Cyclostationary based Spectrum sensing for WiMAX Signal

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Abstract- A software Radio which exploits unused spectrum spaces without causing much interference to licensed spectrum users and thus optimising the use of available radio frequency is, by its virtue of its intelligence, called Cognitive Radio. Spectrum Sensing is the inherent ability of Cognitive Radio to autonomously perform required calculations and detect unused spectrum which can be used for a multitude of purposes. In this paper, Worldwide Interoperability for Microwave Access (WiMAX) signal and their second order cyclostationarity in terms of cyclic autocorrelation function and cyclic frequency is studied.

Keywords – Spectrum Sensing, Cognitive Radio(CR) , WiMAX, cyclostationarity

I. INTRODUCTION

The electromagnetic spectrum is a natural scarce resource. The radio frequency spectrum involves electromagnetic radiation with frequencies between 3000 Hz and 300 GHz. The use of electromagnetic spectrum is licensed by Governments for wireless and communication technologies. Spectrum scarcity is the main problem as the demand for additional bandwidth is going to increase. Measurement studies have shown that the licensed spectrum is relatively unused across many time and frequency slots [1]. The Federal Communications Commission (FCC) published a report prepared by Spectrum Policy Task Force (SPTF) [2].This report indicates that Most of the allotted channels are not in use most of the time; some are partially occupied while others are used most of the time. The most recommended solution for the problem of spectrum scarcity is cognitive radio (CR) described by Joseph Mitola in his doctoral dissertation [3]. CR technology is considered as the best solution because of its ability to rapidly and autonomously adapt operating parameters to changing requirements and conditions [4]. A cognitive radio can be defined as an intelligent wireless communication system that is aware of its surrounding environment, 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 operation parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time[4]. A spectrum hole is a band of frequencies licensed to a primary user but at a particular time and specific geographic location that particular band is not being utilized by that user (PU) [3].

A cognitive radio is a radio frequency transmitter/receiver that is designed to intelligently detect whether a particular segment of the radio spectrum is currently in use, and to jump into the temporarily-unused spectrum very rapidly, without interfering with the transmissions of other authorized users [5].Main functions of cognitive radio are: Spectrum sensing, spectrum management, spectrum mobility and spectrum sharing [6]. Spectrum sensing detects the unused spectrum and shares it without harmful interference with other licensed users. Spectrum Management is the task of selecting the best available spectrum to get user communication requirements. Spectrum Mobility is defined as the process when a cognitive radio user exchanges its frequency of operation. Spectrum Sharing decides which secondary user can use the spectrum hole at some particular time. A number of spectrum sensing methods have been proposed in literature. There are several factors that make spectrum sensing practically challenging. First, the required SNR for detection may be very low. Secondly, multipath fading and time dispersion of wireless channels complicate the spectrum sensing problem. Thirdly, the noise level may change with time and location which yields the noise power uncertainty issue for detection [7-10]. To overcome these challenging factors there is a boom in spectrum sensing methods and a wide scope of research in this area. We can classify these spectrum sensing methods in following three ways: Classical spectrum sensing, cooperative spectrum sensing and Antenna based spectrum sensing. Classical spectrum sensing methods are briefly reviewed in this paper.

The rest of the paper is organized as follows. Proposed Functions of Cognitive Radio are explained in section II. Section III describes the various Spectrum sensing techniques. In section IV and V we discuss the principle of cyclostationarity and WiMAX signal Model. Experimental results are presented in section VI. Concluding remarks are given in section VII.

II. FUNCTIONS OF COGNITIVE RADIO

Duty cycle of cognitive Radio includes detecting spectrum white space, selecting the bestn frequency bands, coordinating spectrum access with other users and vacating the frequency when a primary user appears. Figure 1 shows the duty cycle for Cognitive Radio

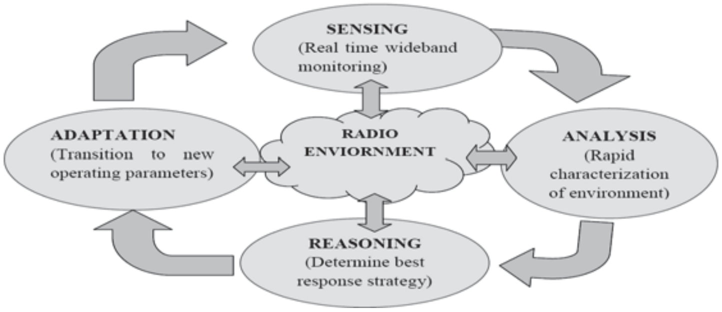

Fig1. Cognitive Cycle

Such a cognitive cycle is supported by the following functions:

- Spectrum sensing and analysis.
- Spectrum management and handoff.
- Spectrum allocation and sharing.

- **Spectrum sensing and analysis:** Through spectrum sensing and analysis, CR can detect the spectrum white space as illustrated in Figure 2 i.e., a portion of frequency band that is not being used by the primary users, and utilize the spectrum. On the other hand, when primary users start using the licensed spectrum again, CR can detect their activity through sensing, so that no harmful interference is generated due to secondary users transmission.

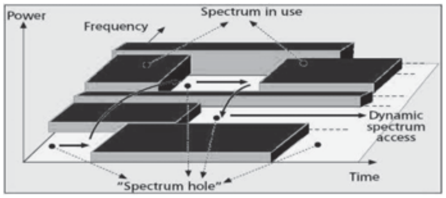

Fig 2. Spectrum holes and spectrum in use

- **Spectrum management and handoff:** After recognizing the spectrum white space by sensing, spectrum management and handoff function of CR enables secondary users to choose the best frequency band and hop among multiple bands according to the time varying channel characteristics to meet various Quality of Service (QoS) requirements. For instance, when a primary user reclaims his/her frequency band, the secondary user that is using the licensed band can direct his/her transmission to other available frequencies, according to the channel capacity determined by the noise and interference levels, path loss, channel error rate, holding time, and etc.
- **Spectrum allocation and sharing:** In dynamic spectrum access, a secondary user may share the spectrum resources with primary users, other secondary users, or both. Hence, a good spectrum allocation and sharing mechanism is critical to achieve high spectrum efficiency. Since primary users own the spectrum rights, when secondary users co-exist in a licensed band with primary users, the interference level due to secondary spectrum usage should be limited by a certain threshold. When multiple secondary users share a frequency band, their access should be coordinated to alleviate collisions and interference [18].

III. VARIOUS SPECTRUM SENSING TECHNIQUES

Cognitive radio is an exciting technology that has potential of dealing with the stringent requirement and scarcity of the radio spectrum. Spectrum sensing refers to the action of monitoring the characteristics of received signals which may include RF energy levels if particular band is occupied. Ideal characteristics of Cognitive Radio are: intelligence, reliability, awareness, adaptability, efficiency and excellent quality of service. To improve the detection probability, many signal detection techniques can be used in spectrum sensing. Signal processing is concerned with improving the quality of signal at the top of measurement systems and its main aim is to attenuate the noise in the signal that has not been eliminated by careful design of measurement system. With the advancement in signal processing, we are able to think about cognitive radio technology. In this section, we give an overview of some well known spectrum sensing techniques.

Generally, the spectrum sensing techniques can be classified as transmitter detection, cooperative detection, and interference-based detection as shown in fig -

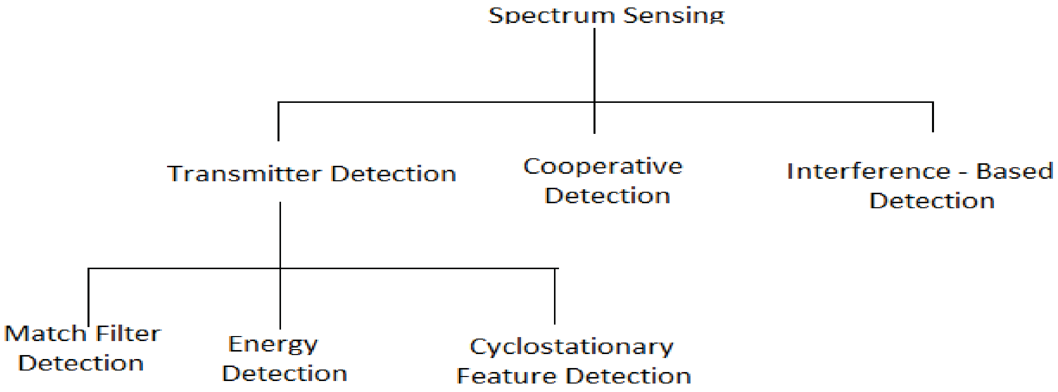

Fig3. Classification of Spectrum Sensing Techniques

3.1 Transmitter Detection

Transmitter detection approach is based on the detection of the weak signal from a primary transmitter through the local observations of users. Basic hypothesis model for transmitter detection can be defined as follows [19]-

$$x_1(t) = \begin{cases} n_1(t), & H_0 \\ h_1(t)s(t) + n_1(t), & H_1 \end{cases} \qquad (1)$$

H_0 = Primary User Absent
H_1 = Primary User Present
where n: 1, 2, 3,…N;
N: sampling interval;
$n_i(t)$: additive white Gaussian noise;
$x_i(t)$: transmitted Signal

where x(t) is the signal received by the CR user, s(t) is the transmitted signal of the primary user, n(t) is the AWGN and h is the amplitude gain of the channel. H0 is a null hypothesis, which states that there is no licensed user signal in a certain spectrum band. On the other hand, H1 is an alternative hypothesis, which indicates that there exist some licensed user signal.

3.1.1 Matched Filtering Method: If there is prior knowledge of the signal transmitted by primary transmitter, the matched filter followed by threshold detector can be used to detect the presence of primary user. The matched filter is an optimal linear filter for maximizing the signal to noise ratio (SNR) in the presence of additive white stochastic noise. This technique is possible if number of users is very small. A matched filter is obtained by correlating a known signal, with an unknown signal to detect the presence of the known signal in the unknown signal. This is equivalent to convolving the unknown signal with a time-reversed version of the signal. Convolution does essentially with two functions that it places one function over another function and outputs a single value suggesting a level of similarity, and then it moves the first function an infinitesimally small distance and finds another value [11]. The end result comes in the form of a graph which peaks at the point where the two images are most similar.

Advantage of matched filter is that it needs less time to achieve high processing gain due to coherent detection. Disadvantage of matched filter is that it would require a dedicated sensing receiver for all primary user signal type and it requires the prior information of primary user signal which is very difficult to be available at the CRs.

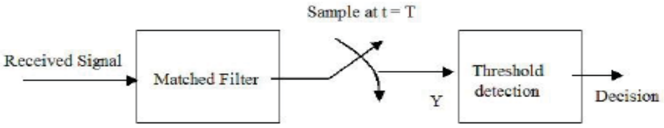

Fig4. Basic operation performed by matched filter

3.1.2 Energy Detector Method: If the prior knowledge of the primary user signal is unknown, the energy detection method is optimal for detecting the presence of PU. In this approach, the radio frequency (RF) energy in the channel or the received signal strength indicator is measured to determine whether the channel is idle or not. The detection is based on some function of the received samples which is compared to a predetermined threshold level [12]. If the threshold is exceeded, it is decided that signal(s) is (are) present otherwise it is absent. However, this method is prone to false detections since it only measures the signal power. When the signal is heavily fluctuated, it becomes difficult to distinguish between the absence and the presence of the signal if prior knowledge of PU signal is unknown since the energy detection method is optimal for detecting any zero mean constellation signals. First step is to filter the input signal with a band pass filter to select the bandwidth of interest and then output signal is squared and integrated over the observation interval. The output of the integrator is compared to a predetermined threshold to infer the presence of the PU signal [13].

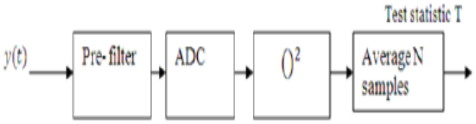

Fig5. Energy detection with pre-filter and square law Device

However, the energy detection approach can be implemented without any prior knowledge of PU signal but still it has some disadvantages:-

i. The first problem is that it has poor performance under low SNR and conditions. This is because the noise variance is not accurately known at the low SNR, and the noise uncertainty may explain the energy detection is useless.
ii. The threshold used in energy detection depends on the noise variance and small noise power estimation errors can result in significant performance loss.

3.1.3 Cyclostationarity Based Feature Detection

In cyclostationary Feature Detection method modulated signals are coupled with sine wave carriers, pulse trains, repeated spreading, hopping sequences, or cyclic prefixes. This results in built-in periodicity. These modulated signals are characterized as cyclostationary because their mean and autocorrelation exhibit periodicity. This periodicity is introduced in the signal format at the receiver so as to exploit it for parameter estimation such as carrier phase, timing or direction of arrival. These features are detected by analyzing a spectral correlation function. The main advantage of this function is that it differentiates the noise from the modulated signal energy. This is due to the fact that noise is a wide-sense stationary signal with no correlation however modulated signals are cyclostationary due to embedded redundancy of signal periodicity. Analogous to autocorrelation function spectral correlation function (SCF) can be defined as:

$$S_x^{\alpha}(f) = \lim_{T\to\infty} \lim_{\Delta t\to\infty} \frac{1}{\Delta t}\int_{-\Delta t/2}^{\Delta t/2} \frac{1}{T} X_T(t,f+\alpha/2) X_T^{*}(t,f-\alpha/2)\,dt \tag{3}$$

where the finite time Fourier transform is given by:

$$X_T(t,v) = \int_{t-T/2}^{t+T/2} x(u)\, e^{-j2\pi vu}\, du \tag{4}$$

Spectral correlation function is also known as cyclic spectrum.

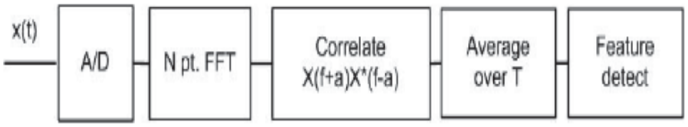

Fig6. Block diagram of cyclostationary feature detection

While power spectral density (PSD) is a real valued one dimensional transform, SCF is a complex valued two dimensional transform. The parameter α is called the cycle frequency. If α = 0 then SCF gives the PSD of the signal.Because of the inherent spectral redundancy signal selectivity becomes possible. Analysis of signal in this domain retains its phase and frequency information related to timing parameters of modulated signals. Due to this, overlapping features in power spectral density are non overlapping features in cyclic spectrum. Hence different types of modulated signals that have identical power spectral density can have different cyclic spectrum. Because of all these properties cyclostationary feature detector can perform better than energy detector in discriminating against noise. However it is computationally complex and requires significantly large observation time. cyclostationary feature detection has several advantages such as;

- Cyclostationary feature detection is more robust to changing noise level than energy detection.
- Cyclostationary detectors can work in lower SNR compared to energy detection because feature detectors exploit information embedded in the received signal.
- Drawbacks of the cyclostationary feature detection is that it requires prior knowledge on the primary user's signal and is very complex to implement.

3.2 Cooperative detection

In Cooperative detection method, all the CR users share their sensing information with each other and a combined detection about the presence or absence of the primary user signal is taken. This decision is much more accurate than Non cooperative detection such as Energy detector, Matched filter detector, Cyclostationary detector. The main idea of cooperative sensing is to enhance the sensing performance by exploiting the spatial diversity in the observations of spatially located CR users. By cooperation, CR users can share their sensing information for making a combined decision more accurate than the individual decisions.[19]

3.3 Interference-based detection

Interference is typically regulated in a transmitter-centric way, which means interference can be controlled at the transmitter through the radiated power, the out-of-band emissions and location of individual transmitters. However, interference actually takes place at the receivers. Therefore recently, a new model for measuring interference, referred to as interference temperature shown in fig-7 has been introduced by the FCC.

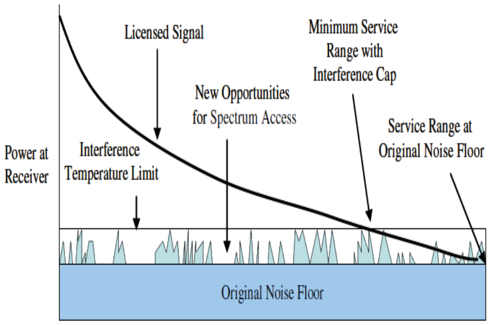

Fig7. Interference Temperature Model

The model shows the signal of a radio station designed to operate in a range at which the received power approaches the level of the noise floor. As additional interfering signals appear, the noise floor increases at various points within the service area, as indicated by the peaks above the original noise floor. Unlike the traditional transmitter-centric approach, the interference temperature model manages interference at the receiver through the interference temperature limit, which is represented by the amount of new interference that the receiver could tolerate. In other words, the interference temperature model accounts for the cumulative RF energy from multiple transmissions and sets a maximum cap on their aggregate level. As long as xG users do not exceed this limit by their transmissions, they can use this spectrum band. However, there exist some limitations in measuring the interference temperature. The interference is defined as the expected fraction of primary users with service disrupted by the xG operations.
This method considers factors such as the type of unlicensed signal modulation, antennas, ability to detect active licensed channels, power control, and activity levels of the licensed and unlicensed users. However, this model describes the interference disrupted by a single xG user and does not consider the effect of multiple xG users. In

addition, if xG users are unaware of the location of the nearby primary users, the actual interference cannot be measured using this method.

IV. PRINCIPLE OF CYCLOSTATIONARITY

Many of the communication signals in use today may be modeled as cyclostationarity signals due to the inherent periodicities. Cyclostationarity Feature detectors have been introduced as a two dimensional signal processing technique for recognition of modulated signals in the presence of noise and interference.Modulated signals have built-in periodicity, characterized as cyclostationary. This information can be used for detection of a random signal with a particular modulation type in the presence of background noise and other modulated signals. Cyclostationary signals exhibit correlation between widely separated spectral components due to the spectral redundancy caused by periodicity. A signal process x(n) is said to be cyclostationary in a wide sense if its mean and autocorrelation are periodic with a period T_0, i.e.,

$Mx(t+T_0)= Mx(t)$ ……….(5)

$Rx((t+T_0,\ )=Rx(t,\ )$…….(6)

For all t and τ Therefore, by assuming that the Fourier series expansion of Rx(t, τ),we can write

$$R_x(t,\tau) = \sum_{n=-\infty}^{+\infty} R_x^{\frac{n}{T_0}}(\tau)e^{i2\pi\left(\frac{n}{T_0}\right)t} \tag{7}$$

where the Fourier coefficients

$$R_x^{\frac{n}{T_0}}(\tau) = \frac{1}{T_0}\int_{-T_0/2}^{T_0/2} R_x(t,\tau)e^{-i2\pi(n/T_0)t}dt \tag{8}$$

are referred to as cyclic autocorrelation functions and the frequencies {n/T0}n€Z are called cycle frequencies. Let α represent cycle frequency when the spectral correlation function (SCF) is defined:

$$S_x^{\alpha}(f) = \int_{-\infty}^{-\infty} R_x^{\alpha}(\tau)e^{-i2\pi f\tau}d\tau \tag{9}$$

There are generally two methods to estimate the signal SDC: frequency smoothing and time smoothing. Time smoothing algorithms are considered to be more computationally efficient for general cyclic spectral analysis. Given the signal x(n), all time smoothing algorithms are based on the time smoothed cyclic cross periodogram

$$s_x^{\alpha}(n,f)_{\Delta t} = \frac{1}{T} < X_T\left(n, f+\frac{\alpha}{2}\right) X_T^*\left(n, f-\frac{\alpha}{2}\right) >_{\Delta t} \tag{10}$$

where XT(n, f + α/2), also called complex demodulators, is the spectral components of signal X(n) **.** Mathematically, computation of the complex demodulators is expressed as

$$X_{T(n,f)} = \sum_{r=-N'/2}^{N'/2} a(r)x(n-r)e^{-i2\pi f(n-r)T_s} \tag{11}$$

where a(r) is a data tapering window of length **$T=N'T_s$** seconds, **T_s** is the sample interval, and **f_s** is the sampling frequency.

After the complex demodulate has been computed, it is correlated with its conjugate over a time span of Δt seconds The correlation operation is expressed as

$$s_x^{\alpha}(n,f)_{\Delta t} = \sum_{r=0}^{N-1} X_T(r,f_1)X_T^{*}(r,f_2)g(n-r) \qquad (12)$$

where g(n) is a data tapering window of width Δt=NTs second. It is shown in [10] that the time smoothed cyclic cross periodogram converges to the spectral correlation function in the limit, as Δt→∞ followed by Δf→ 0, if the time windows a(n) and g(n) are properly normalized .therefore if

$$\sum_n a^2(n) = \sum_n g^2(n) = 1,$$

we have

$$\lim_{\Delta f \to 0} \lim_{\Delta t \to \infty} s_x^{\alpha}(n,f)_{\Delta t} = S_x^{\alpha}(f) \qquad (13)$$

V. WIMAX SIGNAL MODEL

WiMAX, the **W**orldwide **I**nteroperability for **M**icrowave **A**ccess, is a telecommunications technology aimed at providing wireless data over long distances in a variety of ways, from point-to-point links to full mobile cellular type access. It is a wireless digital communications system that is intended for wireless "metropolitan area networks". This technology can provide broadband wireless access (BWA) up to 30 miles (50 km) for fixed stations, and 3 - 10 miles (5 - 15 km) for mobile stations.

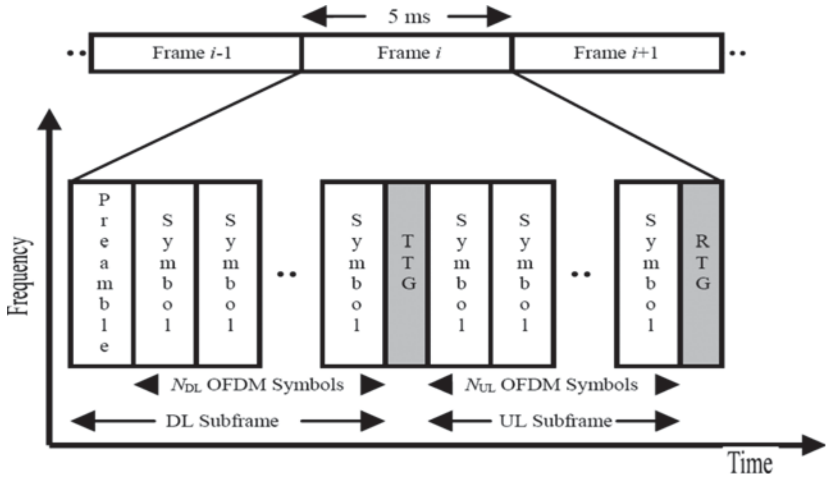

Fig.8 TDD frame structure for Mobile WiMAX

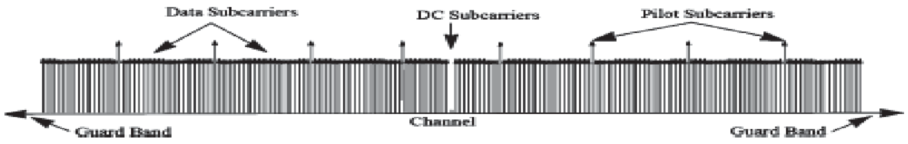

Fig 9. OFDM frequency description

Fig.8 presents the IEEE 802.16e time-division duplex (TDD) frame structure, as per the current mobility certification profiles [14]–[16]. The standard frame duration can range from 2 ms to 20 ms; however, all WiMAX equipments support only a 5-ms frame [17]. The frame is divided into two uplink (UL). The DL-to-UL subframe ratio is variable, to support different traffic profiles. Transition gaps separate the adjacent DL and UL subframes. In Fig. 1, TTG represents the DL-UL gap and is referred to as the transmit/receive transition gap, while RTG represents the UL-DL gap and is referred to as the receive/transmit transition gap. Note that the terminology used here is according to the IEEE 802.16e standard [15], [16]. The DL subframe starts with a preamble as the first symbol, which is used for time and frequency synchronization and uniquely identifies a serving base-station. Therefore, a cognitive user within the coverage area of a base-station will periodically receive the same preamble.

The OFDM frequency-domain description is presented in Fig.9. One can note four types of subcarriers: data subcarriers to transmit information, pilot subcarriers for estimation purposes, null subcarriers for guard bands, and direct current (DC) subcarrier [16]. The first two types of subcarriers are called the used subcarriers. The pilot symbol on subcarrier is generated as $8(0.5\text{-}w_k)/3$ where w_k is a value taken from a pseudorandom binary sequence that is different for each OFDM symbol [14]. The distribution of the pilot subcarriers might differ from one OFDM symbol to another in the frame, while this repeats every frame, i.e., it is the same for each λ_{th} OFDM symbol of a frame [12]–[14]. Note that $\lambda=0$ for the preamble symbol, $1\leq \lambda\leq N_{DL}$for the DL OFDM symbols (excluding the preamble), and $N_{DL}+1 \leq \lambda \leq N_F-1$for the UL OFDM symbols, with N_{DL} and N_F as the number of OFDM symbols in the DL (excluding the preamble) and in the frame, respectively. Note that more than one pilot distribution might be employed in the DL or UL subframes; each pilot distribution is used in a certain set of OFDM symbols in the DL or UL subframes [12]–[14]. The pilot symbols are usually transmitted with boosted power over the data symbols. The preamble contains only null subcarriers and subcarriers used for transmitting preamble data. According to the standard, the preamble data symbols are transmitted every third subcarrier out of the set of subcarriers, $-K_P/2$, $-K_P/2+1$,…….. $K_P/2$ starting from the subcarrier $-K_P/2+S_{p,d}$ up to $-K_P/2+S_{p,d}+3(K_{p,d}-1)$ where $S_{p,d}=0,1,2$ and $K_{p,d}$ is the number of the preamble data symbols [12]–[14].Fig. 10shows the frequency domain description of the preamble when $S_{p,d}=0$.

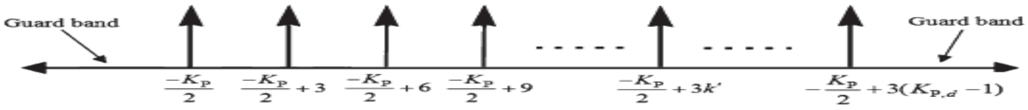

Fig10. OFDM frequency description of the preamble symbol(Sp,d=0)

According to the above description, we express the discrete time mobile WiMAX OFDM signal affected by noise as

$$r(n) = r_{\mathrm{P}}(n) + r_{\mathrm{DL}}(n) + r_{\mathrm{UL}}(n) + w(n) \qquad (14)$$

where $r_P(n)$, $r_{DL}(n)$,and $r_{UL}(n)$,are the signal components corresponding to the preamble, and the DL (excluding the preamble) and UL subframes, respectively, and w(n)is the additive zero-mean Gaussian noise. Furthermore, $r_P(n)$, $r_{DL}(n)$,and $r_{UL}(n)$ are given respectively as

$$r_{\mathrm{P}}(n) = a_{\mathrm{P}} \sum_{\substack{l=-\infty \\ l \bmod N_{\mathrm{F}}=0}}^{\infty} \sum_{k=0}^{K_{\mathrm{P},d}-1} b_k g\left(n - lD - lN_{\mathrm{F}}^{-1} D_{\mathrm{G}}\right) \times e^{j2\pi\left(3k-\frac{K_{\mathrm{P}}}{2}+S_{\mathrm{P},d}\right)(n-lD-lN_{\mathrm{F}}^{-1}D_{\mathrm{G}})/D_{\mathrm{u}}} \qquad (15)$$

$$\begin{aligned} r_{\mathrm{DL}}(n) = a_{\mathrm{DL}} & \sum_{\substack{l=-\infty \\ 1 \leq l \bmod N_{\mathrm{F}} = \lambda \leq N_{\mathrm{DL}}}}^{\infty} \sum_{k=-K_{\mathrm{DL}}/2, k\neq 0}^{K_{\mathrm{DL}}/2} c_{k,l} \\ & \times g\left(n - lD - \left\lfloor l N_{\mathrm{F}}^{-1} \right\rfloor D_{\mathrm{G}}\right) \\ & \times e^{j2\pi k\left(n - lD - \left\lfloor l N_{\mathrm{F}}^{-1} \right\rfloor D_{\mathrm{G}}\right)/D_{\mathrm{u}}} \end{aligned} \tag{16}$$

$$\begin{aligned} r_{\mathrm{UL}}(n) = a_{\mathrm{UL}} & \sum_{\substack{l=-\infty \\ N_{\mathrm{DL}}+1 \leq l \bmod N_{\mathrm{F}} = \lambda}}^{\infty} \sum_{k=-K_{\mathrm{UL}}/2, k\neq 0}^{K_{\mathrm{UL}}/2} d_{k,l} \\ & \times g\left(n - lD - \left\lfloor l N_{\mathrm{F}}^{-1} \right\rfloor D_{\mathrm{G}} \right. \\ & \left. - D_{\mathrm{TG}}\right) e^{j2\pi k\left(n - lD - \left\lfloor l N_{\mathrm{F}}^{-1} \right\rfloor D_{\mathrm{G}} - D_{\mathrm{TG}}\right)/D_{\mathrm{u}}} \end{aligned} \tag{17}$$

Where K_P,K_{DL} and K_{UL} are the number of used subcarriers in the preamble, DL, and UL symbols, respectively, α_P,α_{DL} and α_{UL} are the amplitude factor , D is the OFDM symbol period equal to the useful OFDM symbol duration, $D_{u\ ,}$plus the CP duration, D_{cp}, b_k is k_{th} preamble data symbol transmitted in the $3k-K_p/2+S_{p,d}$th subcarrier of the preamble, with $–K_p/2+Sp,d$ as the position of the first subcarrier used to transmit preamble data and $S_{p,d}$ ε{0,1,2},$c_{k,l}$, and $d_{k,l}$ are the symbols (data and pilot) transmitted on the kth subcarrier and within the lth OFDM symbol which belongs to the DL and UL subframes, respectively (note that the distribution of pilot subcarriers could be different for different groups of OFDM symbols) N_{UL}, is the number of OFDM symbols in the UL subframe, g(n) is the impulse response of the transmit and the receive filters in cascade, and $D_G=D_{TG}+D_{RG}$is the total duration of the transition gaps within each frame, with D_{TG} and D_{RG} as the TTG and RTG transition gaps, respectively. The data symbols are taken either from a quadrature amplitude modulation (QAM) or phase shift keying (PSK) signal constellation, and are assumed to be zero-mean independent and identically distributed (i.i.d.) random variables. The fast Fourier transform (FFT) size for generating OFDM symbols is equal to the total number of subcarriers (used and guard band subcarriers), and equals D_u.

Table1: OFDM parameters for the mobile WiMAX signal

Channal Bandwidth (MHz)	1.25	5	10	20
FFT size	128	512	1024	2048
Subcarrier SpacingΔf(kHz)	10.94			
Useful symbol duration(µs)	91.4			

The OFDM parameters for mobile WiMAX signals are presented in Table I. As one can notice, the FFT size is scalable with the bandwidth: when the available bandwidth increases, the FFT size also increases, such that the useful symbol duration (equal to the reciprocal of the subcarrier frequency spacing, Δf) is fixed. This in turn leads to a constant useful OFDM symbol duration.

Using the signal model in (2)–(4), one can express the autocorrelation function of r(n),R_τ (n,τ)as the sum of autocorrelation functions corresponding to the signal components, signal and noise, and only noise. We expect that non-zero significant values of R τ (n, τ) are attained at certain delays, for which we subsequently study Rτ(n, τ) and its representation as a Fourier series, and further determine the expressions for the CAF at CF α and these delays, Rτ(α, τ) and set of CFs, {α}.

VI. SIMULATION RESULTS

The signals are simulated with 5 MHz double sided bandwidth. For WiMAX, the number of subcarriers is 256, For the mobile WiMAX signal T_{CP}/T_U equals 1/4. Here we use 256 FFT with 1/4 CP.QAM with 16 points and unit variance of the signal constellation is used to modulate the data subcarriers.The pilot subcarriers in mobile WiMAX are modulated according to the IEEE 802.16e standard.

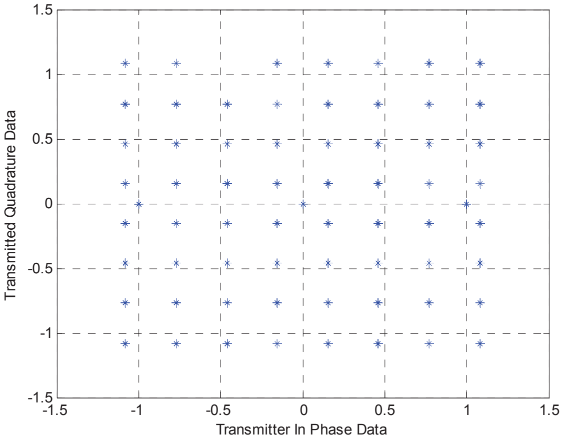

Fig11. Constellation Diagram of Transmitted Signal

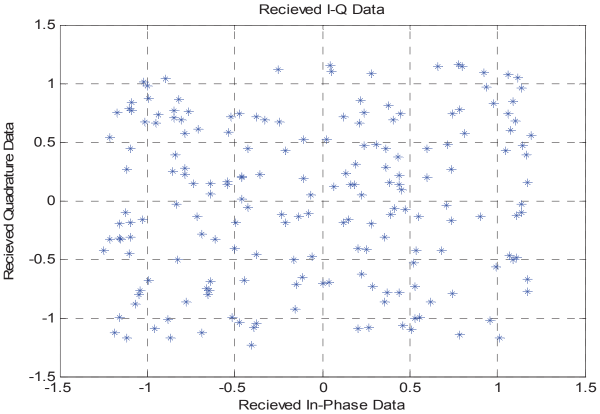

Fig12.Constellation Diagram of Received Signal

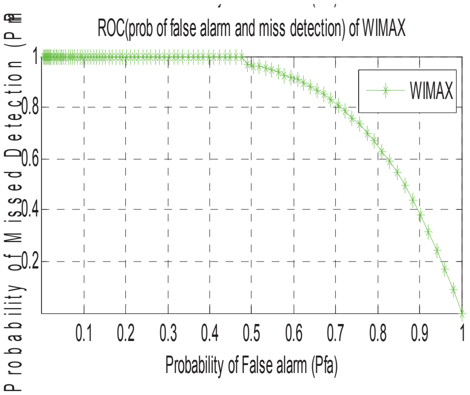

Fig13. ROC curve for WiMAX signal

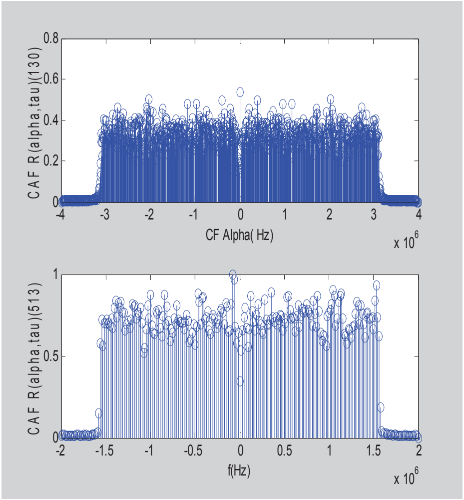

Fig.14Plot of CAF with Frequency& CF

VII. CONCLUSION

Radio frequency spectrum is a very valuable resource in wireless communication systems and it has been a major research topic from last several decades. Cognitive radio is a promising solution which enables spectrum sensing for opportunistic spectrum usage by providing a means for the use of spectrum holes. As described in this paper, the development of the cognitive radio network requires the involvement and interaction of many advanced techniques,including matched filter, energy detection, cyclostationary, periodogram, welch, cooperative spectrum sensing. In this paper, spectrum sensing using wimax is described and studied in terms of cyclic autocorrelation function and ROC curve is simulated.

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