

Spectrum Sensing Techniques for Cognitive Radio Networks

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ABSTRACT

The demand and the usage of wireless devices are rapidly increasing day by day. The spectrum is the important resource for the wireless device. The limited availability of the resource puts a lot of constraints in the usage of the wireless spectrum. The licensed user of the spectrum can be used by the unlicensed user in the absence of the primary user in the spectrum. It is achieved with the intelligent and promising technology of cognitive radio networks. Identifying the spectrum holes is an important task in cognitive radio. It is done with the help of spectrum sensing techniques. In this paper, the concept of cognitive radio technology is discussed. The spectrum sensing techniques are presented and analyzed in detail by giving comparative study of various methodologies used for cognitive radio networks.

1. Cognitive Radio Technology

In Wireless environment of today era, there is a rapid increase in the usage of wireless technologies. It leads to the spectrum scarcity in wireless networks. The bandwidth assigned to the user are not used all the time. Most of the time, the frequency in the bandwidth is idle. Only half of the Spectrum is used mostly by the users of the spectrum. For the efficient utilization of the spectrum, it can be availed by the others users for their transmission without interfering the licensed users access. This is achieved by the intelligent communication technology called as Cognitive Radio(CR). It has two types of users namely the primary or licensed user and the secondary or unlicensed user. The Telecommunications regulations allow the use of the licensed bandwidth by the unlicensed user if the licensed user is not

using the spectrum at that time. CR detect the available channels automatically and adjust the parameters of the network configuration to make the spectrum available for the use of secondary user. Cognitive Radio Networks has four major functions. They are spectrum sensing, spectrum management, spectrum sharing and spectrum mobility. Spectrum sensing is to identify the white spaces, spectrum management is how long these spaces can be used by the unlicensed user, spectrum sharing is sharing the resources among the secondary users and spectrum mobility means maintain the healthy communication during the transmission of data. When comparing all the functions, the most crucial task is spectrum sensing. The process involved in CR technology is depicted in Figure 1. It defines that the cognitive Radio technology process is a cycled one.

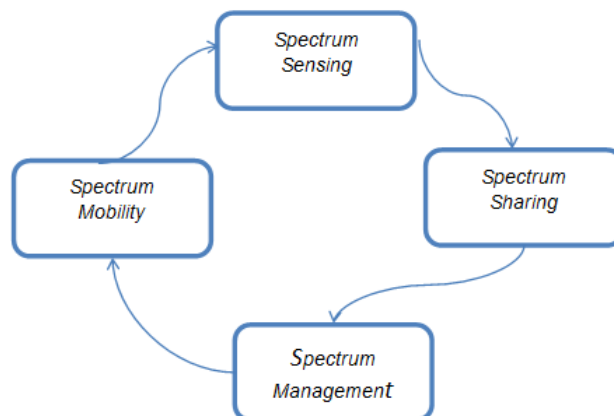


Figure 1: Cognitive Radio Cycle

2. Spectrum Sensing

2.1 Definition of Spectrum Sensing

Identifying the existence or non existence of the licensed user in the spectrum by frequently monitoring the bandwidth of the spectrum is Spectrum Sensing. The spectrum sensing is the key concept of CR is to identify the spectral holes in the

spectrum. Spectral holes are called as white spaces of the spectrum that is not used by the licensed user at present. Figure 2 defines the identification of white spaces in the spectrum. It denotes the spectrum holes are varied from time to time.

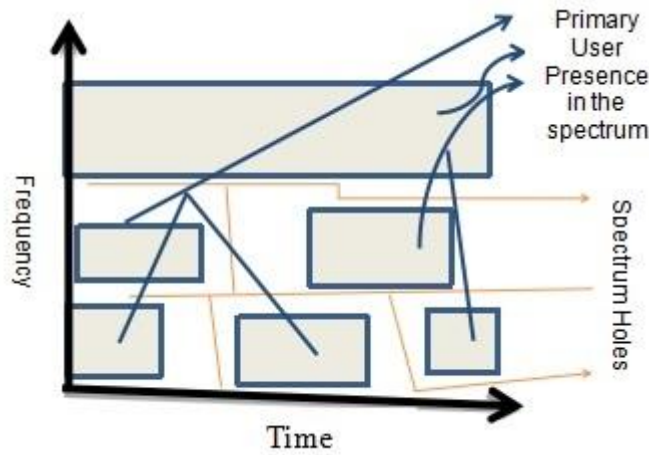


Figure 2: Spectrum Identification

2.2 Spectrum Sensing Techniques

To improve the efficiency of the spectrum usage, identified spectrum holes should be able to utilized by the unlicensed user when it is not used by the primary user. The most important part of CR is to sense the spectrum. The sensing should be done by the secondary user and access the spectrum for transmission as soon as it is available for usage. The licensed user enters the spectrum then the secondary user should immediately vacate the spectrum. The spectrum sensing is done in two ways in the form of cooperative and non cooperative detection.

2.2.1. Non Cooperative Detection

The commonly used Transmitter Detection techniques are Energy Based Detection, Matched filter Detection and Cyclostationary Feature Detection. These techniques are used for identifying the white spaces.

2.2.1.1 Energy Detection Model

The model used for detecting the presence of the primary User(PU) based on the following two hypothesis. The signals received by the Secondary User (SU) are determined using the following equations.

$$S[t] = X[t] \dots \dots \dots H0 // \text{Absence of Primary User}$$

$$S[t] = (\lambda * W[t]) + X(t) \dots \dots \dots H1 // \text{Presence of Primary User} \quad (1)$$

Where S[t] is the SU's received signal, X[t] is the PU's transmitted signal, W[t] is the additive white Gaussian noise and λ is the amplitude gain of the signal.

The presence or absence of PU is determined based on the signal energy. The received energy signal is compared with the threshold value. The decision is taken based on energy and threshold value of the signal. If the estimated energy of the received signal is greater than or equal to the threshold then the signal of the primary user is detected in the spectrum. Otherwise, the spectrum is available for the secondary user usage. The detection statistics is based on the determined threshold. The energy of the signal is determined as the average energy of the observed samples. It is compared with the predetermined threshold. The threshold selection may

be fixed or dynamic. The performance of the energy detection is done with the characteristics like the probability of detection, the probability of false alarm and the probability of missed detection. The algorithm is considered as the best performance algorithm when the detection is high and false alarm is low .

2.2.1.2 Cyclostationary Detection

The secondary user knows some relative information about the structure of the PU's signal like data rate, modulation type, the carrier frequency, and location of guard bands. Demodulated signals have periodic features that may be implicit or explicit. The carrier frequency and symbol rate can easily be estimated via square-law devices. In some standards, the PU network uses a pilot tone frequency that can be exploited by the SU. The use of a cyclic prefix also leads to periodic signal structures. The means and correlation sequences of such signals exhibit periodicity

This detector is easily implemented via Fast Fourier transforms (FFTs). Knowledge of the noise variance is not required to set the detection threshold. The detector does not suffer from the "SNR wall" problem of the energy detector. This method has high computational complexity and long sensing time. Due to these issues, this detection method is less common than energy detection in cooperative sensing.

2.2.1.3 Matched Filter Detection

If the characteristics of the signal is known then the optimized spectrum sensing technique is the matched filter technique. The primary user characteristics of the signal is stored. If any unknown signal is retrieved then it is compared with the stored signal characteristics. If it matches then the primary user is detected in the signal. If the similarities between the signals are not identified then SU quickly catches the opportunity of accessing the spectrum for transmission. The process of matched filter detection contains the following steps.

- The transmitted signal is obtained
- The Additive White Gaussian Noise(AWGN) is Added to the signal before transmission
- AWGN signal is transmitted

- It is compared with the known signal characteristics for the detecting the existence of the user.

2.2.2 Cooperative Detection

Primary users share the spectrum band with the secondary users and the fusion center. The fusion center decides the secondary user for accessing the currently available spectrum of a primary user. Performances of a single detector can be degraded due to fading, shadowing,

multipath propagation. Information from multiple cognitive radio users are appropriately incorporated for PU detection like shown in Figure 3. This approach enhances the accuracy and reliability of the PU detection and it is robust to fading, shadowing and model uncertainties and, consequently, it can resolve the hidden node problem. Also, it reduces the required sensing time. However, the complexity of this approach is high. Also, it needs a control channel and it increases the traffic overhead.

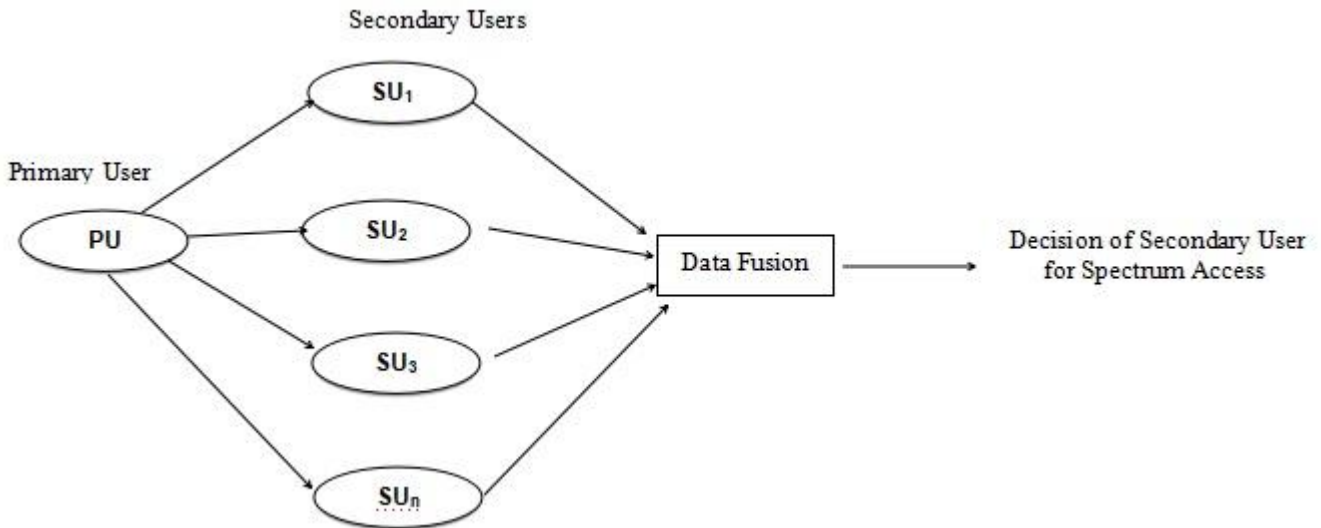


Figure 3: Spectrum Sensing in Cooperative environment

Cooperative sensing can be implemented in two ways as Centralized and Decentralized. In Centralized Cooperative Spectrum Sensing a central unit collects hard and soft sensing information from cognitive radios, identifies the available spectrum, and broadcasts this information to other cognitive radios. In Decentralized Cooperative Spectrum Sensing cognitive nodes share information through local communications in-order to make their own decisions as to which part of the spectrum can be used.

3. Soft Computing Based Techniques

For sensing the spectrum efficiently, soft computing techniques like Fuzzy Logic, Neural Networks are used. Genetic Algorithm can be used for optimization.

3.1 Fuzzy Logic Based Sensing

To increase the performance of local sensing, fuzzy logic can be used by the SU. It has several unique features that make itself a particularly good choice for PU detection. It does not require precise inputs therefore it is inherently robust. Because Fuzzy Inference Rule is governed by user-defined rules, it can be modified easily to improve system performance based on the requirement.

It can be used to detect the maximum possibility of spectrum access for secondary users via cognitive radio. The secondary users are selected on the basis of spectrum utilization, degree of mobility and distance from secondary users to the primary user. Based on the above conditions, fuzzy inference rule can be generated and it will produce the highest possibility of accessing the spectrum band for

secondary users and it reduces the interference with the primary user for efficient spectrum utilization.

3.2 Neural Networks

In the single spectrum sensing, it is difficult to overcome obstacles, path loss, deep noise and fading in the network. Even though CSS can provide better sensing performance than the single spectrum sensing, the problems above mentioned still remain. Thus effective decision method is needed for more adaptive to communication environment weight factors of the neural network are trained by using historical sensing information stored on buffer.

3.3 Genetic Algorithms

Genetic Algorithm (GA) is used to find the optimal solution for complex problems. There are two operations used for optimization as Crossover and Mutations. The old solutions using different algorithm are used for optimization to find the new solution. Crossover is used to move the population over the maximum and minimum at the local center. Crossover is called as converged one. Mutation is differed from crossover as it is diverged one. It divides the population into two or more local centers. From that it find the better solution for spectrum sensing. For optimization of spectrum, GA can be applied. A genetic algorithm can be used to optimize the Bit Error Rate (BER) performance in cognitive radio.

The analysis in terms of the advantages and disadvantages of the above described sensing techniques are presented in Table 1.

4. Hybrid Sensing

Hybrid sensing means using the technique involved in both the cooperative and nonoperative detection techniques. It uses the advantages of both the techniques for developing new algorithm for spectrum sensing. To achieve the better performances, the reporting information about the channel are collected from the Secondary users in different manner. The SU with good quality transmission characteristics report about the available spectrum and the other SUs give the local channel information to the fusion center. Fusion Center collects all the information and decides the secondary user for spectrum access.

Spectrum is an important resource in today wireless communication systems. Cognitive radio is a promising technology which enables the unlicensed user to occupy the primary user spectrum. The spectrum sensing is an essential component of cognitive radio. With the use of the efficient spectrum sensing techniques, the available spectrum can be easily identified. In this paper, different spectrum sensing techniques are discussed that basically involves non cooperative, cooperative and soft computing techniques and it discussed the advantages and disadvantages in spectrum sensing techniques.

5. Conclusion

Table 1 : Advantages and Disadvantages of Various Spectrum Sensing Techniques

Spectrum Sensing Techniques	Methods Used	Advantages	Disadvantages
Non Cooperative Detection	Energy Based Transmitter Detection	<ul style="list-style-type: none"> Does not need any prior information about the PU signal Low computational cost 	<ul style="list-style-type: none"> Selection of threshold Complex in Differentiating interference from PU and noise, poor performance under low SNR values does not work for spread spectrum signals.
	Matched Filter Based Detection	<ul style="list-style-type: none"> Provides optimal detection performance Less detection time 	<ul style="list-style-type: none"> Needs prior information about the PU signal
	Cyclo Stationary Feature based	<ul style="list-style-type: none"> Robust to interference Robust in low SNR 	<ul style="list-style-type: none"> Needs physical structure of the PU signal High computational cost
Cooperative Detection	Centralized	<ul style="list-style-type: none"> It enhances the accuracy and reliability of the PU detection It is robust to fading, shadowing It resolves the hidden node problem. It reduces the required sensing time. 	<ul style="list-style-type: none"> The complexity is high It needs a control channel It increases the traffic overhead.
	Decentralized	<ul style="list-style-type: none"> It does not need any backbone 	<ul style="list-style-type: none"> Large control bandwidth is needed Sensing duration is high
Soft Computing Based Detection	Neural Networks	<ul style="list-style-type: none"> Needs less prior Knowledge Used in any phase of Cognition Cycle 	<ul style="list-style-type: none"> Needs model for analyzing the spectrum work to different protocols
	Fuzzy Logic	<ul style="list-style-type: none"> It reduces complexity Produces more accuracy 	<ul style="list-style-type: none"> Parameters can be added for radio configuration effectively
	Genetic Algorithm	<ul style="list-style-type: none"> Multi objective performance Non mathematical and Non closed form 	<ul style="list-style-type: none"> Weight updating is not done automatically

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