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Approaches to Spectrum Sensing and Spectrum Sharing Algorithms in Cognitive Radio Networks: Survey

Soniya S.Christani[1], Jigneshkumar N. Patel[2]

PG Student, Department of ECE, Sardar Vallabhbhai Patel Institute of Technology, Vasad, India[1]

Assistant Professor, Department of ECE, Sardar Vallabhbhai Patel Institute of Technology, Vasad, India[2]

ABSTRACT: Cognitive Radio is an emerging design paradigm that can potentially alleviate the problem of spectrum shortage. The main requirement for using Cognitive Radio is spectrum sensing. In this paper, survey of various problem of spectrum sensing in cognitive radio networks are presented. The challenges and issues involved in implementation of spectrum sensing techniques are studied. A number of techniques to solve the problem of spectrum sensing and a discussion of their complexity and performance are introduced. The two approaches to spectrum sensing namely cooperative spectrum sensing and non cooperative spectrum sensing are presented. Moreover, in this survey spectrum sharing has been discussed. As the key technology and main objective of Cognitive Radio, spectrum sharing can make full use of the limited spectrum, alleviate the scarcity of frequency resources and improve the system utilities, playing thereby an important role in improving the system performance of cognitive radio networks (CRNs). In this survey, the spectrum sharing in CRNs is discussed in terms of the sharing process. In particular, comparisons of different spectrum sharing strategies are concluded, as well as sensing based sharing is discussed.

KEYWORDS: Cognitive Radio; Primary Users; Secondary Users; Dynamic Spectrum Access; Spectrum Sensing; Spectrum Sharing

I. INTRODUCTION

In the past decade, there has been an explosive growth in spectrum demand because of increasing number of wireless services. A different wireless services are allocated to different licensed frequency bands, leading to a more and more congested radio spectrum[3]. According to survey of the Federal Communications Commission(FCC) show that many licensed frequency bands are underutilized [2]. Cognitive radio (CR) has been proposed as a way to improve spectral efficiency by exploiting unused spectrum in dynamically changing environments. The cognitive transmitters/receivers use the environmental information to move towards an appropriate parameters, such as modulation type, modulation index, coding format, transmission power level and latency in order to maximize their data transmission rates under a constrained interference level.

Cognitive Radio network contains two types of users namely primary users(PU) i.e., licensed user that have higher priority on the usage of spectrum and secondary users (SU) i.e., unlicensed users that have lower priority to use the spectrum in opportunistic manner without causing any interference to the primary users[3].

In this paper, we focus mainly on spectrum sensing as it is the main requirement for the establishment of cognitive radio. The challenges and issues involved in implementation of spectrum sensing techniques are studied. A number of techniques to solve the problem of spectrum sensing and a discussion of their complexity and performance are introduced. Moreover, the problem spectrum sensing under the framework of binary hypothesis testing has been presented.

The rest of this paper is organized as follows: Section II contains different accessing techniques for CR networks. Section III presents techniques commonly used for spectrum sensing. Section IV contains different approaches to spectrum sensing which includes cooperative and non cooperative spectrum sensing. In section V present Spectrum Sharing and its different approaches and finally conclusions are presented in Section VI.

II. ACCESSING TECHNIQUES FOR COGNITIVE RADIO NETWORKS

Access techniques for CR networks can be classified into two types:

- Overlay approach (or interference-free approach): In this approach, the SUs uses that portion of the spectrum which is not used by primary users [5]. As a result SUs do not cause any undue interference to PUs. CR networks that are based on overlay approach are referred as overlay CR networks.

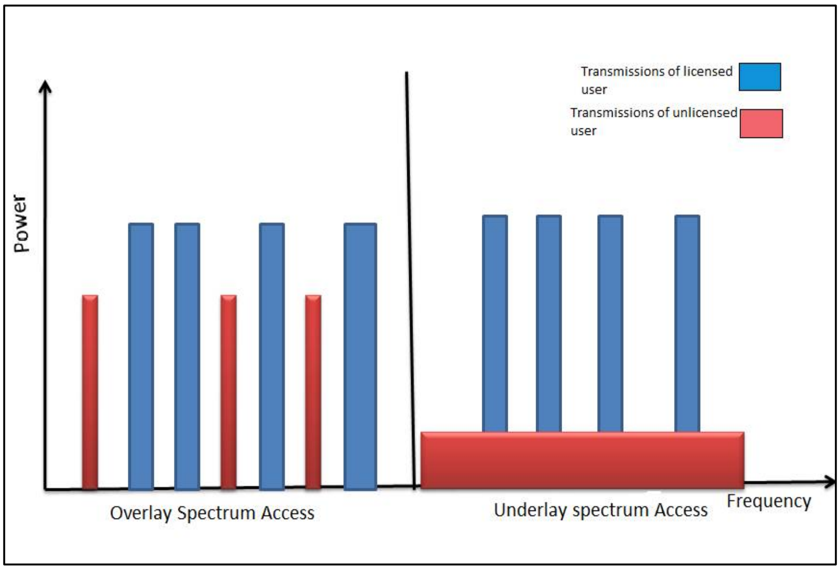

Fig. 1: Accessing techniques for CR networks

- Underlay approach (or interference-tolerant approach): In this approach, [6] the SUs spreads the signals over a wide band of frequencies and thereby pursue its transmission. Spreading over a large bandwidth would help secondary users transmit below the noise floor of primary users. Therefore, the power of secondary users has to be regulated so that they do not cause undue interference to the primary users. The CR networks that employ underlay access techniques are known as underlay CR networks.

For opportunistic transmission of secondary users to be possible the underlying spectrum has to be sensed and detected for the presence or absence of primary users. This problem is referred to as “spectrum sensing” which would be the focus of our work [5].

III. TECHNIQUES FOR SPECTRUM SENSING

Commonly used spectrum sensing techniques[10] in CR networks are: Energy Detection, Matched Filter Detection and Cyclostationary.

A. Energy Detection based Spectrum Sensing

It is the natural way to detect a signal when a priori information about the PUs is not available. In this technique, the total measured energy of PUs signal is compared against a suitable threshold and a decision about presence or absence of PUs is made accordingly [11] as depicted in Figure.2. This technique only

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requires the energy of signal, and not the shapes or other parameters of PUs. This implies low computational and implementation complexities.

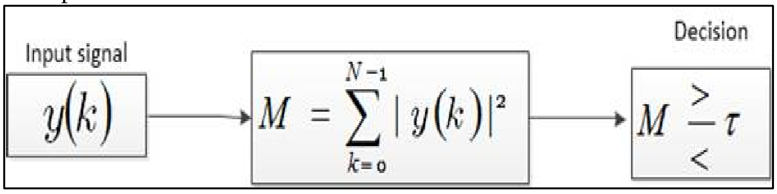

Fig.2 : Energy detection based spectrum sensing

In this the decision metric $E_t = \sum_{t=0}^{N-1} |x_t^2|$ is computed and compared against the threshold Ƭ . The threshold Ƭ is suitably chosen by striking a balance between the P_{FA} and P_D. Choosing the threshold in above mentioned way requires knowledge about noise and signal powers. However obtaining signal power can be quite difficult owing to changes in the characteristics of channels between the PU and SUs [12],[13]. In practice, threshold Ƭ is chosen by fixing P_{FA} to a certain value.

B. *Matched Filter based Spectrum Sensing*

Matched filter is a linear filter which works on phenomena of maximize the signal to noise ratio. Matched filter detection is then applied when the cognitive radio user having information about the type of primary signal. Detection by using matched filter is useful only in cases where the information from the primary users is known to the cognitive users. The waveform based sensing technique is illustrated in Figure.3.

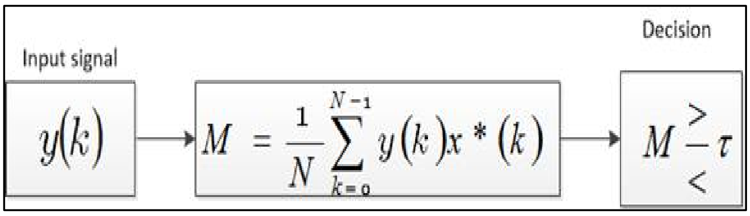

Fig. 3: Matched Filter based Spectrum Sensing

C. *Cyclostationary based Spectrum Sensing*

In Cyclostationary based Spectrum sensing technique, SUs can differentiate between primary signal, interference, and noise (which is not a cyclostationary signal)[12]. Since cyclostationary detection can separate signal from noise, it can be used in low SNR regions. The characteristics of the signal must be known a priori, therefore, cyclostationary detection is limited [14]. Furthermore, cyclostationary detection performs poorly with channel. The cyclostationary feature detection is performed as shown in Figure.4.

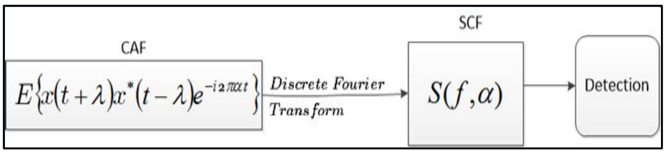

Fig. 4: Cyclostationary based Spectrum Sensing

Among these techniques, energy detector based sensing approach, is the most common way of spectrum sensing because of its simplicity and lack of need to know primary users signal characteristics [10],[15]. Moreover, energy

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detector based sensing has low computational and implementation complexities compared to other sensing techniques. In this paper too, we focus on energy detection based spectrum sensing.

IV. APPROACHES TO SPECTRUM SENSING

Approaches to spectrum sensing can be classified based on the exchange or no exchange of information between the SUs of a CR network into cooperative and non-cooperative spectrum sensing [10], [13]. We describe both these approaches in the following:

A. *Cooperative Spectrum Sensing:*

In Cooperative spectrum sensing[14] can be done by cognitive radio networks, such that the SUs reports their result to the Fusion Center (FC) to make a final decision about the activity of the primary user and therefore the available spectrum holes are reported to other cognitive radio networks. The former approach is known as distributed cooperative spectrum sensing and the later approach is known as centralized cooperative spectrum sensing. In cognitive radio networks, it is also possible that to provided information through cooperative spectrum sensing is used for assigning idle channels to available SUs. However, this approach will result in a trade-off between the SUs throughput and sensing accuracy.

B. *Non Cooperative Spectrum Sensing:*

In non-cooperative spectrum sensing, PUs are detected by each SU independent of others as shown in Fig.6. In other words there is no unambiguous exchange of information between the SUs or transmission of information to the FC as was the case in cooperative spectrum sensing[14].

In general, cooperative spectrum sensing gives better performance than the non-cooperative spectrum sensing. This is because in cooperative spectrum sensing there is a diversity advantage which helps out in averaging the noise introduced by the sensing process. In non cooperative spectrum sensing, there is no diversity advantage as secondary users take decisions independently based on their local measurement values.

V. TECHNIQUES OF SPECTRUM SHARING

In cognitive radio network, the main challenging task after spectrum sensing is to share the spectrum among the secondary users. so solution of this can be classified by three aspects: Spectrum Allocation, Spectrum Access Techniques, an Architecture Behaviour.

The first classification based on Spectrum Allocation behaviour which can be Non-cooperative or Cooperative:

- Non-cooperative Spectrum Sharing: Only a single node is considered in non-cooperative (or non-collaborative, selfish) solutions [18]. Because interference in other CR nodes is not considered, non-cooperative solutions may result in reduced spectrum utilization. However, these solutions do not require frequent message exchanges between neighbors as in cooperative solutions. Cooperative approaches generally outperform non-cooperative approaches, as well as closely approximating the global optimum [18]. Moreover, cooperative techniques result in a certain degree of fairness, as well as improved throughput. On the other hand, the performance degradation of non-cooperative approaches are generally offset by the significantly low information exchange and hence, energy consumption.

The second classification for spectrum sharing in CR networks is based on the Access Technology [20]:

- Overlay Spectrum Sharing: In this technique SUs access the network using a portion of the spectrum that has not been used by licensed users. This minimizes interference to the primary network[19].

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- Underlay Spectrum Sharing: The spread spectrum techniques are exploited such that the transmission of a CR node is regarded as noise by licensed users[19].

The third classification is based on the architecture, which can be Centralized or Distributed:

- Centralized Spectrum Sharing: The spectrum allocation and access procedures are controlled by a central entity. Moreover, a distributed sensing procedure can be used such that measurements of the spectrum allocation are forwarded to the central entity, and a spectrum allocation map is constructed. Furthermore, the central entity can lease spectrum to users in a limited geographical region for a specific amount of time. In addition to competition for the spectrum, competition for users can also be considered through a central spectrum policy server [19].

- Distributed Spectrum Sharing: Spectrum allocation and access are based on local (or possibly global) policies that are performed by each node distributively [19]. Distributed solutions also are used between different networks such that a base station (BS) competes with its interferer BSs according to the QoS requirements of its users to allocate a portion of the spectrum.

VI. CONCLUSION

In this paper, we reviewed CR networks and the problem of spectrum sensing as applied to it. We also reviewed different commonly used spectrum sensing techniques. In this survey discussed the spectrum sharing procedure and the key technologies of spectrum sharing in CRNs, such as centralized and distributed spectrum sharing, cooperative and non-cooperative spectrum sharing and DSA. Finally we have reviewed the sensing based sharing techniques.

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BIOGRAPHY

Soniya S. Christani has received her Bachelor degree in Electronics and Communication Engineering from Gujarat Technological University, Ahmedabad, India. Currently she is pursuing M.E (Communication system engineering) from Gujarat technological University. Her area of interest include wireless communication.

Mr. Jigneshkumar N. Patel has received the B.E. and M.E. degrees in Electronics & Communication Engineering from Dharamsinh Desai University (DDU), Nadiad, Gujarat, India, in 1997 and 1999, respectively. Since 1999, he is working as an Assistant Professor in SVIT, Vasad, Gujarat. His area of interests are Digital & Analog Communication, Digital Electronics.