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Analyzing the Performance of Detection Technique to Detect Primary User in Cognitive Radio Network

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Abstract

There are various spectrum sensing techniques were proposed, but still there is room for researchers in this field to explore more sophisticated approaches. There are three major categories of spectrum sensing techniques; transmitter detection, receiver detection and interference temperature detection. Energy detection is one of the popular Spectrum Sensing Techniques in transmitter–based detection. This paper presents, analyze the performance of energy detection technique to detect primary user (PU) in cognitive radio network. The results show the probability of detection increases significantly, when signal to noise ratio increases. It is also observed that the detection probability decreases when the bandwidth factor increases.

Keywords: CR Network, Spectrum Sensing, Energy Detection Technique, SDR, RF, FCC. PSD

1. INTRODUCTION

The Federal Communications Commission (FCC) is responsible for regulation of interstate telecommunication, management and licensing of electromagnetic spectrum within the United States and it enforces requirements on inter station interference in all radio frequency bands. They license segments to particular user's in particular geographic areas. A few, small, unlicensed bands were left open for anyone to use as long as they followed certain power regulations. With the recent boom in personal wireless technologies, these unlicensed bands have become crowded with everything from wireless networks to digital cordless phones .To combat the overcrowding, the FCC has been investigating new ways to manage RF resources. The basic idea is to let people use licensed frequencies, provided they can guarantee interference perceived by the primary license holders will be minimal. With advances in software and cognitive radio, practical ways of doing this are on the horizon. Cognitive Radio can smartly senses and adapts with the changing environment by altering its transmitting parameters, such as modulation, frequency, frame format etc .In the early days of communication there were fixed radios in which the transmitter parameters were fixed and set up by their operators. The new era of communication includes Software Defined Radio (SDR) [2]. A SDR is a radio that includes a transmitter in which the operating parameters including the frequency range, modulating type or maximum radiated or conducted output power can be altered by making a change in software without making any hardware changes. SDR is used to minimize hardware requirements; it gives user a cheaper and reliable solution. But it will not take into account spectrum availability. Cognitive Radio (CR) is newer version of SDR in which all the transmitter parameters change like SDR but it will also change the parameters according to the spectrum availability. In this authors measure the power spectral density (PSD) of the received 6 GHz wide signal. Figure 1 shows very low utilization of spectrum from 3-6 GHz. In order to improve spectrum efficiency dynamic spectrum access technique is imperative. Dynamic spectrum access techniques allow the cognitive radio to operate in the best available channel. More specifically the cognitive radio technology will enable the user to determine which portion of the spectrum is available, detect the presence of primary user (spectrum sensing), select the best available channel (spectrum management), coordinates the access to the channel with other users (spectrum sharing) and migrate to some other channel whenever the primary user is detected (spectrum mobility).

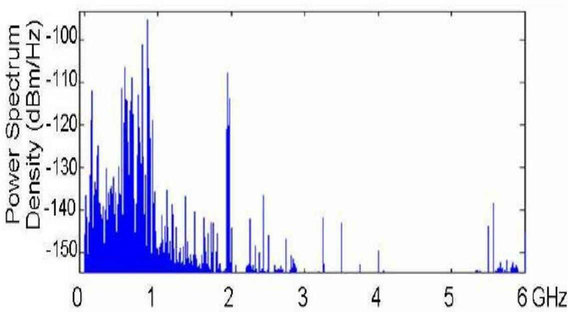

Figure 1: Measurement of 0-6 GHz spectrum utilization at BWRC

2. SPECTRUM SENSING

The ultimate objective of the cognitive radio is to obtain the best available spectrum through Cognitive Capability and re-configurability as described above. Since there is already a shortage of spectrum, the most important challenge is to share the licensed spectrum without interfering with the transmission of other licensed users. The cognitive radio enables the usage of temporally unused spectrum, which is referred to as spectrum hole or white space. If this band is further used by a licensed user, the cognitive radio moves to another spectrum hole or stays in the same band, altering its transmission power level or modulation scheme to avoid interference. The cognitive capability of a cognitive radio enables real time interaction with its environment to determine appropriate communication parameters and adapt to the dynamic radio environment [3-5].

The tasks required for adaptive operation in open spectrum are as follows:

Spectrum sensing: A cognitive radio senses the radio environment. Finds available spectrum band, the information related to its parameters and detects spectrum holes.

Spectrum analysis: The analyses of the spectrum holes that are detected through spectrum sensing and their characteristics are estimated.

Spectrum decision: Cognitive radio first determines its own capabilities e.g. the data rate, the transmission mode, and the bandwidth of the transmission. Then, the appropriate spectrum band selection is made from the spectrum holes determined in spectrum sensing. Once the operating spectrum band is determined, the communication can be performed over this spectrum band [6-8]. However, since the radio environment changes from time to time, the cognitive radio should be aware of the changes of the radio environment. If some primary user wants to communicate on the spectrum band, which is in the use of cognitive radio then the spectrum mobility function is invoked to provide a seamless transmission. Any environmental change during the transmission such as primary user appearance, user mobility, or traffic variation can activate this adjustment.

3. COGNITIVE RADIO ARCHITECTURE

Existing wireless network architectures employ heterogeneity in terms of both spectrum policies and communication technologies. Moreover, some portion of the radio spectrum is licensed for different technologies and some bands remain unlicensed (called Industrial Scientific Medical (ISM) band). A clear description of Cognitive Radio Network architecture is essential for the development of communication protocols.

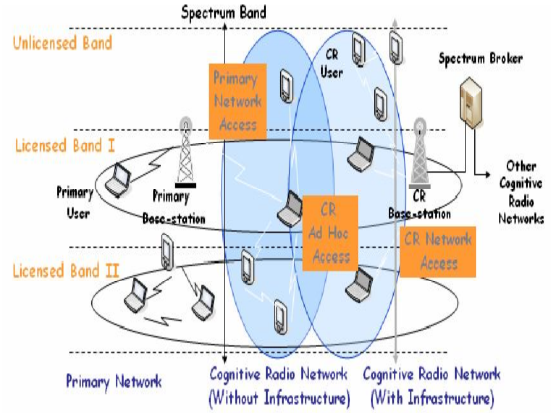

Figure 2: Cognitive Radio Network Architecture [1]

The components of the Cognitive Radio network architecture, as shown in Figure 2, can be classified in two groups such as the primary network and the CR network. The basic elements of the primary and the CR network are defined as follows:

Primary network: A network with rights for a specific radio spectrum band is called primary network. Examples include the common cellular network, WiMAX, CDMA and TV broadcast networks. The components of the primary network are as follows.

a. **Primary user:** Primary user has access to the network via base-station. All of its services and operations are controlled by base-station. Hence, it should not be affected by any unlicensed user or user of any other network. Therefore, primary users do not need any change for coexistence with Cognitive Radio base-stations and Cognitive Radio users.
b. **Primary base-station**: A fixed infrastructure network component for a specific technology with licensed band is called Primary base-station. Examples are base-station transceiver system (BTS) in a cellular system and BTS in Wi-MAX etc. Primary base-station does not have capability for coexisting with Cognitive Radio Network, hence, the primary base-station require some modifications such as the need to have both licensed and Cognitive Radio protocols present for the primary network access of CR users.

Cognitive Radio network: A network where the spectrum access is allowed only in opportunistic manner and does not have license to operate in a desired band is called Cognitive Radio Network. It can be deployed both as an infrastructure network and an ad hoc network as shown in Figure 2. The components of a CR network are as follows.

a. **Cognitive Radio user:** Cognitive Radio user or secondary user has no spectrum license for its operation so some additional functionality is required to share the licensed spectrum band.

b. **Cognitive Radio base-station:** Cognitive radio base-station or secondary base-station is a fixed infrastructure component that provides single hop connection to Cognitive Radio users without any license of radio spectrum. Cognitive Radio user can access the other networks with the help of this connection.

c. **Spectrum broker:** Spectrum broker is a central network entity that provides the sharing of spectrum resources among different CR networks. Hence, spectrum broker can be connected to each network like star topology in Networks and can act as centralized server having all information about spectrum resources to enable coexistence of multiple CR networks.

4. SPECTRUM SENSING TECHNIQUES

The main challenge to the Cognitive radios is the spectrum sensing. In spectrum sensing there is a need to find spectrum holes in the radio environment for CR users.

However it is difficult for CR to have a direct measurement of channel between primary transmitter and receiver. A CR cannot transmit and detect the radio environment simultaneously, thus, we need such spectrum sensing techniques that take less time for sensing the radio environment [9-10]. The spectrum sensing techniques have been classified in the following three categories.

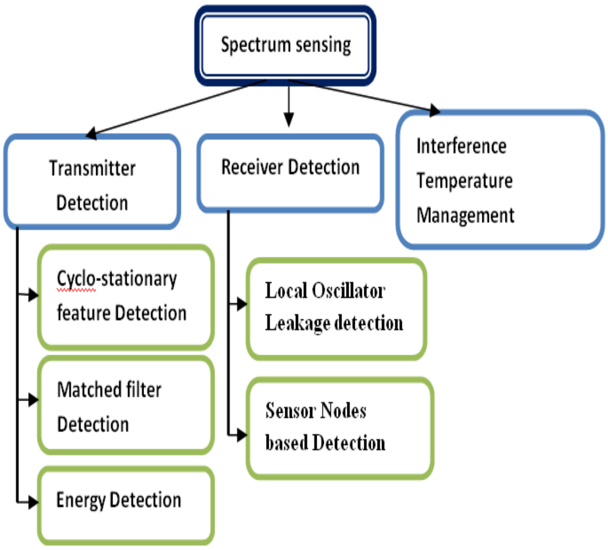

Figure 3: Spectrum Sensing Techniques

4.1 Transmitter Detection

In transmitter detection we have to find the primary transmitters that are transmitting at any given time. Hypothesis model for transmitter detection is defined in that is, the signal received (detected) by the CR (secondary) user is

$$H_o: y(t) = n(t)$$

$$H_1: y(t) = h\, s(t) + n(t)$$

Where y(t) is the signal received by CR, s(t) is the signal received by the primary user(PU), n(t) is the Additive White Gaussian Noise (AWGN), and h is the amplitude gain of the channel.

On the basis of this hypothesis model we generally use three transmitter detection techniques. Now in the following section we will discuss each of the transmitter detection technique their pros and their cons.

i. Matched Filter Detection

A matched filter is a linear filter designed to provide the maximum signal-to noise ratio at its output for a given transmitted waveform. Figure 4 depicts the block diagram of matched filter. The signal received by CR is input to matched filter which is r (t) = s (t) + n (t). The matched filter convolves the r (t) with h (t) where h (t) = s (T-t + τ). Finally the output of matched filter is compared with a threshold λ to decide whether the primary user is present or not.

A Matched filter is an optimal detector in an AWGN channel, if the waveform of primary user is previously known by CR. It means that CR should have knowledge about the waveform of primary user such as modulation type and order, the pulse shape and the packet format. So if CR doesn't have this type of prior information then it's difficult to detect the primary user.

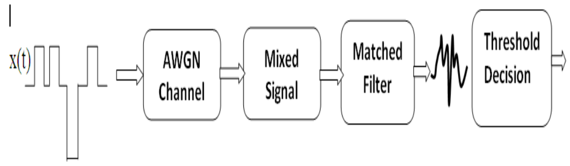

Figure 4: Block Diagram of Matched Filter

We can still use Matched Filter Detection because in most of the communication networks we can achieve this coherency by introducing pilots, preambles, synchronization word or spreading codes in the waveform of primary users. Still there are limitations in matched filter because each CR should have the information of all the primary users present in the radio environment. Advantage of matched filter is that it takes less time for high processing gain. However major drawback of Matched Filter is at a CR would need a dedicated receiver for every primary user class.

ii. Energy Detection

If CR can't have sufficient information about primary user's waveform, then the matched filter is not the optimal choice. However if it is aware of the power of the random Gaussian noise, then energy detector is optimal.

In the authors proposed the energy detector as shown in Figure 5. The input band pass filter selects the center frequency fs and bandwidth of interest W. The filter is followed by a squaring device to measure the received energy then the integrator determines the observation interval, T. Finally the output of the integrator, Y is compared with a threshold, λ to decide whether primary user is present or not.

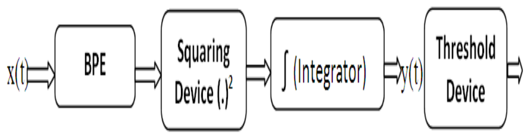

Figure 5: Block Diagram of Energy Detector

In fading environment where different CR users need to cooperate in order to detect the presence of the primary user. In such a scenario a comprehensive model relating different parameters such as detection probability, number and spatial distribution of spectrum sensors and more importantly propagation characteristics are yet to be found. One of the main problems of energy detection is that performance is susceptible to uncertainty in noise power. It cannot differentiate between signal power and noise power rather it just tells us about absence or presence of the primary user.

iii. Cylostationary Feature Detection

Modulated signals are in general coupled with sine wave carriers, pulse trains, repeating spreading, hopping sequences, or cyclic prefixes, which result in built-in periodicity. Even though the data is stationary random process, these modulated signals are characterized as Cyclostationary, since their statistics, mean and autocorrelation, exhibits periodicity. These features are detected by analyzing a spectral correlation function. The periodicity is provided for signal format so that receiver can use it for parameter estimation like pulse timing, carrier phase etc. This periodicity can be used in the detection of random signals with a particular type of modulation with the noise and other modulated signals.

Recent research efforts exploit the Cyclostationary feature of signal as method for classification, which has been found to be superior to simple energy detection and match filtering. As discussed, a matched filter as a coherent detector requires prior knowledge about primary user's wave while as in energy detector as a non coherent detection does not require any sort of prior knowledge about primary user's waveform. Although energy detector is easy to implement, it is highly susceptible to in band interference and changing noise levels and cannot differentiate between signal power and noise power.

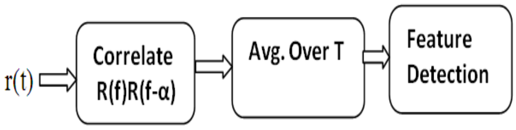

Figure 6: Block Diagram of Cyclostationary Feature Detector

Implementation of spectrum correlation function for Cyclostationary feature detection is depicted in Figure 2.3. Detected features are the number of signals, their modulation types, symbol rates and presence of interferers. If the correlation factor is greater than the threshold then it means that there is a primary user in radio environment. Although it performs better than energy detector because it can differentiate between signal power and noise power, it is computationally very complex that requires long processing time, which generally degrades the performance of Cognitive radio. Signal processing techniques motivate the need to study other feature detection techniques that can improve sensing detection and recognize modulation number and type of signals in low SNR regimes.

Limitations of Transmitter Detection

There are two limitations of transmitter detection, Receiver uncertainty problem and shadowing problem. First, in transmitter detection cognitive radio users have information only about primary transmitter and it has no information about primary receiver. So cognitive radio can identify receiver through weak transmitted signals. This sort of problem is called receiver uncertainty problem. Moreover transmitter detection faces the hidden node problem that limits its usability. Secondly, shadowing causes cognitive radio transmitter unable to detect the transmitter of primary user.

Cooperative Vs Non Cooperative

The detection behavior can be categorized into two main branches, Non cooperative and cooperative. In non cooperative detection behavior cognitive radio user can detect the signal of primary transmitter by its own observation and analysis independent of the other cognitive radio users. While in Cooperative detection behavior the information from many cognitive radio users are combined to detect the primary user. Moreover, Cooperative behavior helps to overcome the multi path fading and shadowing effect that will increase its usability. There are two ways for the implementation of cooperative detection, centralized and distributed. In Centralized Cooperative detection mechanism the base station is responsible for gathering all information from other cognitive radio users to detect the primary user .While in distributed mechanism cognitive radio exchange information among each other to get the desired objective. With comparison to non cooperative mechanism cooperative detection provides more accurate performance at the expense of additional operations and overheads but it still lacks about location of the primary receiver [9].

4.2 Receiver Detection

Now we need such spectrum sensing techniques which are able to remove the problems in transmitter detection. To remove receiver's uncertainty, we have to design techniques which we have some information about primary receiver. The makers of transmitter detection techniques state that we have available the information about primary receiver. The detection of weak signals from primary transmitter where it was shown [10] that the problems becomes very difficult when there is uncertainty in the receiver noise variance. Then new spectrum sensing techniques are introduced in which we will get information about receiver from its own architecture.

i. Local Oscillator Leakage detection

Modern day radio receivers are based on super heterodyne receiver architecture invented by Edwin Armstrong in 1918. This architecture is shown in Fig 6.

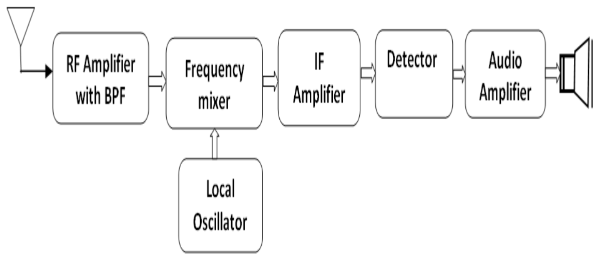

Figure 6: Architecture of Super heterodyne Receiver

This type of receiver architecture converts Radio frequency (RF) into fixed low intermediate frequency (IF). In order to convert RF to IF, frequency mixer is used which consists of local oscillator (LO). Local oscillator is tuned on a frequency such that when mixed with incoming RF signal, it converts it into fixed low IF band. In all of these receivers, there is inevitable reverse leakage, and therefore some of the local oscillator power actually couples back through the input port and radiates out of the antenna. If we are able to measure this LO leakage then problem of receiver uncertainty is solved. But things are never this simple. In the past decade, some improvements have been made to the receiver's architecture, resulting in reduced LO leakage power.

Detecting this leakage power directly with a CR would be impractical for two reasons. First, it would be difficult for the receive circuitry of the CR to detect the LO leakage over larger distances. In they calculate and prove that at a distance of 20m, it would take on order of seconds to detect the LO leakage with a high probability. In section 1 we see that we need sensing time in milliseconds in worst cases. The second reason that it would be impractical to detect the LO leakage directly is that LO leakage power is very variable and depends on the receiver model and year. Currently this method is only feasible in the detection of the TV receivers.

ii. Sensor Nodes for Receiver Detection

This is proposed to build tiny, low cost sensor nodes that would be mounted close to the primary receivers. The node would first detect the LO leakage to determine to which channel the receiver was tuned. It would then relay this information to the CR through a separate control channel using a fixed power level. Working of this is shown in Figure 7.

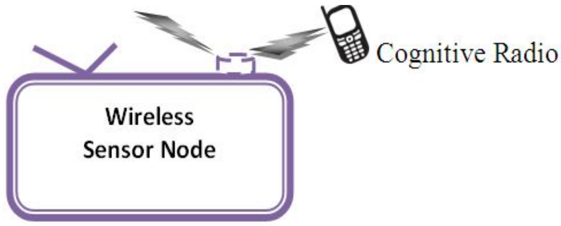

Figure 7: Sensor Nodes Notifying Cognitive Radio

4.3 Interference Temperature Management

Interference is typically regulated in a transmitter centric way. Interference can be controlled at the transmitter through radiated power, out-of-band emissions, location of individual transmitters and frequencies used by specific type of radio operations. There interference management techniques served well in the past but do not take into account the interference from the receiver point of view, as most of interferences occur at the receiver. Moreover, the dramatic increase in the overall demand for spectrum based services, rapid technical advancements in radio systems; in particular the introduction of new robust modulation techniques demands a new technique that focuses on actual RF environment and interaction between transmitter and receiver. This demand moves us towards new interference management technique known as Interference Temperature Management. We can define interference temperature as measure of the RF power generated by undesired (CR) emitters plus noise that is present in the receiver system per unit of bandwidth. The emissions from undesired (CR) transmitters could include out of band emission from transmitters operating on adjacent frequencies as well as from transmitters operating on the same frequency as a desired transmitter. In principle, the interference temperature measurements would be taken at various receiver locations and these measurements would be combined to estimate real time condition of RF environment. The interface temperature model shown below explains the signal of a radio 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. This model manages the interference at the receiver through the interference temperature limit, which is represented by the amount of new interference that the receiver can tolerate.

5. IMPLEMENTATION

Energy detector measures the energy received from primary user during the observation interval. If energy is less then certain threshold value then it declares it as spectrum hole. Let y(t) is the received signal which we have to pass from energy detector.

Algorithm:

Step 1: initialize the carrier frequencies F_{Cn} = {1000, 2000, 3000, … , N} and let the user message/data signal frequency F_{Sn} ={ 1000, 2000, 3000, ……. ,N}

F_{Cn}= {F_{C1}, F_{C2}, F_{C3},……,F_{Cn}} , F_{Sn}={F_{S1}, F_{S2}, F_{S3},……F_{Sn}} and Where n=1, 2,3,…N.

Step 2: Determining the every user's base band data Signal (x) is as given

$$X_n = \cos(2*\pi*1000*t)$$

Once user 1's data arrive, it is modulated at the first carrier F_{C1}, similarly as the 2^{nd} user's data arrives, it is modulated at the 2^{nd} carrier F_{C2}, so on till N^{th} user is assigned the F_{Cn} band. If any user's data is not present his frequency band remains empty which is called a Spectral Hole.

Step 3: Analyze and assign the spectral hole to Secondary user (SU) and this can be done as given,

```
in_p = input ('\nDo you want to enter first primary user Y/N:  ','s');
if(in_p == 'Y' | in_p == 'y')
  Yn = ammod(x,FCn,FSn); where n=1,2,3,…N
  end
```

Once all the assignment is complete we add all the signals to create a carrier signal which will be analyzed for empty slots as the channel.

$$Y_n = y_1+y_2+y_3+\ldots+y_N;$$

Step 4: Now estimate Power Spectral Density (PSD) by using periodogram function in MATLAB and the values are stored in an array P_{xx}.

$$P_{xx} = \text{periodogram}(Y_n);$$

Step 5: The power spectral density (PSD) is intended for continuous spectra. The integral of the PSD over a given frequency band computes the average power in the signal over that frequency band. This value is then stored in a dspdata object and then plotted.

```
Hpsd = dspdata.psd(Pxx);
plot(Hpsd);
```

Step 6: Now one frequency component takes almost 20 points in MATLAB. So for each frequency there points are summed and get the result.

Step 7: On experimental basis when results at low and high SNR are compared then threshold λ is set to be 5000.

Step 8: Finally the output of the integrator, Y is compared with a threshold value λ to decide whether primary user is present or not.

We assume that energy detection is applied at each CR user. The energy detector consists of a square law device followed by a finite time integrator. The output of the integrator at any time is the energy of the input to the squaring device over the interval *T*. The noise pre-filter serves to limit the noise bandwidth; the noise at the input to the squaring device has a band-limited and flat spectral density.

5.1 Result and Discussion

All simulation was done on MATLAB version R2011a under AWGN channel. We use receiver characteristics (ROC) analysis for the signal detection theory to study the performance of the energy detector. ROC has been widely used in the signal detection theory due to the fact that it is an ideal technique to quantify the tradeoff between the probability of detection (Pd) and the probability of false alarm (Pfa).

Figure 8 shows that ROC of spectrum sensing for different SNR under AWGN channel. The simulation was carried out for the analysis of detection probability under different number of SNR. Where Pfa=0.01 and time bandwidth factor *u*=100 were taken for this simulation. SNR was taken 0dB to 25dB and figure 8 shows that performance of detection varies based on SNR. It also shows that with the increasing of the SNR (from 0dB to 25dB) the detection also increased and detection probability was almost zero before 15dB. The detection probability increased after the 15dB and significantly increased after 20dB and finally we get detection probability 1 when SNR is 25dB.

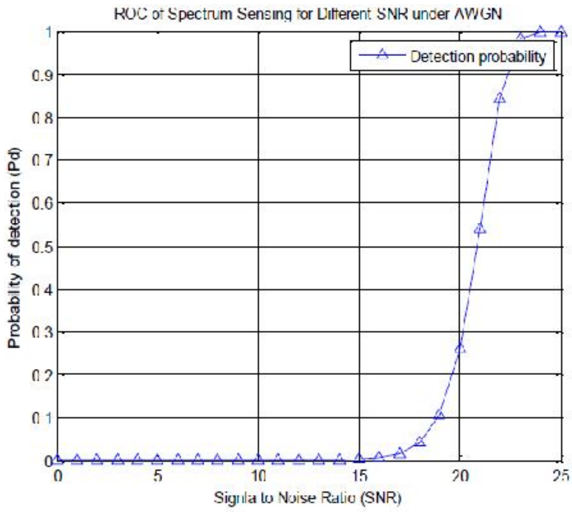

Figure 8: ROC of spectrum sensing for different SNR

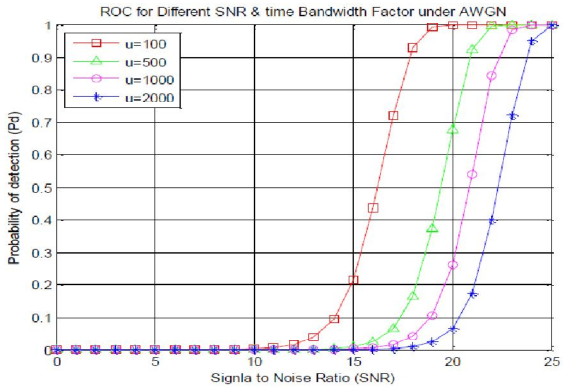

Figure 9: ROC for different SNR and time bandwidth factor under AWGN

Figure 9 shows that ROC of spectrum sensing for different SNR and time bandwidth factor under AWGN channel. Receiver operating characteristic (ROC) curves are drawn for several time-bandwidth products. From fig.8, we saw that probability of detection is best for the signal to noise ratio from SNR=22dB to 24dB and detection is 1 for 25dB. For this again SNR from 0dB to 25dB is used for fig. 9 Where Pfa=0.01 and time bandwidth factor *u* is changed to 100, 500, 1000 and 2000. By changing *u*, it shows that probability of detection is decreases when *u* increases.

- It shows that when *u*=100, SNR from 17dB to 20dB is approximately good. When SNR is 21dB to 25dB, then detection probability is 1.
- In the case of *u*=500, then SNR from 20dB to 22dB is approximately good. When SNR is 23dB to 25dB, then detection probability is 1.
- In the case of *u*=1000, then SNR from 21dB to 24dB is approximately good and when SNR is 25dB, then probability of detection is 1.
- Again in the case of *u*=2000 and SNR =25dB, the detection probability is almost good. So when the time bandwidth factor is increasing, the probability of detection is decreasing. It also shows that SNR=25dB is approximately good.

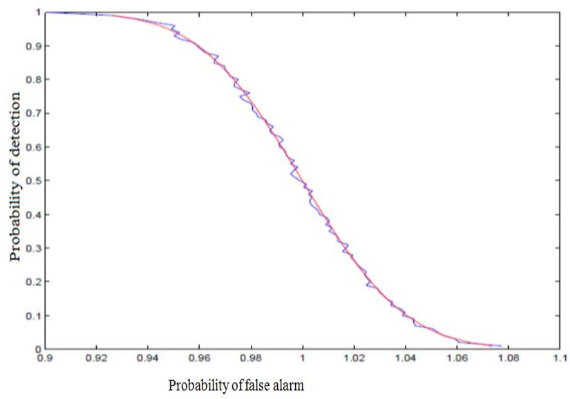

Figure 10: ROC of Spectrum Sensing for Different Probability of False alarm and Probability of detection

We can observe that probability of false alarm decreases as probability of detection increases .At Pd = 0.1, $P_f = 1.07$ so indirectly $P_d \propto \frac{1}{pf}$.

6. CONCLUSION

In this paper, we have discussed spectrum sensing based on energy detection in CR networks. ROC curves are used to plots of the probability of detection vs. the probability of false alarm. The probability of detection varies based on SNR, probability of false alarm and various time bandwidth factors. SNR influences on the detection probability. When SNR increases, the detection probability increases and we also get SNR=25dB is better where detection probability. Again the detection probability varies depend on time bandwidth factor. If time bandwidth factor increases, the detection probability decreases. The false alarm probability also effects on detection probability. If false alarm increases, the detection probability increases. We also get the suitable SNR for the energy detector. So we almost get the final result of the spectrum sensing for cognitive radio based on Energy Detection as we expected.

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