%) with around 90% overhead savings, making it of interest in OFDM cognitive radio. The rigid current spectrum allocation policies have led to an inefficient use of the spectrum. Indeed, several measurement campaigns confirm that there is space to greatly improve the spectrum utilization and efficiency. To achieve this goal the concept of cognitive radio has emerged. A CR is an intelligent radio system which can dynamically adapt to the environment, using its sensing
capabilities to provide the needed information to correctly use the spectrum. This agility allows to use the spectrum efficiently. A CR system needs to be highly flexible with respect to the spectral shape of the transmitted signal. Orthogonal Frequency Division Multiplexing is the favorite air-interface for CR systems, since by nulling some subcarriers we can easily shape the spectrum.

Cognitive Radio (CR) allows the usage of both incumbent and opportunistic users. Incumbent users are the licensed users who can use the spectrum whenever they wish to and are the owners of the spectrum. Opportunistics use the spectrum when not in use by the incumbents. These opportunistics make use of the subcarriers that are momentarily unused by the incumbents. It is assumed that the opportunistic user transmit signal is asynchronous relative to the incumbent. In such a situation, the subcarriers orthogonality is lost resulting into spectral leakage from the opportunistic user into the incumbent. To avoid harmful interference of opportunistic users on the incumbent it is desirable that the power spectral density of the incumbents’ subcarriers exhibits a quick decay when out of band. The same principle applies to the interference of the incumbent over the opportunistic users, but since the incumbent is the licensee, it is the opportunistic user who has to guarantee non-harmful interference. To reduce the spectral leakage we propose an enhancement to conventional OFDM, where modification from a rectangular to a smooth window allows high and controlled out-of band roll-off.

2.1. Conventional OFDM System

High spectral efficiency of OFDM is due to the fact that carrier power and modulation scheme can be individually controlled for each carrier. The input data stream is modulated by a QAM modulator, resulting in complex stream \( X[0], X[1], \ldots, X[N-1] \). This symbol stream is passed through a serial to parallel converter, whose output is a set of \( N \) parallel QAM symbols \( X[0], X[1], \ldots, X[N-1] \) corresponding to symbols transmitted over each subcarrier. The symbols from serial to parallel converter are the discrete frequency components of the OFDM modulator output. These frequency components are converted to time samples by inverse DFT implemented using IFFT algorithm. The IFFT yields OFDM symbol consisting of the sequence \( x[n] = x[0], \ldots, x[N-1] \) of length \( N \) where

\[
x[n] = \left(\frac{1}{\sqrt{N}}\right) \sum_{k=0}^{N-1} X[k] e^{j2\pi kn/N}, \quad 0 \leq n \leq N-1 \quad (1)
\]

OFDM splits the information into \( N \) parallel streams which are then transmitted by modulating \( N \) distinct carriers (henceforth called SCs or tones). Symbol duration on each SC thus becomes larger by a factor of \( N \). In order for the receiver to be able to separate signals carried by different SCs, they have to be orthogonal.

![Figure 1: Conventional OFDM Processing](image)

The cyclic prefix is then added to the OFDM symbols and the resulting time samples are then ordered by the parallel-to-serial converter and passed through a D/A converter, resulting in the baseband OFDM signal \( x(t) \), received signal is then downconverted to baseband and then filtered to remove the high frequency components. The A/D converter samples the resulting signal. The prefix is then removed and this results in \( N \) time samples. These time samples are serial-to-parallel converted and passed through an FFT. The FFT output is parallel-to-serial converted and passed through a QAM demodulator to recover the original data. The OFDM system thus effectively decomposes the wideband channel into a set of narrowband orthogonal subchannels with a different QAM symbol sent over each subchannel.

2.2. Windowed OFDM Processing

Conventional OFDM used rectangular window for the reduction of sidelobes. Soft window which replaced rectangular window requires a length of \( (1 + \beta)T_o \) for the symbol instead of \( T_o \) in the conventional OFDM using a rectangular window where \( \beta \) is the roll-off factor of the window. This symbol period extension implies a reduction of the transmission bit-rate.

Vestigial symmetry constitute orthogonal waveforms and therefore with the correct synchronization we can recover the data symbols without interference. Moreover, several null derivatives at the extremes of the window yields a fast out-of band decay. Let us first consider the asymptotic performance with RC \( \beta \). To compensate for the extended length of the window one has to increase the modulation cardinality if one wants to preserve the bit rate. For a roll-off factor \( \beta \) the rate is decreased by a factor \( 1 + \beta \). If, for example, \( \beta = 1 \) the modulation order should be doubled so that the bit-rate is preserved, i.e. if one assumes a QPSK modulation for the rectangular window, then with the new window, with double duration, the new modulation scheme should be one with 16 symbols e.g. 16-QAM. The use of a window that when normalized has values between 0 and 1 implies reduction of power.

The block diagram of the incumbent transmitter in figure shows the similarity with conventional OFDM, the only replacement being the windowing at the end of the chain, which requires a length of \( (1 + \beta)T_o \) for the symbol instead of \( T_o \) in the conventional OFDM using a rectangular window. \( \beta \) is the roll-off factor of the window. This symbol period extension implies a reduction of the transmission bit-rate. The operation performed in the windowing block, includes two main steps. Let us consider one data block \((B_n)\). This block can be represented as the concatenation of two sub-blocks \(B_1n\) and \(B_2n\), where \(B_1n\) has a duration \(\beta T_o\) and \(B_2n\) \((1 - \beta)T_o\). \(B_n\) is extended by appending \(B_1n\), which leads to a block of duration \((1 + \beta)T_o\). This extended block is then multiplied...
by the window which for the same roll-off $\beta$ has the same duration. To overcome the eventual multipath effects a time guard filled with zeros is added. After removal of the zero prefix, the extended block is appended with zeros to meet a duration of $2T_0$ and then the second part of the block is summed to the first half, leading to the block transmitted. Following these split and add operations we then have the FFT and all the conventional OFDM processing. It can be easily understood from the bottom part of the figure for windowed OFDM processing.

2.3. Cognitive Radio
Cognitive Radio is an intelligent radio that can be reprogrammed and reconfigured dynamically to adapt to the environment. It has sensing capability to provide the needed information to correctly use the spectrum improving spectrum utilization and efficiency. It is flexible with respect to spectral shape and OFDM is the favorite air interface for Cognitive Radio systems. Cognitive Radio allows the usage of both incumbent and opportunistic users. Opportunistic users can use the subbands when not in use by the incumbents. Opportunistic terminals use the subcarriers momentarily unused by the incumbents. OFDM which is highly flexible is the favorite interface for Cognitive Radio. Multipath delay spread tolerance can be achieved by the insertion of guard time and cyclic extension. Coding and interleaving brings immunity to frequency selective fading channels. Efficient modulation and demodulation is possible due to the usage of IFFT and FFT algorithms by dividing the entire bandwidth into subbands. High transmission bit rates and easy equalization are the attractive features of multitone modulation. Here, there is a chance to cancel any channel if it is affected by fading.

3. Simulation Results
As per the conventional block diagram, the input to the OFDM system is first encoded, IFFT modulated, and final output is obtained after FFT demodulation. Angular windowing was used in the conventional OFDM for the reduction of sidelobes.

IFFT output of the OFDM system is shown in the fig1. This is the method by which data is modulated using different subcarriers.

The equation for rectangular windowing and Orthogonally FD Multiplexed signal is given as follows.

\[
w(t) = 1 \tag{2}
\]

\[
e(t) = \sum_{\alpha} e^{-j2\pi \alpha \omega_0 t} w(t) \tag{3}
\]

Since the use of windowing in time domain led to the extension of symbol period in time domain which inturn had negative effects on the data transmitted, came the optimization of sidelobes using Raised Cosine window. RC guard periods of consecutive OFDM symbols can overlap with each other and are omitted at the receiver. The RC period smoothes the signal transition between consecutive symbols and thus reduces the sidelobe level. A higher ROF $\beta$ leads to faster decay of the side lobes.
and thus requires a smaller guardband, which increases the spectral efficiency. On the other hand, higher \( \beta \) implies longer symbol duration, which in turn reduces the data rate. Thus, a trade-off between the value of \( \beta \) and the guardband size must be found to obtain the maximal achievable data rate, so that the radio resource is exploited most efficiently. The equation for RC windowed signal is given as follows.

\[
\langle |w(t)|^2 \rangle = 1, \quad \text{Rectangular Window}
\]
\[
\frac{(4-\beta)}{4(1+\beta)}, \quad \text{RC} \beta \text{ Window}
\]

The gain of the RC pulse relative to the rectangular is around 115 dB and the loss due to multipath around 20 dB. The Spectral precoding scheme has a gain of around 20 dB in relation to the conventional OFDM, and a gap of around 100 dB to the RC 100% and NP 10%, as seen previously. Concerning the new pulse a similar performance to the RC 100% is obtained for a roll-off of 10%, which represents an overhead saving of around 90%, enabling to achieve the same performance with higher bit-rates.

![Figure 4: Soft Windowed Output](image)

Henceforth, due to its spectral leakage attenuation properties and low overhead the addition of the proposed window in the conventional OFDM systems allows a smooth evolution path for the introduction of the CR paradigm in the current wireless communication systems. The equation for New Pulse which is formed by giving modifications to the RC windowed output is given as follows.

\[
<w(t)^2> = \frac{(128-23\beta)}{(128(1+\beta))} \quad (5)
\]

Fig.5 shows the soft window output generated by the combination of equations (5) and (6).

![Figure 5: Comparison of Three Windows](image)

Fig.6 shows the comparison of all the three methods and it can be seen that soft window reduces the sidelobes to the minimum. Rectangular window reduces the sidelobes by an amount of 10 dB/dec, raised cosine window decreases the sidelobe by an amount of 90 dB/dec. Figure shows it clearly and it is assumed that implementation of a Gaussian filter before IFFT processing and then windowing will further reduce the sidelobe to a much extent by keeping the bit rate same as that of before going for windowing.

4. Conclusion

Sidelobe reduction of about 90 dB/dec is obtained and the soft window designed has 100% performance similar to that of raised cosine window. Also, the overhead savings in terms of power has also been achieved. The rectangular and raised cosine windowed are also obtained and can be used further for comparisons. The plots based on the simulations are available for observation. The method has proved to be a simple, computationally efficient and low cost implementation. It has also proved to provide better SNR and BER performances compared to other methods.
5. References


