IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 9, Issue 1, Ver. IV (Jan. 2014), PP 57-63
www.iosrjournals.org

"A Survey: A Cognitive Radio for Wireless Communication"

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Abstract : *As we know that for communication we require radio spectrum resources. And our spectrum is naturally limited resources. We can't create resources but we can reuse the available resources. As earlier spectrum allocation done based on Fixed Spectrum Allocation (FSA). Due to this our spectrum is underutilized and result in spectrum scarcity. Now a days as the rapid growth of wireless technology, government regularity like FCC having a problem to satisfied the user demand. To solve this problem cognitive radio is the resent trends to over utilize the available spectrum. Cognitive radio utilizes the dynamic spectrum allocation to utilize the available spectrum resources. This paper surveys the concept of cognitive radio, overview, different sensing techniques, standard and recent advancement in research technology.*
Keywords: *cognitive radio (CR), spectrum hole, cognitive radio's fundamentals and cycle, primary users (PU), secondary users(SU), different sensing techniques, IEEE 802.22.*

I. INTRODUCTION

As far as the rapid growth of various wireless communication technologies and applications from last decade, wireless spectrum resources faced the more and more user demands. As earlier to satisfy the user need FCC has adopted Fixed Spectrum Allocation policy but due to FSA the spectrum is underutilized which result in spectrum scarcity. According to the report published by the federal communication commission (FCC) in November 2002 [2].
1) Some of the frequency band is largely unoccupied for a long time;
2) Some of the frequency band is partially occupied;
3) And the remaining frequency bands are heavily used

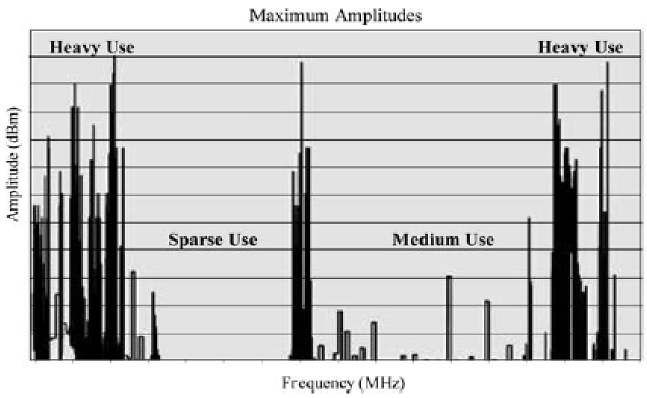

Fig.1.1 Spectrum Utilization.

By utilizing this unused spectrum part there is large variation of about 15to 85 %. So there is a scope to improve the spectrum efficiency. To fully utilize the limited naturally radio spectrum and inefficient utilization require new approach to solve this problem. Here we proposed the dynamic spectrum allocation strategy in which the part of the spectrum which is not utilized by the primary user is utilized by the secondary users on the based that they don't interfere with the primary user. For efficient utilization of spectrum, DSA require intelligent radio which can sense the spectrum. So the key enable technology of DSA techniques is CR. The part of primary user spectrum which is not utilized is known as the spectrum hole or white space. So CR is capable to utilize the band of frequencies which are not utilized known as spectrum hole. [5]. Cognitive radio having ability to sense and detect the spectrum hole and share the spectrum in opportunistic manner so the primary user don't affect with the secondary users. Depending upon the utilization of band spectrum hole divided in to 3 categories. [1]

1. **Black spaces**: part of the spectrum utilized by the primary users. Means having the high-power "local" interfere some of the time.
2. **Gray spaces:** part of the spectrum which is rarely utilized by the primary user.

3. **White spaces:** part of the spectrum which are not utilized by the primary user, free of RF interference except the white Gaussian noise.

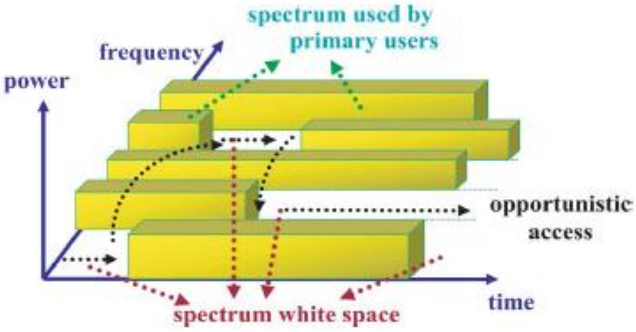

Fig. 1.2 spectrum white space or spectrum hole [5]

Among this three white space and gray space can be utilize for the secondary user or unlicensed user if accurate sensing method is used. Black space will not be used for secondary user because it creates interference to the primary user or licensed user.

II. COGNITIVE RADIO FUNDAMENTALS

Cognitive radio first invented by the Dr. Joseph mitola in 1999. According to them cognitive radio is: "A radio that employs model based reasoning to achieve a specified level of competence in radio-related domains." [1].after the six year later Simon haykin gave the idea of CR 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 operating parameters in real-time", with two primary objectives in mind:

- Highly reliable communication whenever and wherever needed.
- Efficient utilization of the radio spectrum.

Means depending upon the set of criteria taken into consider, there are two main types of CR [1]

- Full CR (mitola radio): In which every possible parameters are considered by an unlicensed users.
- Spectrum sensing CR (Haykin radio): In which only the radio frequency spectrum is considered.

After that FCC has defined a CR as "an intelligent wireless communication system capable of changing its transceiver parameters based on interaction with the environment in which its operates" [1]

1.1 CR characteristic [1]

Cognitive capability: It is also called as intelligent aware ness. Means being aware of the surrounding environment and continuously observed according to the user and environment needs.

Re-configurability: ability to make changed in the operating parameters like transmission and reception power in real time, radio frequency, modulation scheme and communication protocol.

1.2 cognitive radio functions

Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment, learns from the environment and adapts its internal states to statically variation in the incoming RF stimulation. [7]

A typically cycle of CR includes detecting spectrum white space, selecting the best vacant band of frequency for secondary users when primary user appears and such that interference does not occur to both. So the key issues in the cognitive radio are awareness, intelligence, learning, adaptively, reliability, and efficiency. Such cognitive cycle includes following functions. [9]

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

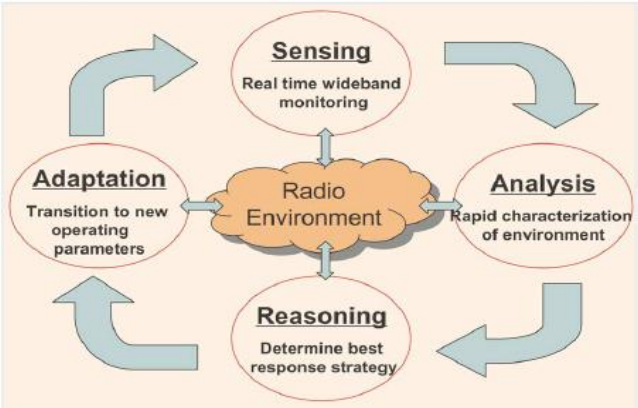

Fig 2.1 cognitive cycle [5]

Cognitive radio function consist four major steps to follow [1]

1. **Spectrum sensing:** A CR user can only allocated unused portion of the radio spectrum. Therefore, the CR user should monitor the spectrum bands, and detect the available white space and also presence of the primary user. CR users collect the information of primary users so that no harmful interference occurs.
2. **Spectrum Decision:** after detecting the available white space through sensing CR users enable to choose the best spectrum band among the multiple bands according to the time varying channel.so that Qos can be maintain.
3. **Spectrum sharing:** in dynamic spectrum access, there are multiple users trying to access the spectrum. So SU share the spectrum with either other SU or PU to efficient utilization of available spectrum. Hence good spectrum allocation and high spectrum efficiency can be achieved.
4. **Spectrum Mobility:** if primary user want to use spectrum which is used by the other SU, then to continue communication we require spectrum mobility. Hence to continue the seamless communication during transmissions we require spectrum mobility.

III. SPECTRUM SENSING TECHNIQUES

Spectrum sensing is the main task in cognitive cycle. An important requirement of cognitive network is to sense and detect the spectrum holes before allowing the licensed band. So spectrum sensing allows the secondary user to find out the white space and sharing it while avoiding the spectrum that is occupied by PU. This can be defined as "action of a radio measuring signal feature" [8]. Spectrum sensing involves observing the radio frequency spectrum and these observations is use to decide that the channel is occupied or not by the licensed users' transmission. The principle of spectrum sensing is based on a binary hypothesis-testing.

H0: Primary User Is Absent. (null hypothesis)

H1: Primary user is present. (alternative hypothesis)

$$x(t) = \begin{cases} n(t) & H0, \\ hs(t) + n(t) & H1, \end{cases} \tag{3.1}$$

Here x(t) is the signal received by the SU user, s(t) is the transmitted signal of the primary user, n(t) is the AWGN with zero mean and variance σ_n^2 and h is the amplitude gain of the channel.

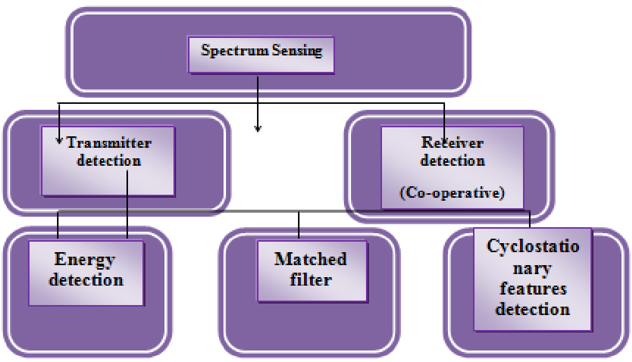

Fig 3.1 spectrum sensing techniques.

The probability of correct detection Pd, probability of false alarm, and probability of miss alarm are the key metrics in spectrum sensing:

Pd: probability of detection {Decision = H1/H1}

Pf: probability of false alarm {Decision = H1/H0}

Pm: probability of miss alarm {Decision = H0/H1}

A wealth of literature on spectrum sensing focus on primary detection based spectrum sensing. According to the a priori information they require and the resulting complexity and accuracy, spectrum sensing techniques can be categorized in the following types and all techniques are briefly described here.

3.1 Transmitter Based Detection (non-cooperative)

In transmitter detection each CR must independently have ability to determine the presence or absence of the PU in a specified spectrum.

3.1.1 Energy Detection

Energy detection has been widely used for spectrum sensing of unknown deterministic signals If the previous information of the primary user is unknown then, the energy detection method is optimal for detection the signals. So it is non-coherent method for spectrum sensing. In this method to determine whether the channel is free or not then, we measured the received signal strength or radio frequency energy. The most common approach used in energy detection is Neyman-Pearson (NP) lemma. The NP lemma criterion increases the probability of detection (Pd) for a given probability of false alarm (Pfa). It is having low computational complexity and can be implemented in both times as well frequency domain. [1], [6], [9], [10], [11].

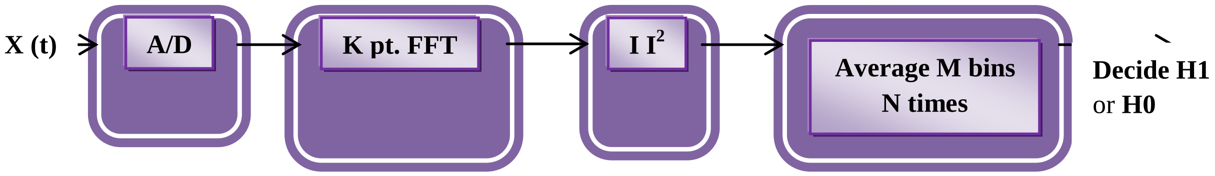

Fig 3.2 energy detection

3.1.2 Matched Filter

Matched filter is optimum method for detection of primary users when transmitted signal is known. The main advantage of this technique is that it requires short time for detection compared to others techniques. It is also referred as coherent detector because it requires primary user information to sense. Hence this technique is very accurate and it increases the received SNR. Moreover, since cognitive radio need receivers for all signal types, the implementation complexity of this method is very high. Disadvantage of this technique is large power consumption compared various receiver algorithms. [1], [8], [9], [11].

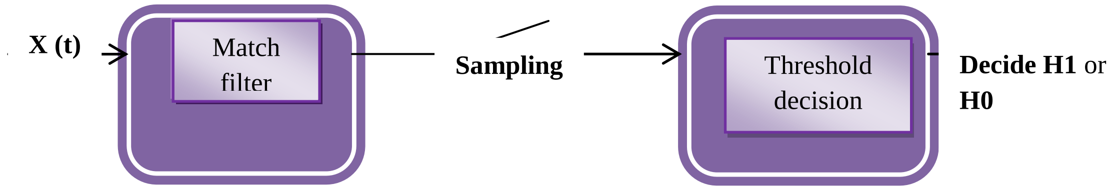

Fig 3.3 matched filter detection

3.1.3 Cyclostationary Detection

Cyclostationary feature detection is a method for detecting primary user transmission by exploiting the Cyclostationary features of the received signals. Cyclostationary features are caused by the periodicity in the signal or in its statistics like mean and autocorrelation. Instead of power spectral density, cyclic correlation is used for detecting signals in a given spectrum. The periodicity is commonly maintained through sinusoidal carriers, pulse train, spreading code, hopping sequences or cyclic prefixes of the primary signals. Due to the periodicity, these Cyclostationary signals exhibit the features of periodic statics and spectral correlation, which is not found in stationary noise interference.

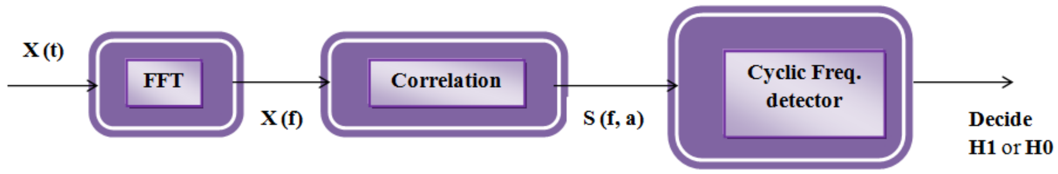

Fig 3.4 Cyclostationary detection

Thus, Cyclostationary features detection is robust to noise uncertainties and performs better then energy detection in low SNR regions. This occurs because nose is totally random and does not exhibit any periodic behavior. Although it requires a priori knowledge of the signal characteristics, Cyclostationary features detection is capable of distinguishing the CR transmissions in cooperative sensing. [1], [5], [8], [12], [13].

3.2 Comparisons of these techniques are shown in following figure.

Type	Test statistics	Advantages	Disadvantages
Energy detector	Energy of the received signal samples	• Easy to implement • Not require prior knowledge about primary signals	• High false alarm due to noise uncertainty • Very unreliable in low SNR regimes • Cannot differentiate a primary user from other signal sources
Feature detector	Cyclic spectrum density function of the received signal, or by matching general features of the received signal to the already known primary signal characteristics	• More robust against noise uncertainty and better detection in low SNR regimes than energy detection • Can distinguish among different types of transmissions and primary systems	• Specific features, e.g., cyclostationary features, must be associated with primary signals • Particular features may need to be introduced, e.g., to OFDM-based communications
Matched filtering and coherent detection	Projected received signal in the direction of the already known primary signal or a certain waveform pattern	• More robust to noise uncertainty and better detection in low SNR regimes than feature detector • Require less signal samples to achieve good detection	• Require precise prior information about certain waveform patterns of primary signals • High complexity

Fig 3.5 comparisons of sensing method [5]

3.3 Receiver Detection (co-operative detection) [1], [14], [15], [16], [17]

Co-operative detection is proposed in the literature as a solution to problem in spectrum sensing due to noise uncertainty, fading, and shadowing. Co-operative sensing decreases the probabilities of miss detection and false alarm and can also solve hidden primary user problem and it can decrease sensing time. CR co-operative spectrum sensing occurs when groups of CR user share the sense information of PU detection. This provides a more accurate sensing over the area where the CRs are located. There are two approaches to cooperative spectrum sensing

3.3.1 centralized approach

In this CR cooperative spectrum sensing approach, a central CR called fusion center (FC) within the network that collects the sensing information from all the sense CRs within network. The available spectrum is identified and this information is broadcast to other CRs or directly controls the CR traffic. All CRs are tuned to control channel and also physical point to point link between each cooperating CR and the FC for sending the sensing results is called reporting channel. The goal is to increase detection performance by improving the fading effects of the channel. The sensing is performed by applying two threshold values instead of only one.

3.3.2 distributed approach

In distributed sensing cognitive nodes share information between each other. Unlike centralized approach, distributed cooperative sensing does not depend on a FC for making the cooperative decision. Using the distributed approach no one CR takes control. Each CR sends its specific data of sensing to other CRs, merges its data with the received data of sensing and decides whether primary user PU is present or not. However this approach requires the individual CRs to have a much higher level of independences.

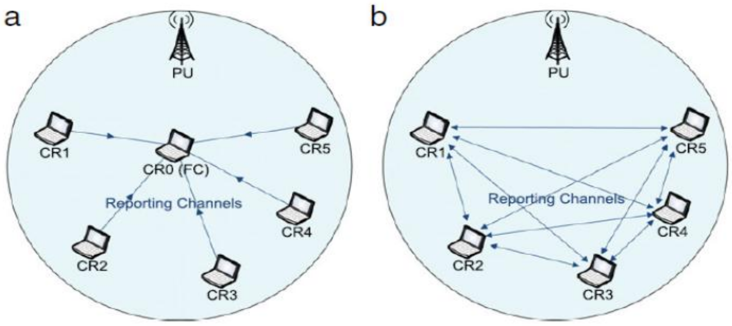

Fig. 3.6 Classification of cooperative sensing: (a) Centralized, (b) Distributed. [1]

IV. IEEE 802.22 STANDARD AND COGNITIVE RADIOS

4.1 IEEE 802.22 System Topology [19],[20], [21]

The IEEE 802.22 system specifies a fixed point-to-multipoint wireless air interface. The base station (BS) manages its own cell which is formed by a single 802.22 BS and zero or more 802.22 CPEs associated by a single 802.22 BS, whose coverage area extends up to the point where the transmitted signal from the 802.22 BS can be received by associated 802.22 CPEs with a given minimum SNR quality, and all associated Consumer Premise Equipment, as depicted in fig.1. For the protection of primary users services, the 802.22 system follows a strict master/slave relationship, where in the BS performs the role of the master and CPEs are the slaves. CPEs is not allowed to transmitted before receiving the proper authorization from a BS, which also control all the RF characteristics (e.g., modulation, coding, and frequencies of operation) used by the CPEs. The main role of a BS is to regulate data transmission in a cell in addition to that BS also manages a unique features of distributed sensing. This is needed to ensure proper licensed user protection and is managed by the BS, which instructs various CPEs to perform distributed measurement activities. Based on the feedback received; the BS decides which steps are to be taken.

It also manages the cognitive radio aspects of the system. The CPEs performs distributed measurements of the signal levels of possible television signals on the various channels at their individual locations. These measurements are collected and BS decides whether any actions are to be taken. In this way IEEE 802.22 standard is one of the first cognitive radio networks that has been defined.

The IEEE 802.22 standard should provide additional usage of the huge amount of broadcast spectrum that is available in many countries. As a result of the fact that 802.22 uses cognitive radio technology, it will be possible to ensure that no undue interference is caused to any existing services and users should not suffer any degradation in performance of their terrestrial television reception.

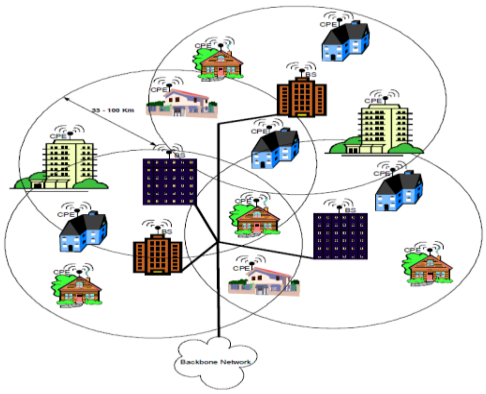

Fig 4.1 IEEE 802.22 Deployment configuration [19]

The basic specification parameters of the IEEE 802.22 standard can be seen in the below table

TABLE 3.1 Parameters and specification of IEEE 802.22 [19]

PARAMETER	SPECIFICATION
Typical Cell Radius (Km)	30-100 Km
Methodology	Spectrum Sensing To Identify Free Channels
Channel Bandwidth(MHz)	6-8MHz.
Modulation	OFDM
Channel Capacity	18mbps
User Capacity	Downlink:1.5kbps Uplink:384kbps

V. CONCLUSION

Spectrum is a naturally limited and valuable resource in wireless communication system. Cognitive radio (CR), is an innovative technology that has been proposed to utilize the available spectrum more efficiently by using the white space spectrum resources in an adaptively and intelligently. CR technology provides future wireless devices with additional frequency band and reliable communication and flexibility for rapidly growing data application. CR users monitor the spectrum and sense white space for communication such that interferences do not occur between PU and SU. In this survey the cognitive radio fundamental, functions, standard, characteristics, different sensing techniques are discussed. Sensing is the very significant step in CR technology. For sensing here we discussed different sensing techniques like, matched filter, energy detection, Cyclostationary, cooperative. Different techniques having advantages and disadvantages depending upon various aspects. Many researchers are currently working on developing different algorithms for different sensing methods to improvement in wireless communication technologies.

The IEEE 802.22 working group is first worldwide interface based standard based on CR techniques. This standard, which will operate in the TV bands, and performs various task like spectrum sensing, incumbent detection and avoidance, and spectrum management and sharing to achieve maximum utilization of spectrum resource

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