Spectral Sculpting for OFDM based Cognitive Radio

Shaheen Mushtaq Farooqi[1] Malik Azizullah[2]
[1]Research Scholar [2]Associate Professor
[1,2]Department of Electronics and Communication Engineering
[1,2]Al-Falah School of Engineering & Technology, Faridabad, India

Abstract— In this article, the techniques of OFDM in cognitive radio have been studied. The objective of the study is to evaluate the effectiveness of various techniques to avoid interference. In cognitive radio while primary and secondary users are present at the same time, the key issue is to avoid interference to primary as well as secondary users. Cognitive radio involves software computing while detecting spectrum holes which constantly vary with time, and assign them to the secondary users. OFDM technique is widely used in implementing cognitive radio. OFDM systems are much simpler then FBMC techniques but they lack the ability to avoid crosstalk and inter carrier interference effectively. OFDM utilize guard bands to avoid such interferences, these guards bands however come at the cost of spectrum. Windowing techniques also are utilized in OFDM system. Length of window can determine the amount of interference occurring in the communication systems.

Key words: Orthogonal Frequency Division Multiplexing (OFDM), Cognitive Radio, Spectral Sculpting, Primary User (PU), Secondary User (SU), Software Defined Radio (SDR)

I. Introduction

Scarcity of electromagnetic spectrum is one of the key issues associated with present day communication systems. Cognitive radio provides an alternative to efficiently use the available spectrum. This is possible by exploiting the spectrum holes. However this efficient use comes at the cost of complexity. Cognitive radio requires addition computing system and is also known as software defined radio.

High Date Rate communications can be successfully achieved by employing Orthogonal Frequency Division Multiplexing (OFDM) that utilizes a certain number of orthogonally spaced frequency bands which in turn modulates by a number of slower data streams [2]. Furthermore, the division of the spectrum available into multiple orthogonal subcarriers making the transmission system highly robust to fading that occurs in multipath channel [4].It is also possible to turn off the subcarriers in the zone of the primary user transmissions, and thus white spaces present in the spectrum can be efficiently filled [5].

II. Cognitive radio

Joseph Mitola first described the term Cognitive Radio [1]. He described the Cognitive Radio as a communication adept of analyzing the environment which includes the users and frequency band. Cognitive Radio can learn and compute efficient way to utilize the available spectrum [1-3]. Cognitive radio was introduced to avoid the inefficient methods of using the spectral resources with the emphasis on spectrum.

Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to

Statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind:

- Highly reliable communications whenever and wherever needed;
- Efficient utilization of the radio spectrum.[1]

In any communication cell, if the subscriber doesn't utilize the electromagnetic spectrum, it creates a spectrum hole in that cell. Spectrum Hole consists of a band of frequencies which remains unused at a particular time even though they are assigned to the users.

A spectrum hole is a band of frequencies assigned to a primary user, but, at a particular time and specific geographic location, the band is not being utilized by that user. Spectrum utilization can be improved significantly by making it possible for a secondary user (who is not being serviced) to access a spectrum hole unoccupied by the primary user at the right location and the time in question. [1]

Cognitive radio exploits these spectrum holes and thus leads to efficient utilization of spectrum.

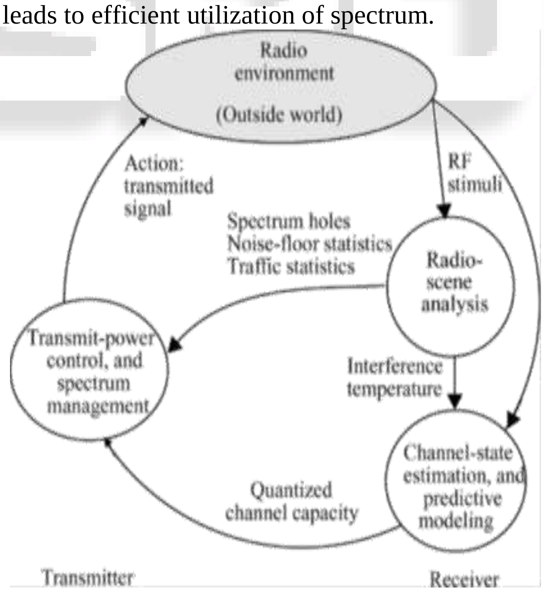


Fig. 1: Tasks involved in Cognitive radio.

III. Spectrum sculpting

The detection of the presence of primary subscribers in a certain frequency spectrum is the primary task for CR network operation. in order to exploit the time varying available bands , interference to the primary users has to be avoided by CR, additionally CR also guarantee secondary signal is properly received. The tasks used in CR network achieve following goals:

- Band-Dropping.

- Tone-Nulling, in an OFDM Network.
- Signal-Shaping or Spectrum Shaping and
- Interference Cancelation.

A dropping of band occurs during adjacent channel interferences that takes place to the primary and from the primary users. This demands the Cognitive radio system to realize and integrate frequency diversity so that uninterrupted communication is maintained, which is supported by OFDM. Band-dropping causes use of the spectrum to be used inefficiently but provides an advantage that is of a simple and easy much handling of signal digitization and quantization right after the intermediate-frequency stage of the demodulation process [4]. Band dropping and Tone nulling are similar but Tone nulling requires much more advanced techniques for suppression of the side lobes. Computing cancellation tones for OFDM symbol which has been affected, to create additional notch depth is required in active interference cancellation.

IV. OFDM-BASED COGNITIVE RADIO

Due to ever increasing rate of advanced applications in wireless devices as well as increased number of wireless users, it has become imperative to exploit the spectral resources available to cater this growing demand. In order to find an effective solution for fulfilling the demand for even more spectrum allocation the conventional spectrum allocation policies were studied. This means allotting a certain fixed portions of the spectrum to users who are licensed can result in wasting of spectral resources available because the allotted spectrum is highly wasted over time and frequency [4]. Hence it's the need of the hour to discuss a whole new strategy that has to be developed and which would ensure licensed spectrum is also utilized secondarily while maintaining that the primary user who is licensed to use the spectrum is not affected. This latest strategy is termed as “Spectrum Pooling”. Term “spectrum pooling”, was initially presented in paper [3] and explained as a method of pooling the frequency resources from one licensed band user and to rent the same to an users who is unlicensed, when the licensed user doesn't use the same i.e. idle periods. Though this strategy ensure efficient use of spectral resources but it brings in various concerns such as;

- Technological,
- Jurisdictional
- Economical
- Political

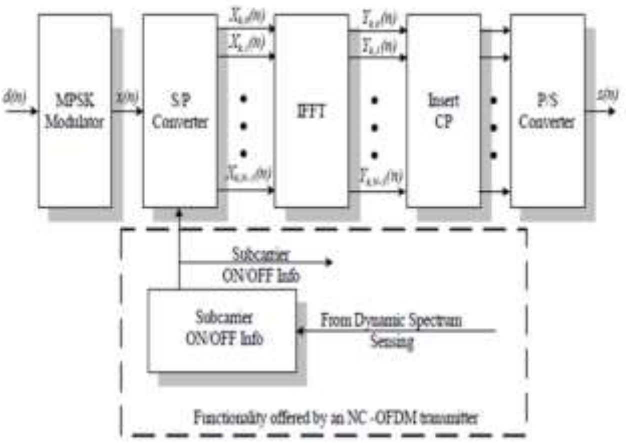


Fig. 2: OFDM based transmitter

Aspects regulating the pooling of spectrum. Out of the above the technological challenges has been the centre of research for various groups at research centres across the globe. In order to make pooling of spectrum practical various steps are being taken and have also been proposed in certain research related works.

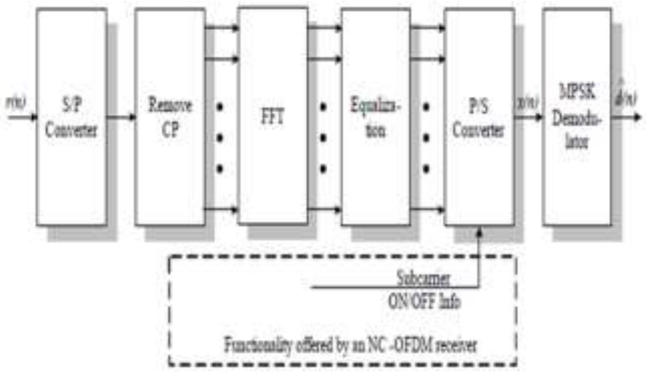


Fig. 3: OFDM based Receiver

V. MATHEMATICAL REPRESENTATION

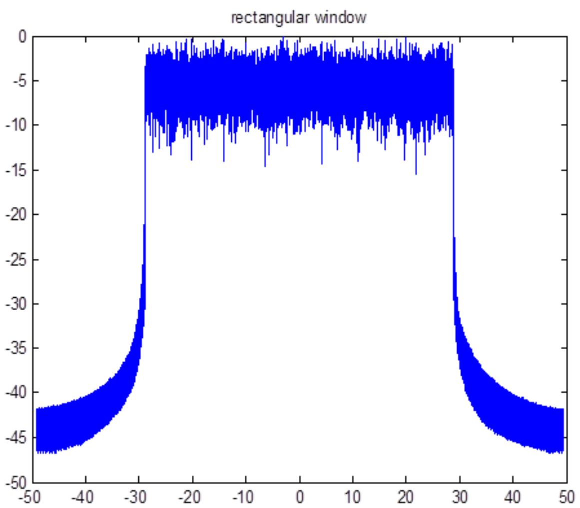
The baseband signal which is transmitted in continuous time, and is commonly used in both OFDM and FBMC, can be written as follows.

$$s(t) = \sum_{k=-\infty}^{+\infty} \sum_{n=0}^{N-1} x_{n,k} p_{n,k}(t)$$

where $x_{n,k}$ represents the data symbol which is transmitted on nth subcarrier during kth symbol interval, N is the length of DFT, and $p_{n,k}(t)$ denotes the synthesis filters obtained from the time frequency relation of the prototype filter p(t). OFDM and FBMC differ mainly in choosing the type of prototype filters p(t) and the symbol duration. In the conventional OFDM system, $x_{n,k}$ could be complex-valued symbols, and p(t) is a rectangular pulse, thus, the synthesis filters can be given by:

$$p_{n.k}(t) = p(t-kT)\, e^{j2\pi n f_0 (t-kT)}$$

with $j=\sqrt{-1}$, the symbol duration T and the inter-subcarrier frequency spacing f_0. To simplify the equalization in time dispersive channels, a cyclic prefix (CP) with duration of T_{cp} is added in front of each OFDM symbol with duration of T_0.Then, the total symbol duration amounts to $T=T_{cp} + T_0$.



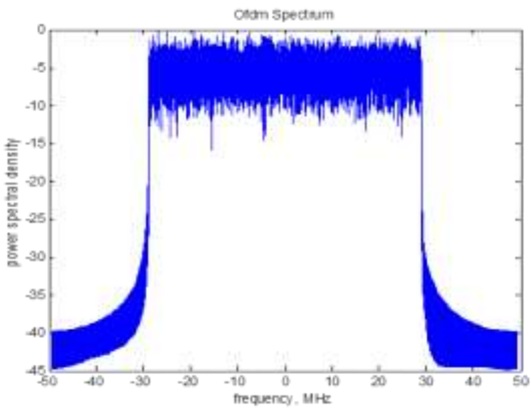


Fig. 4: OFDM Spectrum

VI. SIDELOBE-SUPPRESSED OFDM

In this section, an overview on existing techniques for sidelobe suppression in OFDM systems is given,

A. Insertion of Guard Bands:

Due to the low implementation complexity, the insertion of guard bands, enabling to deactivate OFDM subcarriers lying at the edges of the used spectrum band, is often utilized in practice to reduce the OOB power leakage of OFDM signals. However, this measure comes at the cost of spectral efficiency, while the OOB radiation suppression is still unsatisfactory, since it decays asymptotically with f-2 [10].

B. Time Windowing:

Time windowing scheme applies appropriate windows, such as half-sine or Hanning window, to the transmitted signal. By letting the signal's amplitude drop to zero smoothly at the symbol boundaries, the spectral side lobes are significantly reduced. According to [3], different window functions can be uniformly formulated as follows

$$p(t) = R(t/T) * h(t)$$

where * denotes linear convolution, and the normalized rectangular pulse defined by:

$R(t) = \{ 1, \quad 0<t\leq 1$

For the commonly used half-sine pulse, h(t) can be given by:

$$h(t) = \frac{\pi}{2\beta T}\sin\left(\frac{\pi t}{\beta T}\right) R\left(\frac{t}{\beta T}\right) \qquad 0, \quad \textit{Otherwise}$$

where β represents the roll-off factor. Note that a roll-off factor β > 0 effectively broadens the duration of the OFDM signal, thus increasing the overhead and diminishing the achievable spectral efficiency.

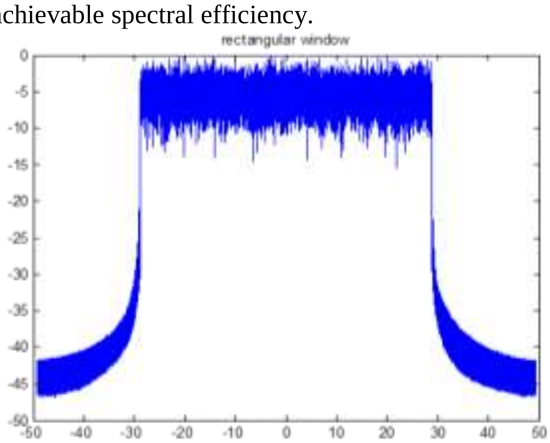


Fig. 5: OFDM spectrum using Rectangular window

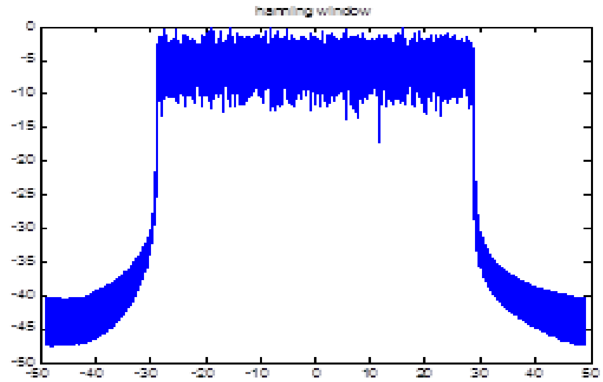


Fig. 6: OFDM spectrum using Hanning window

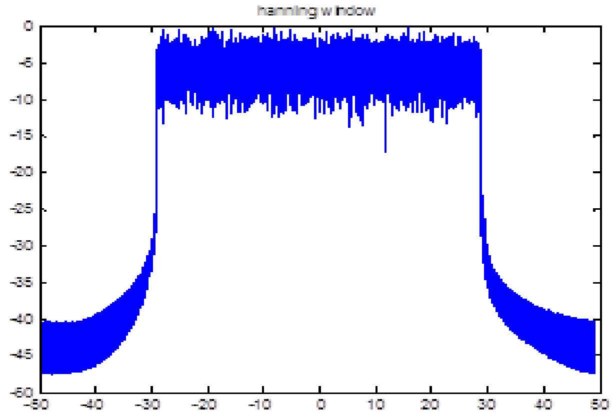


Fig. 7: OFDM spectrum using Hanning window

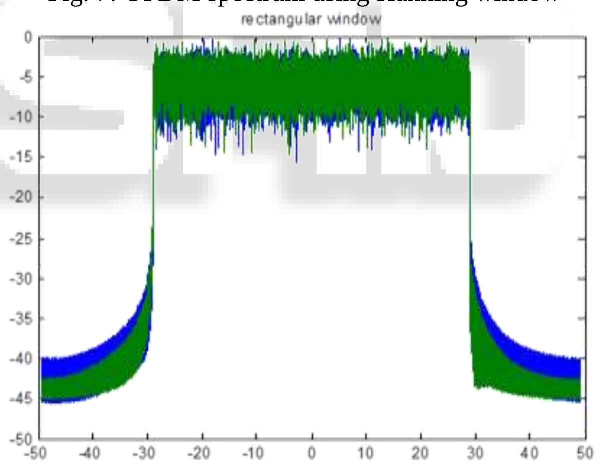


Fig. 8: OFDM spectrum while varying length of Rectangular window

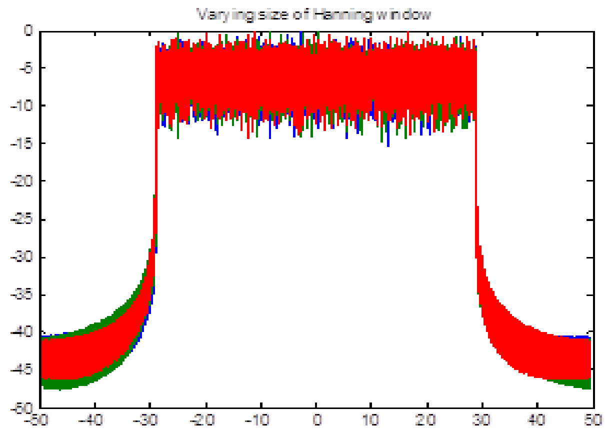


Fig. 9: OFDM spectrum while varying length of Rectangular window

VII. CONCLUSIONS

In this Paper we have executed Orthogonal frequency division multiplexing (OFDM) technique is executed and this technique is employed for broadband communications which are wireless in nature. OFDM is used because it offers many advantages. First, trivial equalization one scalar technology gain for every subcarrier is allowed by orthogonality of subcarrier channels. Second, closely spaced orthogonal subcarriers are closely spaced and thus partition of the available bandwidth is done into a set of narrow sub bands. For maximizing the bandwidth efficiency per transmission rate, adaptive modulation schemes are used for such subbands. Third, tasks of carrier and symbol synchronizations are simplified by very unique structure of OFDM symbols. These points have been widely verified and documented [8]. The recent research propose to widen the use Orthogonal frequency division multiplexing of for various multiple access applications. It has been proposed to extend the use of Multiple access OFDM, or orthogonal frequency division multiple access i.e. OFDMA, for many standards and some proprietary waveforms[15]. For CR, OFDMA of certain forms have been proposed.[9]. A sub set of the subcarriers is assigned to ever user node in a particular network while using OFDM. There is a need to synchronize the user signals at the receiver input so that the inter carrier interference is prevented.

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