

Issues and Challenges in Spectrum management in Cognitive Radio Networks

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Abstract — Cognitive radio is a revolutionary technology that allows efficient, adaptable and intelligent use of spectrum without causing interference to the current licensed users. For cognitive radio adaptability, optimal usability and the power to evolve are the major factors that set apart an evolutionary machine. This paper introduces the concept of spectrum and network heterogeneity in case of cognitive radio technology, spectrum management and spectrum sharing techniques. The challenges faced in networking in an cognitive environment is also discussed with some proposed solutions.

Keyword — Cognitive radio, optimal usability, network heterogeneity, spectrum decision, spectrum sensing.

1. INTRODUCTION

The components of the CR network architecture, can be classified as two groups: the primary network and the CR network. The primary network (or licensed network) is referred to as an existing network, where the primary users have a license to operate in a certain spectrum band. If primary networks have an infrastructure, primary user activities are controlled through primary base stations. Due to their priority in spectrum access, the operations of primary users should not be affected by unlicensed users. The CR network (also called the dynamic spectrum access network, secondary network, or unlicensed network) does not have a license to operate in a desired band. Hence, additional functionality is required for CR users to share the licensed spectrum band. CR networks also can be equipped with CR base stations that provide single-hop connection to CR users. Finally, CR networks may include spectrum brokers that play a role in distributing the spectrum resources among different CR networks.

2. SPECTRUM HETEROGENEITY

Let us familiarize ourselves to the concept of spectrum heterogeneity[1]. CR users are capable of accessing both the licensed portions of the spectrum used by primary users and the unlicensed portions of the spectrum through wideband access technology. Consequently, the operation

types for CR networks can be classified as licensed band operation and unlicensed band operation[1],[2].

- Licensed band operation: The licensed band is primarily used by the primary network. Hence, CR networks are focused mainly on the detection of primary users in this case. The channel capacity depends on the interference at nearby primary users. Furthermore, if primary users appear in the spectrum band occupied by CR users, CR users should vacate that spectrum band and move to available spectrum immediately.
- Unlicensed band operation: In the absence of primary users, CR users have the same right to access the spectrum. Hence, sophisticated spectrum sharing methods are required for CR users to compete for the unlicensed band.

3. NETWORK HETEROGENEITY

As the nomenclature suggests network heterogeneity[1] refers to the different access rights and priority rules for primary and secondary users in cognitive radio networks. So after spectrum heterogeneity which mainly talks about how much of spectrum usage is not out of bounds for a particular user, the next fundamental concept of network awareness in cognitive networks is network heterogeneity. [3]The CR users have the opportunity to perform three different access types:

- CR network access: CR users can access their own CR base station, on both licensed and unlicensed spectrum bands. Because all interactions occur inside the CR network, their spectrum sharing policy can be independent of that of the primary network.
- CR ad hoc access: CR users can communicate with other CR users through an ad hoc connection on both licensed and unlicensed spectrum bands.
- Primary network access: CR users can also access the primary base station through the licensed band. Unlike for other access types, CR users require an adaptive medium access control (MAC) protocol, which enables roaming over multiple primary networks with different access technologies.

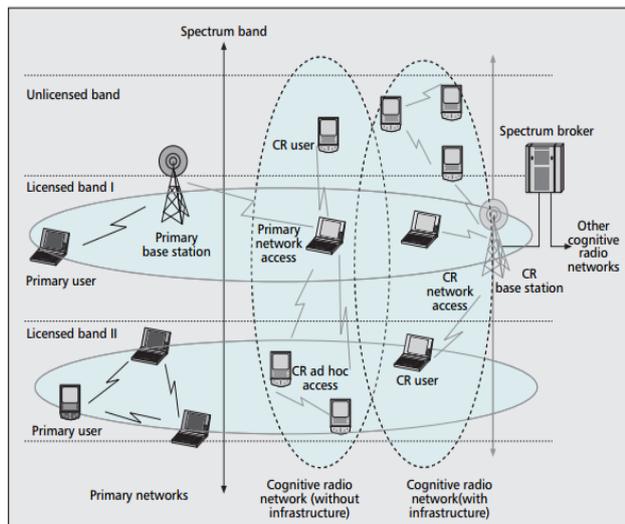


Fig. 1. Cognitive Radio Network Architecture

4. SPECTRUM MANAGEMENT FUNCTIONALITY AND CHALLENGES

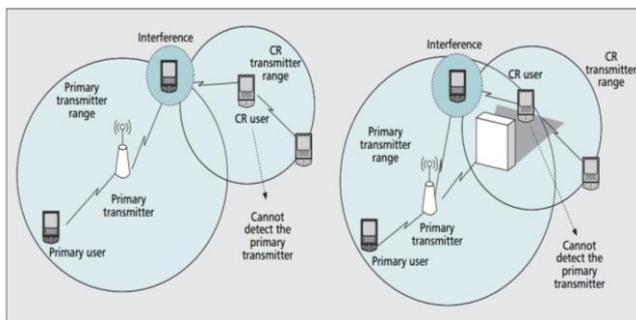


Fig. 2. : Some issues faced during spectrum management Transmitter detection problem: a) receiver uncertainty; b) shadowing uncertainty.

There are several issues faced during spectrum management.[6][7]

CR networks impose unique challenges [8] due to the coexistence with primary networks, as well as diverse quality of service requirements. A CR is designed to be aware of and sensitive to the changes in its surroundings, which makes spectrum sensing an important requirement for the realization of CR networks. Spectrum sensing enables CR users to adapt to the environment by detecting spectrum holes without causing interference to the primary network. This can be accomplished through a real-time wideband sensing capability to detect weak primary signals in a wide spectrum range. Generally, spectrum sensing techniques can be classified into three groups: primary transmitter detection, primary receiver detection, and interference temperature management. Spectrum sensing is the task of obtaining awareness about the spectrum usage and existence of primary users in a geographical area. This awareness can be obtained by using geo-location and database, by using beacons, or by local spectrum sensing at cognitive radios. When

beacons are used, the transmitted information can be occupancy of a spectrum as well as other advanced features such as channel quality. The definition of opportunity determines the ways of measuring and exploiting the spectrum space. The conventional definition of the spectrum opportunity, which is often defined as “a band of frequencies that are not being used by the primary user of that band at a particular time in a particular geographic area”,[9] only exploits three dimensions of the spectrum space: frequency, time, and space. Conventional sensing methods usually relate to sensing the spectrum in these three dimensions. Thus, new spectrum management functions are required for CR networks with the following critical design challenges:

- **Interference avoidance:** CR networks should avoid interference with primary networks.

- **QoS areness:** To decide on an appropriate spectrum band, CR networks should support QoS-aware communication, considering the dynamic and heterogeneous spectrum environment.

- **Seamless communication:** CR networks should provide seamless communication regardless of the appearance of primary users. To address these challenges, we provide a directory for different functionalities required for spectrum management in CR networks. The spectrum management process consists of four major steps:

- **Spectrum sensing:** [10] A CR user can allocate only an unused portion of the spectrum. Therefore, a CR user should monitor the available spectrum bands, capture their information, and then detect spectrum holes. The goal of the spectrum sensing mechanism is to determine the status of the spectrum (e.g. to detect the signature of a signal from a licensed user) and the activity of the licensed user by periodically sensing the target frequency band. In particular, a CR transceiver detects an unused spectrum or spectrum hole (i.e., band, location, and time) and also determines the method of accessing it (i.e., transmission power and access duration) without interfering the transmission of the licensed user. Spectrum sensing can be either centralized or distributed. In centralized spectrum sensing, a sensing controller (e.g., an access point or a base station) senses the target frequency band, and the information obtained from sensing is shared with other nodes in the system. Centralized spectrum sensing can reduce the complexity of user terminals, as all the sensing functions are performed at the sensing controller. However, centralized spectrum sensing suffers from location diversity. For example, the sensing controller may not be able to detect licensed user at the edge of the cell. In distributed spectrum sharing, unlicensed users perform spectrum sensing independently, and the spectrum sensing results can be either used by individual CRs (i.e., noncooperative sensing) or shared among other users (i.e., cooperative sensing). Although cooperative sensing incurs more communication and processing overhead, the

accuracy of spectrum sensing is higher than that of noncooperative sensing. [11]

• **Spectrum decision:** Based on the spectrum availability, CR users can allocate a channel. This allocation not only depends on spectrum availability, but is also determined based on internal (and possibly external) policies. The information obtained from spectrum sensing is used to schedule and plan the spectrum access by the unlicensed users. In this case, the communication requirements of the unlicensed users are also used to optimize the transmission parameters. The major components of spectrum management mechanisms are spectrum analysis and spectrum access optimization.[12] In spectrum analysis, information from spectrum sensing is analyzed to understand the ambient RF environment (e.g., the behavior of licensed users) and gain knowledge about the spectrum holes (e.g., interference estimation, duration of availability, and probability of collision with licensed user due to sensing error). A knowledge base of the spectrum access environment can be built and maintained on the basis of learning and knowledge extraction. Machine learning algorithms [13] from the field of artificial intelligence can be applied for learning and knowledge extraction. Subsequently, a decision to access the spectrum (e.g., frequency, bandwidth, modulation mode, transmission power, location, and time duration) is made by optimizing the system performance given the desired objective (e.g., maximize throughput of the unlicensed user) and constraints (e.g., maintain the interference caused to the licensed users below the target threshold).

• **Spectrum sharing and access:** Because there may be multiple CR users trying to access the spectrum, CR network access[14] should be coordinated to prevent multiple users colliding in overlapping portions of the spectrum. After the decision is made on spectrum access on the basis of spectrum analysis, the spectrum holes (also called spectrum opportunities) are accessed by the unlicensed users. Spectrum access is performed on the basis of a cognitive medium access control (MAC) protocol that intends to avoid collision/harmful interference with/to licensed users and also with other unlicensed users. The CR transmitter is also required to perform negotiation with the CR receiver to synchronize the transmission so that the transmitted data can be received successfully. A cognitive MAC protocol could be based on a fixed-allocation MAC (e.g., frequency-division multiple access, time-division multiple access, and code division multiple access [CDMA]) or a random access MAC (e.g., ALOHA and CSMA with collision avoidance). The optimal spectrum access decision depends on the ambient environment and the cooperative or competitive behavior of the unlicensed users. The spectrum access decision can be made in a non-cooperative and distributed way based on a local optimization objective. Alternatively, a cooperative spectrum access decision can be made either in a distributed or a centralized way based on a global

optimization objective. The spectrum access decisions are then communicated among CR transmitters and receivers. In a CRN, the secondary users may use either an interference control (or spectrum underlay) approach or an interference avoidance (or spectrum overlay) approach to exploit the spectrum opportunities. In the spectrum underlay approach, the secondary users transmit over the same spectrum as the primary users as long as the interference caused to the primary users does not exceed a threshold level. Therefore, such an approach requires a sophisticated power control scheme for secondary transmitters. In the spectrum overlay approach, the secondary users need to have the knowledge about spectrum holes so that the secondary users can exploit them, ensuring that there are no interference caused to the primary users. The interference avoidance [16] approach is, therefore, more conservative than the interference control approach, and no strict power control is required for this spectrum access paradigm.

• **Spectrum mobility:**[17] CR users are regarded as visitors to the spectrum. Hence, if the specific portion of the spectrum in use is required by a primary user, the communication must be continued in another vacant portion of the spectrum. Spectrum mobility is a function related to the change of operating frequency band of CR users. When a licensed user starts accessing a radio channel that is currently being used by an unlicensed user, the unlicensed user can switch to the idle spectrum band. This change in operating frequency band is referred to as spectrum hand-off [18]. During spectrum hand-off, the protocol parameters at the different layers in the protocol stacks have to be adjusted to match with the new operating frequency band. Spectrum hand-off must ensure that the data transmission by the unlicensed user can continue on the new spectrum band. The terms non-cooperative and co-operative sensing are simply introduced here. The different types of spectrum sensing techniques will be discussed later in this paper.

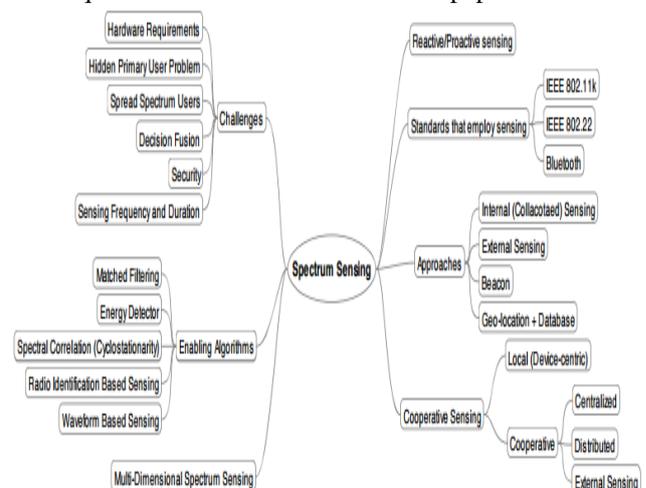


Fig. 3. Various aspects of spectrum sensing for cognitive radio.

5. SPECTRUM SENSING TECHNIQUES

5.1. HORIZONTAL AND VERTICAL SPECTRUM SHARING TECHNIQUES

Cognitive radio basically works by making fundamental changes in the way radio spectrum is regulated. Basically we are focusing on horizontal and vertical spectrum sharing.[19][20]. Cognitive radios share spectrum with radio systems that are designed to access spectrum with different priorities based on the regulatory status of radios working within the same spectrum. The spectrums are named primary and secondary based on their priority, licensed radio systems are those have specially assigned bands and unlicensed radio systems are designed to live with some interference. Sharing with primary radio systems is referred to as vertical sharing, and sharing with secondary radio systems is referred to as horizontal sharing. Apparently, dissimilar cognitive radios that are not designed to communicate with each other may also share the same spectrum. This is another common example of horizontal sharing, because the dissimilar cognitive radio systems have the same regulatory status, i.e. similar rights to access the spectrum. The main work of the cognitive radio is to find out the unutilized spectrum. Opportunities keep changing over time and it is needless to say that that vertical sharing is more stringent than horizontal sharing. So "spectrum etiquettes"[21] and "value orientation" [22] are useful to control unpredictable uses. High transmission powers for large coverage areas in a particular broadcast area are used to guarantee reliable reception, so receivers close to the broadcast site have such high power that a little interference by cognitive radios in the vicinity cannot create much disturbance. It might therefore help to allow reuse of the broadcast band for cognitive radios after scanning for spectrum opportunities and change in scenario.

The following figure depicts the scenario clearly.

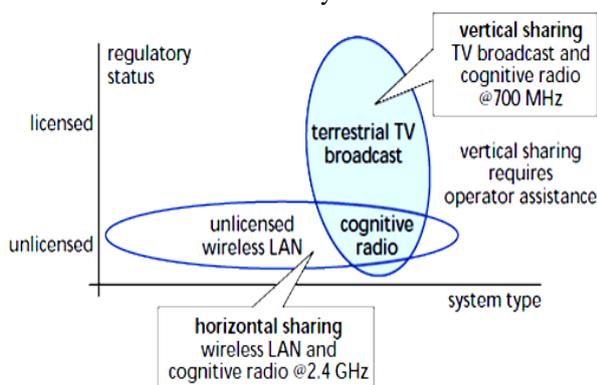


Fig.4. Horizontal and vertical spectrum sharing techniques

To guarantee fairness and efficiency, the way a cognitive radio makes decisions must be traceable for regulators. In traditional radio systems, algorithms for spectrum

management, such as power control and channel selection, are implemented in many radio devices, but are vendor-specific and not visible to the outside world, for example regulators. As a result, today's standards and regulation have to drastically constrain parameters like power levels and frequency ranges for operation, to achieve a minimum level of interoperability, spectrum efficiency, and fairness in spectrum access. The unique characteristic of cognitive radios on the other hand is that their radio resource management algorithms are weakly constrained by standards or regulation. This implies that the entire algorithms for decision-making in spectrum management have to be visible to the outside world, and control mechanisms for regulators have to be developed. For this purpose, DARPA XG proposes to realise such a control mechanism with a machine-understandable policy language. We discuss more details on this unique approach below. Figure 5 illustrates the full vision of overlay sharing and open spectrum. Unlike underlay sharing of radio systems like ultra wideband, cognitive radios are permitted to share spectrum in an overlay approach[23]: Transmission powers of cognitive radios exceed ultra wideband limits and may be even similar to the powers of incumbent radio systems. This clearly requires intelligent decision-making and/or operator assistance for protecting licensed services, and mitigating interference.

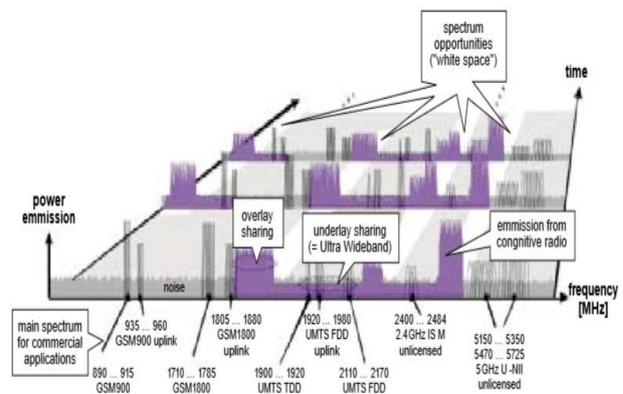


Fig.5. Opportunistic spectrum usage by cognitive radios in a wide range of frequencies

Unlicensed reuse of TV broadcast channels can also be performed as follows. The terrestrial TV broadcast band is currently in the process of being reorganised for the roll-out of digital video broadcast. This change is pursued in parallel in many regulatory domains worldwide. However, even with digital broadcast, high transmission powers for large coverage areas per broadcast site are used to guarantee reliable reception throughout the coverage area. This implies that many TV receivers for example close to the broadcast sites will be served with unnecessarily high power, and can therefore reliably operate even if some level of interference is emitted by cognitive radios at close proximity. It is therefore envisioned to allow such re-use of the entire TV

broadcast band[24] for cognitive radios that scan all TV channels throughout the band and operate only upon identification of spectrum opportunities. This is proposed for IEEE 802.22™, an emerging radio standard for access networks, designed to operate in the TV broadcast channels. Figure 5 illustrates this scenario: Shown are two adjacent TV broadcast sites and two independent pairs of cognitive radio devices that re-use parts of the spectrum for their own communication. Locally unused TV channels are identified as spectrum opportunities, and after some knowledge dissemination and negotiation, the pairs of cognitive radio devices communicate by using these opportunities. During their active communication, cognitive radios continue to scan the spectrum from time to time for signals from primary radio systems, i.e. the TV broadcast signals, in case the scenario should change.

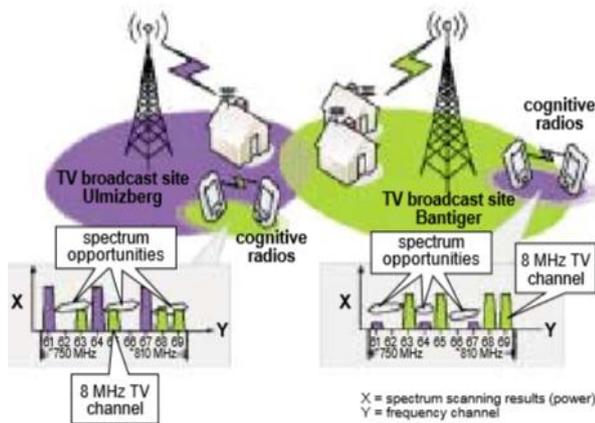


Fig.6. Cognitive radio in the TV band: At different locations, the cognitive radio devices detect different frequency channels as free and interpret them as opportunities for their own communication. This example for vertical spectrum sharing is discussed at IEEE 802.22™ standardisation.

5.2. CHALLENGES IN NETWORK AWARENESS OR SPECTRUM MANAGEMENT

Channel Uncertainty in wireless communication networks, uncertainties in received signal strength arises due to channel fading or shadowing which may wrongly interpret that the primary system is located out of the secondary user's interference range as the primary signal may be experiencing a deep fade or being heavily shadowed by obstacles. Therefore, cognitive radios have to be more sensitive to distinguish a faded or shadowed primary signal from a white space. Any uncertainty in the received power of the primary signal translates into a higher detection sensitivity requirement. Figure 6 shows the tradeoff between spectrum sensing time and user throughput.

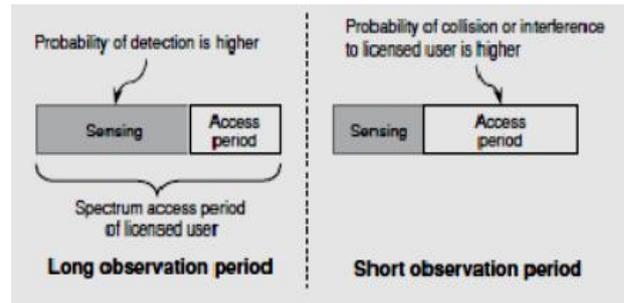


Fig 7: Trade off between spectrum sensing time and user throughput [25]

Noise uncertainty is also a problem.

The detection sensitivity can be defined as the minimum SNR at which the primary signal can be accurately (e.g. with a probability of 0.99) detected by the cognitive radio[26],

$$\gamma_{\min} = \frac{P_p L(D+R)}{N}$$

Where N is the noise power, Pp is transmitted power of the primary user, D is the interference range of the secondary user, and R is maximum distance between primary transmitter and its corresponding receiver. The above equation suggests that in order to calculate the required detection sensitivity, the noise power has to be known, which is not available in practice, and needs to be estimated by the receiver. However the noise power estimation is limited by calibration errors as well as changes in thermal noise caused by temperature variations. Since a cognitive radio may not satisfy the sensitivity requirement due to an underestimate of N, min should be calculated with the worst case noise assumption, thereby necessitating a more sensitive detector.

Aggregate Interference is another challenge to overcome uncertainty. In future, due to the widespread deployment of secondary systems, there will be increased possibility of multiple cognitive radio networks operating over the same licensed band. As a result, spectrum sensing will be affected by uncertainty in aggregate interference (e.g. due to the unknown number of secondary systems and their locations). Though, a primary system is out of interference range of a secondary system, the aggregate interference may lead to wrong detection. This uncertainty creates a need for more sensitive detector, as a secondary system may harmfully interfere with primary system located beyond its interference range, and hence it should be able to detect them. Sensing Interference Limit is another such challenge. Primary goal of spectrum sensing is to detect the spectrum status i.e. whether it is idle or occupied, so that it can be accessed by an unlicensed user. The challenge lies in the interference measurement at the licensed receiver caused by transmissions from unlicensed users. First, an unlicensed user may not know exactly the location of the licensed receiver which is required to compute interference caused

due to its transmission. Second, if a licensed receiver is a passive device, the transmitter may not be aware of the receiver. So these factors need attention while calculating the sensing interference limit.

Conventional sensing methods usually relate to sensing the spectrum in three dimensions only – frequency, time and space. However, there are other dimensions that need to be explored further for spectrum opportunity. For example, the code dimension of the spectrum space has not been explored well in the literature. Therefore, the conventional spectrum sensing algorithms do not know how to deal with signals that use spread spectrum, time or frequency hopping codes. As a result, these types of signals constitute a major problem in sensing the spectrum. If the code dimension is interpreted as part of the spectrum space, this problem can be avoided and new opportunities for spectrum usage can be created. Naturally, this brings about new challenges for detection and estimation of this new opportunity. Similarly, the angle dimension has not been exploited well enough for spectrum opportunity. It is assumed that the primary users and/or the secondary users transmit in all the directions. However, with the recent advances in multi-antenna technologies, e.g. beam forming, multiple users can be multiplexed into the same channel at the same time in the same geographical area. In other words, an additional dimension of spectral space can be created as opportunity. This new dimension also creates new opportunities for spectral estimation where not only the frequency spectrum but also the angle of arrivals (AoAs) needs to be estimated. With these new dimensions, sensing only the frequency spectrum usage falls short. The radio space with the introduced dimensions can be defined as “a theoretical hyperspace occupied by radio signals, which has dimensions of location, angle of arrival, frequency, time, and possibly others”. This hyperspace is called electro space, transmission hyperspace, radio spectrum space, or simply spectrum space by various authors, and it can be used to describe how the radio environment can be shared among multiple (primary and/or secondary) systems [27],[28]. It is of crucial importance to define such an n-dimensional space for spectrum sensing. Spectrum sensing should include the process of identifying occupancy in all dimensions of the spectrum space and finding spectrum holes, or more precisely spectrum space holes. For example a certain frequency can be occupied for a given time, but it might be empty in another time. Hence, temporal dimension is as important as frequency dimension.

Most of these issues can be eradicated by the following ways :-

- Search for the best frequency band: A cognitive radio must keep track of available frequency bands so that if necessary (e.g. a licensed user is detected), it can switch immediately to other frequency band. During transmission by an unlicensed user, the condition of the frequency band has to be observed. In a similar way to spectrum sensing, this would of course incur some

overhead. The observation can be performed in a proactive manner or in an on demand basis. In the proactive approach, the condition of the available channels is periodically observed and the knowledge about these channels is continuously updated. In an on demand approach, channel observation can be performed only when an unlicensed user needs to switch the channel.

- Protocol stack adaptation: Since the latency due to spectrum handoff could be high, the modification and adaptation of other components in the protocol stack is required. For example, when an unlicensed user switches channel, the TCP timer at the transport layer can be frozen to avoid any miss interpretation of the delay incurred for the acknowledgement message. A cross layer optimized framework for protocol adaptation has to be developed to cope up with spectrum mobility.

- Self coexistence and synchronization: When an unlicensed (or secondary) user performs spectrum handoff, two issues have to be taken into account. First, the target channel must not currently be used by any other secondary user (i.e. the self coexistence requirement), and the receiver of the corresponding secondary link must be notified of the spectrum handoff (i.e. the synchronization requirement). For the self coexistence issue, a spectrum broker can be used to manage spectrum allocation. For synchronization, the MAC protocol must be designed with provision for spectrum handoff information exchange.

6. SOME SPECTRUM SHARING ALGORITHMS

6.1 SPECTRUM SENSING FOR SPECTRUM OPPURTUNITIES

a. Primary transmitter detection: In this case, the detection of primary users is performed based on the received signal at CR users. This approach includes matched filter (MF) based detection, energy based detection, covariance based detection, waveform based detection, cyclostationary based detection, radio identification based detection and random Hough Transform based detection.

b. Cooperative and collaborative detection [29]: In this approach, the primary signals for spectrum opportunities are detected reliably by interacting or cooperating with other users, and the method can be implemented as either centralized access to spectrum coordinated by a spectrum server or distributed approach implied by the spectrum load smoothing algorithm or external detection.

6.2 SPECTRUM SENSING FOR INTERFERENCE DETECTION

a. Interference temperature detection: In this approach, CR system works as in the ultra wide band (UWB) technology where the secondary users coexist with primary users and are allowed to transmit with low power and are restricted by the interference temperature level so as not to cause harmful interference to primary users.

b. Primary receiver detection:[30] In this method, the interference and/or spectrum opportunities are detected

based on primary receiver's local oscillator leakage power.

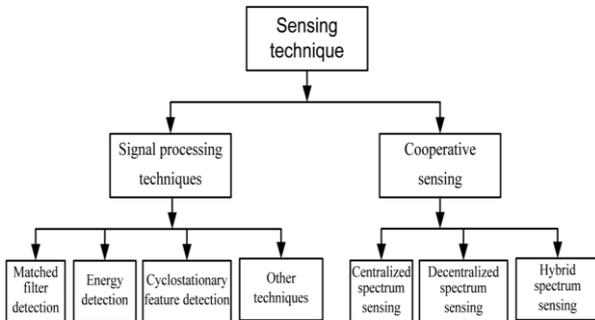


Fig 8: Various spectrum sensing techniques.

There are different types of spectrum sensing methods: transmitter detection, co-operative detection and interference detection.

In transmitter detection, the usage of the spectrum is determined by checking whether the signal from a primary transmitter is present in the spectrum. This can be done using three techniques:

- 1) Matched Filtering,
- 2) Energy Detection and
- 3) Cyclostationary detection.

1. Matched Filtering [31]: The matched filter is the optimal linear filter for maximizing the signal to noise ratio (SNR) in the presence of additive stochastic noise. Matched filters are commonly used in radar, in which a known signal is sent out, and the reflected signal is examined for common elements of the out-going signal. In matched filtering technique the user uses prior knowledge of the primary user's waveform to determine whether the spectrum is in use. A matched filter (MF) is a linear filter designed to maximize the output signal to noise ratio for a given input signal. When secondary user has a priori knowledge of primary user signal, matched filter detection is applied. Matched filter operation is equivalent to correlation in which the unknown signal is convolved with the filter whose impulse response is the mirror and time shifted version of a reference signal. The operation of matched filter detection is expressed as:

$$Y[n] = \sum_{k=-\infty}^{\infty} h[n-k]x[k]$$

Where 'x' is the unknown signal (vector) and is convolved with the 'h', the impulse response of matched filter that is matched to the reference signal for maximizing the SNR. Detection by using matched filter is useful only in cases where the information from the primary users is known to the cognitive users.

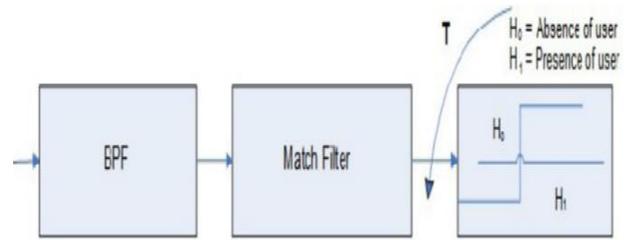


Figure 9: Matched Filtering

Advantages: Matched filter detection needs less detection time because it requires only $O(1/\text{SNR})$ samples to meet a given probability of detection constraint. When the information of the primary user signal is known to the cognitive radio user, matched filter detection is optimal detection in stationary Gaussian noise.

Disadvantages: Matched filter detection requires a prior knowledge of every primary signal. If the information is not accurate, MF performs poorly. Also the most significant disadvantage of MF is that a CR would need a dedicated receiver for every type of primary user.

2. Energy Detection[32] It is a non coherent detection method that detects the primary signal based on the sensed energy. Due to its simplicity and no requirement on a priori knowledge of primary user signal, energy detection (ED) is the most popular sensing technique in cooperative sensing.

The block diagram for the energy detection technique is shown in the Figure 9.

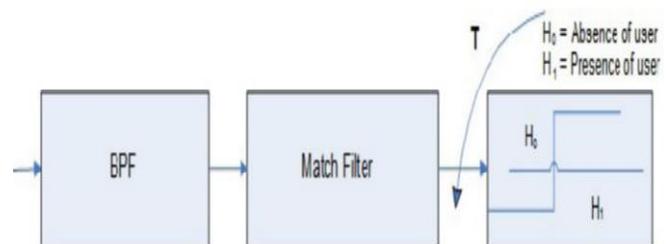


Figure 10: Energy Detection

In this method, signal is passed through band pass filter of the bandwidth W and is integrated over time interval. The output from the integrator block is then compared to a predefined threshold. This comparison is used to discover the existence of absence of the primary user. The threshold value can set to be fixed or variable based on the channel conditions. The ED is said to be the Blind signal detector because it ignores the structure of the signal. It estimates the presence of the signal by comparing the energy received with a known threshold v derived from the statistics of the noise. Analytically, signal detection can be reduced to a simple identification problem, formalized as a hypothesis test,

$$y(k) = n(k) \dots \dots \dots H_0$$

$$y(k) = h * s(k) + n(k) \dots \dots \dots H_1$$

Where $y(k)$ is the sample to be analyzed at each instant k and $n(k)$ is the noise of variance σ^2 . Let $y(k)$ be a sequence of received samples $k \in \{1, 2, \dots, N\}$ at the signal detector, then a decision rule can be stated as,

$$H_0 \dots \text{if } \epsilon < \nu$$

$$H_1 \dots \text{if } \epsilon > \nu$$

where $2\epsilon = E[y(k)^2]$ the estimated energy of the received signal and ν is chosen to be the noise variance σ^2 . However ED is always accompanied by a number of disadvantages

- i) sensing time taken to achieve a given probability of detection may be high.
- ii) detection performance is subject to the uncertainty of noise power.
- iii) ED cannot be used to distinguish primary signals from the CR user signals. As a result CR users need to be tightly synchronized and refrained from the transmissions during an interval called Quiet Period in cooperative sensing.
- iv) ED cannot be used to detect spread spectrum signals.

3. Cyclo-stationary Feature Detection

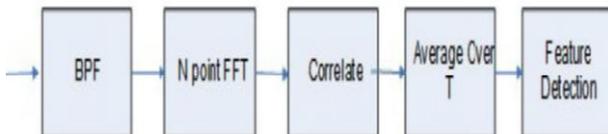


Figure 11 : Cyclostationary Feature Detection

[33] It exploits the periodicity in the received primary signal to identify the presence of primary users (PU). The periodicity is commonly embedded in sinusoidal carriers, pulse trains, spreading code, hopping sequences or cyclic prefixes of the primary signals. Due to the periodicity, these cyclostationary signals exhibit the features of periodic statistics and spectral correlation, which is not found in stationary noise and interference. Thus, cyclostationary feature detection is robust to noise uncertainties and performs better than energy detection in low SNR regions. Although it requires a priori knowledge of the signal characteristics, cyclostationary feature detection is capable of distinguishing the CR transmissions from various types of PU signals. This eliminates the synchronization requirement of energy detection in cooperative sensing. Moreover, CR users may not be required to keep silent during cooperative sensing and thus improving the overall CR throughput. This method has its own shortcomings owing to its high

computational complexity and long sensing time. Due to these issues, this detection method is less common than energy detection in cooperative sensing accuracy.

6.2 WIRELESS SPECTRUM SENSING

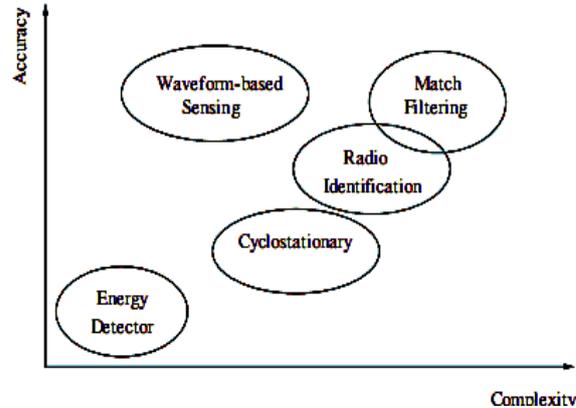


Figure 12: Sensing and complexity of various sensing methods [34]

Recently developed wireless standards have started to include cognitive features. Even though it is difficult to expect a wireless standard that is based on wideband spectrum sensing and opportunistic exploitation of the spectrum, the trend is in this direction. In this section, wireless technologies that require some sort of spectrum sensing for adaptation or for dynamic frequency access (DFA) are discussed. However, the spectrum knowledge can be used to initiate advanced receiver algorithms as well as adaptive interference cancellation. A proposed extension to IEEE 802.11 specification is IEEE 802.11k which defines several types of measurements. Some of the measurements include channel load report, noise histogram report and station statistic report. The noise histogram report provides methods to measure interference levels that display all non-802.11 energy on a channel as received by the subscriber unit. AP collects channel information from each mobile unit and makes its own measurements. This data is then used by the AP to regulate access to a given channel. The sensing (or measurement) information is used to improve the traffic distribution within a network as well. WLAN devices usually connect to the AP that has the strongest signal level. Sometimes, such an arrangement might not be optimum and can cause overloading on one AP and underutilization of others. In 802.11k, when an AP with the strongest signal power is loaded to its full capacity, new subscriber units are assigned to one of the underutilized APs. Despite the fact that the received signal level is weaker, the overall system throughput is better thanks to more efficient utilization of network resources. Bluetooth A new feature, namely adaptive frequency hopping (AFH)[35], is introduced to the Bluetooth standard to reduce interference between wireless technologies sharing the 2.4 GHz unlicensed radio spectrum. In this band, IEEE 802.11b/g devices,

cordless telephones, and microwave ovens use the same wireless frequencies as Bluetooth. AFH identifies the transmissions in the industrial, scientific and medical (ISM) band and avoids their frequencies. Hence, narrow-band interference can be avoided and better bit error rate (BER) performance can be achieved as well as reducing the transmit power. By employing AFH, collisions with WLAN signals are avoided in this example. AFH requires a sensing algorithm for determining whether there are other devices present in the ISM band and whether or not to avoid them. The sensing algorithm is based on statistics gathered to determine which channels are occupied and which channels are empty. Channel statistics can be packet-error rate, BER, received signal strength indicator (RSSI), carrier to-interference-plus-noise ratio (CINR) or other metrics. The statistics are used to classify channels as good, bad, or unknown.

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The preferred spelling of the word “acknowledgment” in American English is without an “e” after the “g.” Use the singular heading even if you have many acknowledgments. Avoid expressions such as “One of us (S.B.A.) would like to thank....” Instead, write “F. A.

REFERENCE

- [1] A Spectrum Sharing Algorithm Based on Spectrum Heterogeneity for Centralized Cognitive Radio Networks Guoqin Ning, Xuege Cao, Jiaqi Duan, Kaushik Roy Chowdhury
- [2] Smart Radio Spectrum Management for Cognitive Radio Partha Pratim Bhattacharya, Ronak Khandelwal, Rishita Gera, Anjali Agarwal
- [3] Cognitive Radio Communications and Networks Principles and Practice
- [4] Cognitive Radio Communications and Networks Principles and Practice -Alexander M. Wyglinski, Maziar Nekovee, Y. Thomas Hou
- [5] A Survey on Spectrum Management in Cognitive Radio Networks - Ian F. Akyildiz, Won-Yeol Lee, Mehmet C. Vuran, and Shantidev Mohanty, Georgia Institute of Technology
- [6] Spectrum Management in Cognitive Radio Ad Hoc Networks-Ian F. Akyildiz, Won-Yeol Lee, and Kaushik R. Chowdhury, Georgia Institute of Technology
- [7] I. F. Akyildiz et al., “NeXt Generation/Dynamic Spectrum Access/Cognitive Radio Wireless Networks: A Survey,” *Comp. Net. J.*, vol. 50, Sept. 2006, pp. 2127–59
- [8] D. Cabric, S. M. Mishra, and R. W. Brodersen, “Implementation Issues in Spectrum Sensing for Cognitive Radios,” *Proc. IEEE Asilomar Conf. Signals, Sys., and Comp.*, Nov. 2004
- [9] P. Kolodzy et al., “Next generation communications: Kickoff meeting,” in *Proc. DARPA*, Oct. 2001
- [10] SPECTRUM SENSING METHODS IN COGNITIVE RADIO - Under the aegis of PROF. SARAT KUMAR PATRA by SIDDHARTH JAIN and RAVI BAID JAIN
- [11] Cooperative and noncooperative spectrum sensing techniques using Welch’s periodogram in cognitive radios-Sarvanko, H.; VTT Tech. Res. Center of Finland, Oulu; Mustonen, M.; Hekkala, A.; Mammela, A. more authors
- [12] Optimization of Spectrum Sensing for Opportunistic Spectrum Access in Cognitive Radio Networks-Ghasemi, A.; Sousa, E.S.
- [13] Machine Learning Techniques in Cognitive Radio Networks-Peter Hossain, Adaulfo Komisarczuk, Garin Pawetczak, Sarah Van Dijk, Isabella Axelsen
- [14] Cognitive Radio and Dynamic Spectrum Sharing Systems Ivan Cosovic1*, FriedrichK Jondral2, MilindM Buddhikot3 and Ryuji Kohno4
- [15] MAC protocol adaptation in cognitive radio networks-Kuo-Chun Huang; WINLAB, Rutgers Univ., North Brunswick, NJ, USA; Raychaudhuri, D.
- [16] Interference avoidance in cognitive radio networks-Hamdi, Karama
- [17] Spectrum mobility in cognitive radio networks-Christian, I.; Moh, S.; Ilyong Chung; Jinyi Lee
- [18] Spectrum Handoff Strategies for Multiple Channels Cognitive Radio NetworkAdisorn Lertsinsruttavee, Naceur Malouch, and Serge Fdida
- [19] Cognitive Radio and Management of Spectrum and Radio Resources in Reconfigurable Networks - Lars Berlemann, RWTH Aachen University, Germany, George Dimitrakopoulos, University of Piraeus, Klaus Moessner, The University of Surrey, Jim Hoffmeyer, Panasonic Research
- [20] Operator Assisted Cognitive Radio and Dynamic Spectrum Assignment with Dual Beacons-Detailed Evaluation-Mangold, S.; Swisscom Innovations, Beme; Jarosch, A.; Monney, C.
- [21] Adaptive Channel Allocation Spectrum Etiquette for cognitive radio- N Nie
- [22] Spectrum Sharing with Value-orientation for Cognitive Radio Authors: Mangold, Stefan and Berlemann, Lars and Nandagopalan, Saishankar
- [23] Resource Allocation for Spectrum Underlay in Cognitive Radio Networks Long Bao Le, Member, IEEE, and Ekram Hossain, Senior Member, IEEE
- [24] Proposal for Part 15.244 Cognitive Radio operation in the TV Band
- [25] Proposal for Part 15.244 Cognitive Radio operation in the TV Band-Ying-Chang Liang; Inst. for Infocomm Res., Singapore; Yonghong Zeng; Peh, E.C.Y.; Anh Tuan Hoang
- [26] D. B. Rawat, G. Yan, C. Bajracharya (2010), “Signal Processing Techniques for Spectrum

Sensing in Cognitive Radio Networks”, International Journal of Ultra Wideband Communications and Systems, Vol. x, No. x/x, pp:1-10)

- [27] R. Matheson, “The electro space model as a frequency management tool,” in Int. Symposium On Advanced Radio Technologies, Boulder, Colorado, USA, Mar. 2003, pp. 126–132)
- [28] A. L. Drozd, I. P. Kasperovich, C. E. Carroll, and A. C. Blackburn, “Computational electro magnetics applied to analyzing the efficient utilization of the RF transmission hyperspace,” in Proc. IEEE/ACES Int. Conf.on Wireless Communications and Applied Computational Electromagnetics, Honolulu, Hawaii, USA, Apr. 2005, pp.1077–1085.
- [29] Cooperative spectrum sensing and signal detection in cognitive radio-Armi.N
- [30] Detecting primary receivers for cognitive radio applications-Wild B
- [31] MATCHED FILTER BASED SPECTRUM SENSING FOR COGNITIVE RADIO AT LOW SIGNAL TO NOISE RATIO-VADIVELU,SANKARANARAYANAN, VIJAYAKUMARI
- [32] ENERGY DETECTION TECHNIQUE FOR SPECTRUM SENSING IN COGNITIVE RADIO: A SURVEY Mahmood A. Abdulsattar and Zahir A. Hussein
- [33] Cyclostationary Based Spectrum Sensing in Cognitive Radio: Windowing Approach Jayanta Mishra, Deepak Kumar Barik, Ch. Manoj Kumar Swain
- [34] SPECTRUM SENSING TECHNIQUES IN COGNITIVE RADIO NETWORKS: A SURVEY Mansi Subhedar1 and Gajanan Birajdar
- [35] Spectral sensing for cognitive radio: Estimation of adaptive frequency hopping signal-Jaiswal K

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