Spectral Sculpting for OFDM based Cognitive Radio

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ABSTRACT:
In this article we describe the software-controllable spectral capabilities available in OFDM based UWB signals. Here we intend to show how MB-OFDM signal might adapt local regulations, remedy future interference situations prepare UWB for the opportunities of cognitive radio. Spectrum sculpting for interference control is more easier and more effective with OFDM based UWB used in cognitive radio than direct sequence Ultra wide band (DS-UWB). Simulation is performed by zeroing 6 and 8 tones out of 128 which results in the notch depth > 45dB and >70dB.

Keywords
Orthogonal frequency division multiplexing (OFDM), Cognitive radio, spectral sculpting, Notch, Interference, Ultra wide band (UWB), Code division multiple axis (CDMA)Forward error correcting code(FCC)

1. INTRODUCTION
Main idea behind OFDM is to split data stream into N parallel streams of reduced data rate and transmit each on a separate subcarrier. When the sub carriers have appropriate spacing to satisfy orthogonality, their spectra will overlap. OFDM modulation is equivalent to the IDFT.[1] . In 1993 three slightly different schemes were independently proposed- CDMA multicarrier DS-CDMA and MT-CDMA. The CDMA based OFDM is capable of combining concepts of CDMA and OFDM.[2] OFDM by itself is not a multi-access scheme, but a modulation scheme. Existing multi-access schemes can be combined with OFDM (e.g. TDMA, FDMA, CDMA).The advantages of OFDM are spectral efficiency, simple implementation and tolerance to intersymbol interference (ISI). Its disadvantages are Bandwidth loss due to guard time ,prone to frequency and phase shift errors and peak to average power problem. Several techniques have been proposed to combat the problem of carrier frequency offset in OFDM the scheme is based on the transmission of a training symbol composed of two identical halves in the time domain [3].However OFDM finds a great application in UWB application, such as cognitive radio. A cognitive radio can change its transmitter parameters based on the interaction with the environments it operates. Cognitive radio can determine its location, sense spectrum use by neighboring devices, change frequency, adjust output power, and even alter transmission parameters and characteristics [4]. In this paper we have made an attempt to shape the spectrum OFDM so that it can be implemented in UWB OFDM based cognitive radio.

Cognitive Radio (CR) that can transform the transmitter parameters based on interaction with the environment in which it operates. This interaction may involve active negotiation or negotiation with other spectrum users and passive sensing and decision making within the radio.

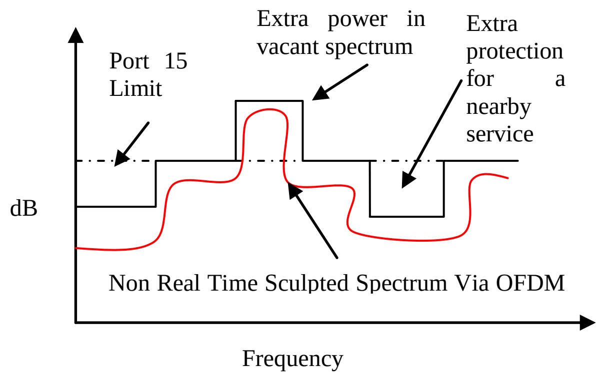

Fig. 1. Cognitive radio plausible application to UWB application.

2. OFDM FACTS
- Invented more than 40 years ago.
- Adopted and proven many times for
  - Asymmetric DSL (ADSL)
  - IEEE 802.11a/g, 802.16 a
- Power line networking (Home Plug)
- Digital audio (DAB) and video (DVB) (DVB Europe, and ISDB, Japan).
- Proposed by Texas instruments for IEEE 802.15.3a
- A natural for the future
  - FCC Cognitive Radio
  - Multimode Radio

3. OFDM STRENGTHS
- OFDM is spectrally efficient

  -IFFT/FFT creates non interfering sub carriers

  -Sub carrier can be brought together which enhances spectral efficiency.
- OFDM is resistant to narrowband interference

  - Narrow band interference will effect at most a couple of tones.

  -Erase information from the affected tones, since they are now unreliable. Use FECs to recover the lost information
- OFDM with FEC is resistant to multi-path Impairments

- Cyclic prefix helps preserve orthogonality between the sub-carriers[5].

4. ULTRAWIDE BAND (UWB) TECHNOLOGY

Unique RF technology formerly

- classified for military applications
- Declassified in mid 90s with Feb, 2002
- FCC commercial use approval
- Uses wide spectrum (3.1-10.6 GHz)
- Initially narrow-pulse-based; now many favor OFDM-based modulation

Compelling about UWB

- Supports datacom speeds greater than 100 Mbps within 10m radius
  - OFDM supports 480 Mbps at 2 meters; multi-Gbps speeds for the future
- Can determine range between devices to within a few inches
- CMOS, low power, low cost designs Plausible

UWB is uniquely qualified to meet the needs of high speed WPAN. UWB can fit in Desk top-Room for a radius 1m-10m.

- Application

Bluetooth, Zigbee and Low speed WPAN

- Evolution of UWB

Impulse- Pulsed Multi Band- Multi Band OFDM

5. SPECTRAL SCULPTING FOR MULTIBAND OFDM SIGNAL

In a multi-band OFDM system, the information is transmitted instantaneously on a single band whose bandwidths 528 MHz. The information is further interleaved across three consecutive frequency bands. For example, the first OFDM symbol could be transmitted in sub-band #1, the second OFDM symbol on sub-band #3, the third OFDM symbol on sub-band #2, and so forth. Within a single band, the information is transmitted on multiple tones, where the frequency spacing between two adjacent tones is 4.125 MHz.

Hence a single 7 MHz wide radio astronomy band would overlap with at most three tones of the multi-band OFDM system. An advantage of the multi-band OFDM system is that the signal is constructed in the frequency domain; therefore it is easier, both mathematically and computationally, to shape the spectrum of the transmitted signal.[6]

Different spectral sculpting techniques

a. Tone Nulling
b. Time-Domain Windowing
c. Dummy Tone Insertion
d. Constrained Dummy Tone Insertion

Tone Nulling: Sub-carriers that overlap spectrally with victim band can be zeroed out.

*Advantages***:** Receiver does not require knowledge of nulled tones. Channel coefficients (including the nulled tones) are estimated using the preamble.

*Disadvantages***:** Requires zeroing out 29 sub-carriers (~120 MHz) to obtain a rejection of 23 dB. Performance degrades significantly since ~25% of the data-and-pilot tones are lost. Slower side-lobe decay due to rectangular windowing in the time domain.

Time-Domain Windowing: The decay rate of the side-lobes can be increased by introducing a time-domain windowing. Would reduce the required number of sub-carriers to be nulled out. Can be implemented by inserting a cyclic postfix at the IFFT output followed by multiplication with a time-domain windowing function.

*Advantages***:** No changes are required at the receiver.

*Disadvantages***:** The multi-path robustness is reduced by an amount equal to the length of the cyclic postfix.

Dummy Tone Insertion: Data-specific dummy tones are added at the TX at the edge of the victim band. Dummy tones are computed at the input of the IFFT for each OFDM symbol,

Advantages: Insertion of 2 dummy tones in addition to 3 null tones results in a rejection of >23 dB.

*Disadvantages***:** Dummy tone insertion creates peaking of the TXPSD near the band edges. Requires a transmit power back-off of~1.8 dB. Reduction in range for all data rates

Constrained Dummy Tone Insertion: Placing no constraint on the magnitude of the dummy tones causes peaking at the spectral edges. Can be implemented as a filtering operation for computing the dummy tones.

*Advantages***:** It is possible to introduce a 23 dB notch with minimal ripple or peaking in the pass-band (~ 0.5 dB).

Disadvantages: One potential draw-back of this technique is the fact that insertion of dummy tones may have to be communicated to the receiver.

6. METHODOLOGY

Spectral shaping is controlled via software, in near-real-time, to respond to local regulations and time-varying local conditions. Such shaping should be as "surgical" as possible in order minimize the degradation to UWB performance. the method adopted is tone nulling. This results in the notch in the OFDM spectrum, which is compared with the FIR notch. MB-OFDM receiver FFT allows spectrum scan for other services One-time, just-in-time, spectrum self-regulation which makes it attractive for cognitive radio.

7. FUNDAMENTAL BUILDING BLOCK

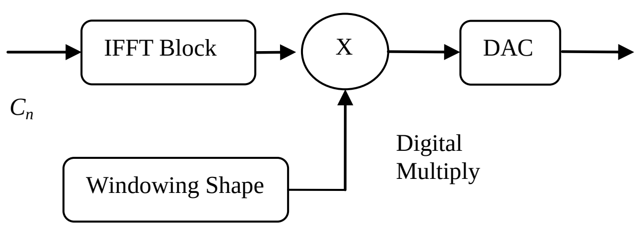

Fig. 2. Building Block to generate the Notched spectrum

In multiband OFDM coarse spectrum control, whole bands are dropped to accommodate local situations, it may be useful in some situations but fine control of the spectrum is not possible. Figure2 shows the better option for fine controlling of the spectrum. Windowed pulses are used instead of dropping the entire band. Here we make use of the concept that OFDM symbol is the summation of N orthogonal tones as mentioned below

$$Z(t) = \sum_{k=0}^{N-1} C_k e^{j2\pi(k-\frac{N}{2})t/T} \text{ - - - - - - - (1)}$$

Z(t) is the summation of N orthogonal signal and T is the time period of each signal. In the above diagram DAC used is of six bit. Out of 128 tones OFDM it zeros out six tones near detected services.122 out of 128 tones are still available. The result is that there will be a notch in the spectrum as shown in the Figure [3]. There is an improvement in the result which offers notch depth greater than 70 dB when 8 tones are zeroed out figure [4]. .All operations are digital and no analog filtering is required. Advanced technique allows deeper notches of the order of 23dB and above are reported.

8. COMPARATIVE ANALYSIS

Other popular technique is the use of FIR filter for spectrum notching. Some of the advantages and disadvantages of FIR and OFDM notch techniques are listed below.

In FIR notching

- Tunability is less
- Multiple notching is difficult
- Useful spectrum is suppressed

In contrast OFDM notching is

- Simpler to implement
- Easily tunable in software
- Less UWB spectrum suppression
- Rx FFT enables spectrum scan
- Multi-notch capable – enables on-the-fly spectral sculpting
- Better fit to future cognitive designs

9. RESULTS

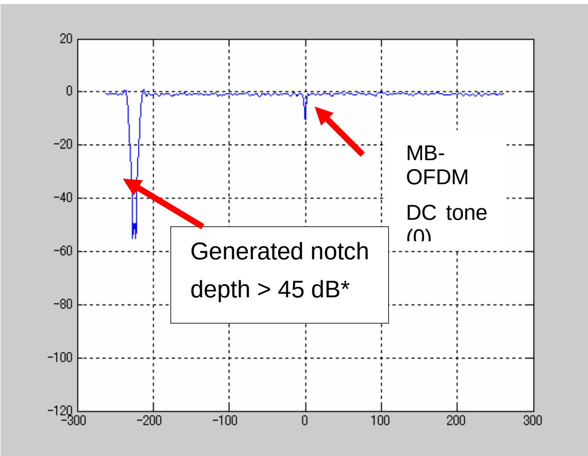

Fig. 3. 7.25 MHz notch (RAS) band generated by 6 tones

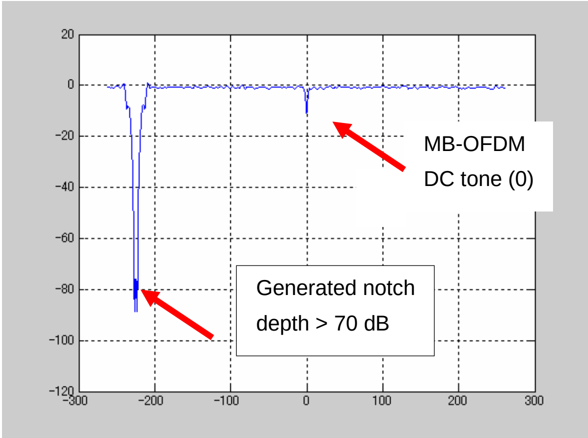

Fig. 4. 7.25 MHz notch (RAS) band generated by 8tones

10. CONCLUSIONS

Precision shaping of UWB signal spectra will help us:

- Offer new degrees of freedom in negotiating regulations.
- Adapt to local regulations & interference situations "on the fly".
- Mitigate future interference problems we cannot foresee today.
- Encourage, and then exploit, more liberal UWB power limits.

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