Performance Analysis of Non Cooperative Spectrum Sensing Schemes in 5G Cognitive Radio Networks

R.Ramyea
Department of ECE
Kongu Engineering College
Perundurai - 638060,TamilNadu,India

N.Kasthuri
Department of ECE
Kongu Engineering College
Perundurai-638060, Tamil Nadu, India

***Abstract*—Cognitive Radio Networks (CRN) and the Fifth Generation of wireless cellular standard (5G) is considered as the vital solution for the increasing usage of cellular and internet services. 5G Architecture consists of interconnection of different wireless networks, including LAN, WAN, World Wide Web. The usage of smart antennas, CDMA technologies and CRN will lead to the development of the ultra-high speed and efficient 5G network. The unoccupiedwireless channels in the spectrumband can be effectively utilized by using an intelligent radio called "Cognitive Radio",therby eliminating the user interference and blockage. Cognitive radio network monitors the nearby radio links and tracks information regarding the availability of the spectrum. Collected information and dataare used to provide the access to the cognitive radio users while guaranteeing the normal operation of the licensed users. In this context, spectrum awareness and spectrum exploitation techniques are the major mechanisms of cognitive radio technology. Among these, spectrum sensing comes under the spectrum awareness technique. It plays a major role in any CRN for a better selection of the radio link from the available pool of spectrum. This paper exploits various non cooperative spectrum sensing methodssuch as Energy Detector, Matched Filter, Covariance Detector and Eigen value based detector. These spectrum sensing algorithms are simulated and the simulation results are analyzed and compared.**

Keywords—CRN, 5G, Spectrum sensing, non cooperative

I. INTRODUCTION

Emerging advances in the technology in the field of telecommunicationresults in the huge need of the limited natural resource, so called "Electromagnetic radio spectrum"[4]. Due to the static allocation of the available frequency bands, few bands are overutilised whereas some of them are underutilised. Conventional technique of spectrum management is not flexible because of the allocation of the dedicated frequency band to each wireless service provider. Hence it is very difficult to allocate frequency band for new users and services. In order to overcome this condition, more efficient and dynamic spectrum allocation techniques is needed.

Cognitive Radio is the vital solution for spectrum underutilization in a wireless communication system. The Role of a CRis to offer reliable channel for all the usersof the network.Fig. 1 illustrates how the licensed spectrum band is being utilized and also indicates the unoccupied bands.Many regulatory authorities and network providersbeginto find a new technique to utilize the unused licensed bands. These bands are known to be "white spaces"[5].

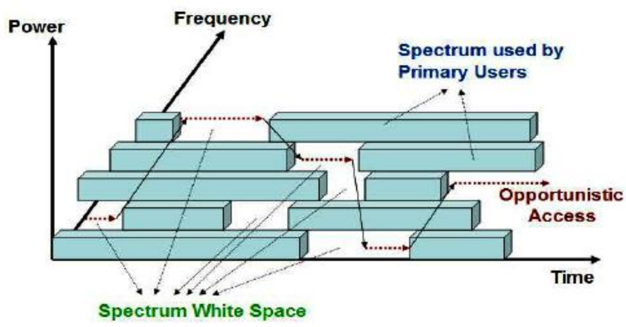

Fig. 1. Concept of Spectrum white space

Spectrum sensing, spectrum management, spectrum sharing and spectrum mobility are the main sub domains of the cognitive radio techniques.Users in the cognitive domain are splitted as Primary User (PU) and Secondary User (SU) or Cognitive Radio User (CRU).The existence of the licensed users or primary users andthe availability of the channelcan be determined by spectrum sensing. Spectrum management is to estimates the time duration of the available spectrum white spaces for providing access to the unlicensed users (SU or CRU)[1]. Secondary users can access the spectrum until it is required by the licensed user. Those secondary users should not create any interference to the licensed user's signal. Then the secondary users has to choose another unfilled portion of the spectrum via spectrum sensingin such a way to meet its QoS requirements. This is named as spectrum sharing. Section II deals with the overview of the cognitive radio and spectrum sensing mechanism. Section III dealts with non cooperative spectrum sensing techniques. Simulation results of the algorithms are analyzed and compared in the section IV. Section V concludes the paper with further scope of improving the usage of spectrum through cognitive radio.

II. COGNITIVE RADIO

An adaptive, dynamic radio tovary the transmission parameters of itself according to the current condition of the channel is termed as "Cognitve Radio". The main intention of CR is to select the best channel available from the radio spectrum. The CR user senses the spectrum to detect the unoccupied one. Those unoccupied group of channels are called as the spectrum holes or white space. Cognitive user can access the channel until the licesnsed usersignal arrives, on that case, cognitive user leaves the spectrum and moves to new unfilled spectrum for a seamless transmission of data. The spectrum white space concept is depicted in Fig. 1

[7]. Level of the Interference between CR and PU user decides the effectiveness in the usage of channel.

Some of the features of cognitive radio are: Parameters such as frequency of the transmitting signal, allocated bandwidth, power, type of modulation employed, etc can be sensed and the corresponding information can be collected by a cognitive radio node from its radio link. The optimum channel available can be chosen by adjusting those parameters. It also adjusts those parameters without altering any hardware components [6]. Cognitive cycle can be explained as follows: The cycle starts by sensing the radio environment and fetching the information (spectrum sensing). With the collected data, it adjusts the parameters and makes a decision (spectrum decision). CR will also organize the accessing of spectrum with others (spectrum sharing). CR monitors the usage of both PU and SU users and moves the channel to SU effectively with less congestion and interference with PU (spectrum mobility).

Channel selection and spectrum hole detection are the two main mechanism under spectrum sensing. The knowledge of the spectrum availability is collected through the spectrum sensing. And with the known knowledge, the presence of PU is identified. The duration of sensing time greatly influence the accuracy of the gained knowledge[7], but the transmission time will get reduced. Sensing time ca be reduced by employing cooperative spectrum sensing, because of the cooperation between the users.Non-Cooperative Spectrum sensing techniques are discussed in the following section.

III. SPECTRUM SENSING SCHEMES

A. Energy Detection

If the prior knowledge of the primary user signal is not known , then the energy detection method is thebest suitedone for detecting any sequence of signals [6].In this technique, the energy level of the received Radio-Frequencysignalin the channel is measured to decide whether the channel isidle or not. The presence of any primary user can be detected via the energy of the received signal. If the energy level exceeds the predefined threshold level, then it indicates the presence of primary user otherwise it indicates the absence of primary user[6]. Threshold value can be determined and fixed based on the noise variance and current state of the channel. Initially, the required frequency band of the signal is obtained using a bandpass filter. Then, for the finite interval of time, the filtered signal is intergrated.To decide whether the primary user is present or not, the final output signal is compared to the fixed threshold level.

Energy detection detects the presence or absence of the PU signal before allocating the channel to any SU. This process of detection is known as “Hypothesis test”. Probabilty of detection indicates the presence of PU signal and the probability of false alarm indicates the presence of random noise in the channel. The values of these probabilities decide whether the channel is idle or not.

Let x be any random signal in the channel,

H_0 and H_1 be the hypothesis 0 and hypothesis 1 for indicating the absence and presence of primary user signal in the channel respectively.

γ be the predefined threshold level of energy

Hypothesis is H_1 , if $H_1 > H_0$

Hypothesis is H_0 , if $H_0 > H_1$

Probability of detection of the signal is high and the corresponding probability of the false alarm is low for H_1 and vice versa for H_0. Fast Fourier Transform (FFT) methods can also be employed inorder to analyze the signal spectrum in digital domain. Time domain sampling is done with the received signal and finaly the power spectrum is obtained. By employing suitable windowing technique, the peak portion of the spectrum can be clipped off in the frequency domain.Although there is no need of any the prior knowledge of primary user signal, energy-detection technique has some shortcomings. The first one is the poor performance for low SNR systems. This is due to the lack of accurate knowledge of noise variance at low SNR and this uncertainity of noise value may make the energy detection useless. Another challenging problem is the high level of difficulty indifferentiating theprimary user with the interference and other secondary users sharing the same channel [6]. A small error in noise power estimation leads to a notable loss in the performance, since the threshold level fixed in energy selection is dependent on the noise variance.

B. Matched Filter Detection

In matched filter detection, prior knowledge of primary user signalis required for feature detection. The detection process mainly compares the received signals with PU signals in the channel and maximizes the SNR.Major advantage ofmatched filter detection technique is that it attains highprocessing gain with the minimal duration of time [9]. All the prior information such asmodulation type, pulse shape, and packet format etc., should be correct. Otherwisethe performancewill decay.

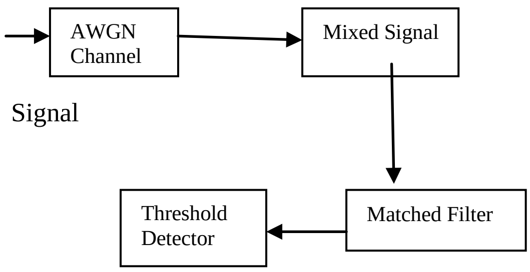

Fig. 2. Block diagram of Matched filter spectrum sensing

Fig. 2 illustrates the operation of the matched filter spectrum sensing. It can be seen that the transmitted signal is made to pass through AWGN channel ie. the signal is now added with the additivie noise and combination of signal and noise is fed to the next stage. Thecombined signal is made to pass through as an input to the matched filter. Convolution of the incoming signal and thematched filter impulse response is taken. Next, comparison is done between the matched filter output signal and the threshold level to detect the primary user signal. The threshold (γ) of a signal is determined as a function of signal variance, Q function ofprobability of false alarm. Detection/ sensing of the primary user signal is mainly dependent on the approporiate selection of threshold level.

The signal component at output of the mateched filter at an instant of time t is given by,

$$signal(t) = 1/2\pi\ (s(\omega))^2 = E$$

where E indicates energy of a signal.

if,

y(t) >γ : it indicates thepresence of PU signal

y(t) <γ : it indicates the absence of PU signal.

where y(t) is the output of the matched filter and it can be given as

$$y(t) = signal(t)+w0(t)$$

$$y(t) = E + w0(t)$$

Here w0(t) is a noise.

In the absence of a PU, received signal will be

$$y(t) = w0(t)$$

It indicate the presence of noise only.

C. Covariance Detection

The time dispersive nature of wireless channel provides many signal samples at the receiver. These samples are then need to be checked for correlation between them for an effective reproduction of the transmitted signal at the receiver. These correlation properties are utilized through a technique called covariance detection. The correlation between the samples can be obtained interms of time and space. Oversampling of the signal guartantees the time correalation. Some of the advantages of this method would be independency of the information of PU signal or noise. Probability of false alarm (P_{fa}) and sample size are the parameters considered for threshold level determination. Noise power estimation is not required. Therefore, the problem of noise power uncertainity, present in Energy Detection (ED) method is reduced [10,14]. This detection method produces good results if the received signal samples are highly correlated with each other. When the level of uncorrelation increases then the uncertainity in the output will also increase.

D. Eigen Value Based Detection

Spectrum can be sensed through the calculation of eigen values obtained from the sample covariance matrix. It relates the maximum or average eigen value and the minimum eigen value. [13,12]. Prior information of signal to noise power is needed in techniques such as energy detection, but the eigen value based detection employes the comparison process among the energy of the signal and the minimum eigenvalue of the sample covariance matrix. These matrices are calculated only from the received signal. This method doesn’t require any information about the nature of the transmitted signal and channel. Thesetechniquesare termed as “blind detection” methods. It doesn’t exploits the threshold value with the noise power [10,11]. The threshold value can be computed at the beginning, which is based only on number of samples, probabbilty of false alarm, irrespective of signal and noise.

IV. SIMULATON RESULTS

Non cooperative spectrum sensing algorithms such as Energy detection, Matched filter, Covariance and Eigen value based detection are simulated in MATLAB platform and the simulation results are discussed in the following section. The algorithms are initialized with the number of samples, probability of false alarm, signal to noise ratio, variance and the threshold value of energy signal.From the simulation results it can be seen that the probability of detection of the energy signal of the primary user in the channel has different values for the four different algorithms. Fig. 3 shows the variation of the probability of detection with SNR values in dB for Energy detection algorithm. It can be seen that the for different values of probablility of false alarm, probablility of detection vs signal to noise ratio is plotted in the Fig. 3. Output of Energy Detector shows that when SNR increases with varies fixed values of P_{fa} , the probability of detection (P_D) approaches to one for lowest value of P_{fa} . It can be inferred that whenever the false probability reduces it results in high chance of detection of the primary user with the required level of SNR in dB. Matched filter output curve is shown in the Fig. 4. It produces result similar to energy detector algorithm. Probabilty of detection approaches to unityfor the lowest value of P_{fa}.

Fig. 5 shows the variation between P_{fa} and P_D with the signal to noise ratio in dB as constant for Covariance detector. It can be noted that the likelihood of detection of primary user directly related to the SNR values. The maximum probability is achieved with the highest value of SNR (-12 dB). Therefore, signal power transmitted need to be high inorder to achieve low probability of false alaram which leads to high chance of detecting the PU signal.

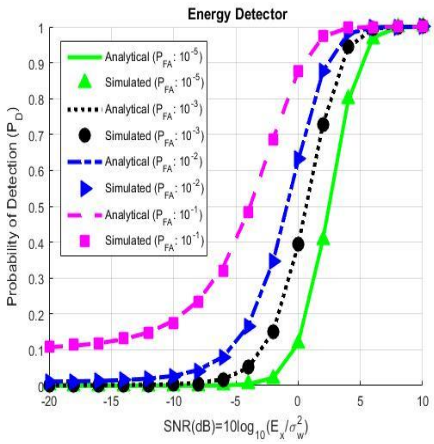

Fig.3. Output Curve for the Energy Detector

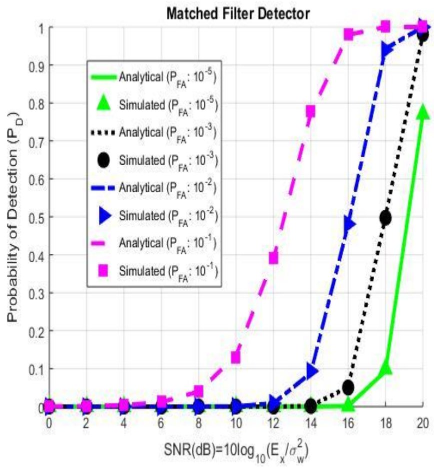

Fig.4. P_D vs SNR for various values of $P_{fa}$for Matched Filter

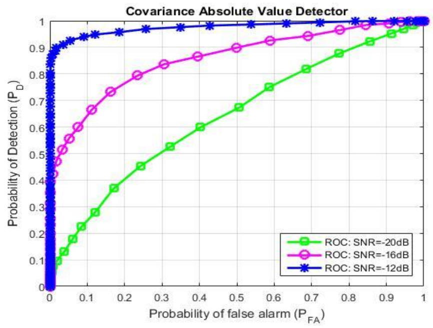

Fig.5. ROC Curve of the Covariance Detector

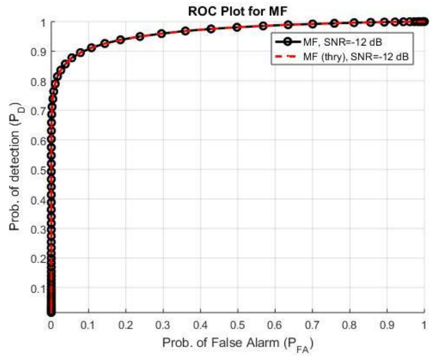

Fig. 8. ROC Curve for Matched Filter

Fig. 7 and Fig. 8 shows the ROC plot for energy detector and matched filter respectively. Maximum eigenvalue detector algorithm results in a similar way to covariance detector. The difference between them is the achievable probability of detection. It can be seen from the Fig. 6, P_D is approaching to one for lower values of SNR (-16 dB) and exactly one for -12dB.

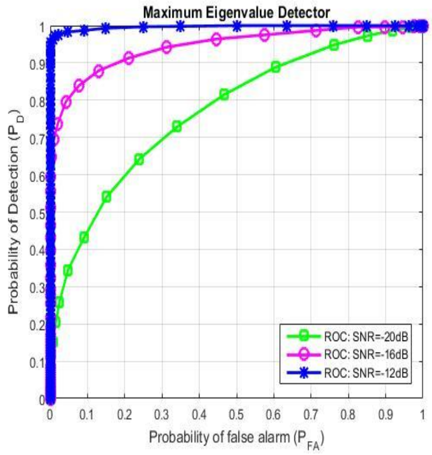

Fig. 6 ROC curve for Eigen value Detection Algorithm

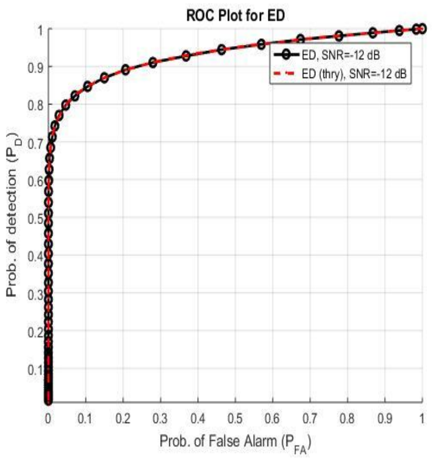

Fig. 7. ROC curve for Energy Detector

Among the four spectrum sensing algorithms, it is noted that the Eigenvalue based detection outperforms the other three algorithms. This is due to the consideration of eigen values and the distinct way of determining threshold value. ROC is the Receiver Operating Characteristic curve plotted between the probability of detection and probability of false alarm.

From Table I, it can be seen that the matched filter requires more transmitter signal power inorder to achieve the maximum detection probability. Table 2 shows that the Eigen value detector performs well when compared to other three algorithms. This is because the detection of primary user can be done faster at a minimal value (0.1) of probability of false alarm.Table II shows the comparison of all the four spectrum sensing algorithms for -12 dB SNR.

TABLE I. COMPARISON OF SNR AND P_D

Algorithm	P_D	**SNR(dB)**
Energy Detector	0.9	5
Matched Filter	0.9	20

TABLE II. COMPARISON OF ALGORITHMS FOR SNR -12DB

Algorithm	P_{fa}	
Energy Detector	0.9	PD (approaching maximum value) ie. 1
Matched Filter	0.6	
Covariance Detector	0.4	
Eigen Value	0.1	

V. CONCLUSION AND FUTURE ENHANCEMENT

The performance analysis of the four non cooperative spectrum sensing algorithms are discussed. All the four algorithms are simulated and the simulation results shows that the eigen value based spectrum sensing provides effective and reliable results even for lower levels of SNR. Therefore, it is more suitable for 5 G based communication than other algorithms. More recently, cooperative spectrum sensing schemes are more focused in the wireless communication[8]. For developing an algorithm for such schemes, the basic knowelge is required in the non-cooperaive sensing methods. The paper provides the start up knowelge in the spectrum sensing domain. Future wireless communication greatly relies on the cognitive radio due to the increasing demand of wireless devices. Hence any of these algorithms can be further explored interms of cooperative methodologies for the improvement of primary user detection, which is the mandatory process of any spectrum sensing.

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