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Recent trends in Survivable cognitive radio networks and Spetrum sensing Methods

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***Abstract*— With the rapid deployment of new wireless devices and applications, the last decade has witnessed a growing demand for wireless radio spectrum. However, the fixed spectrum assignment policy becomes a bottleneck for more efficient spectrum utilization, under which a great portion of the licensed spectrum is severely under-utilized. The inefficient usage of the limited spectrum resources urges the spectrum regulatory bodies to review their policy and start to seek for innovative communication technology that can exploit the wireless spectrum in a more intelligent and flexible way. The concept of cognitive radio (CR) is proposed to address the issue of spectrum efficiency and has been receiving an increasing attention in recent years, since it equips wireless users the capability to optimally adapt their operating parameters according to the interactions with the surrounding radio environment. There have been many significant developments in the past few years on cognitive radios. This paper surveys recent advances in research related to cognitive radios. The fundamentals of cognitive radio technology, architecture of a cognitive radio network and its applications are first introduced. The existing works in spectrum sensing are reviewed, and important issues in dynamic spectrum allocation (DSA) and sharing are investigated in detail.**

***Index Terms*—Cognitive radio (CR), Radio spectrum management, Dynamic spectrum allocation (DSA) software radio, spectrum sensing, wireless communication**

I. INTRODUCTION

Cognitive Radio (CR) developments have recently been debated through the IEEE 1900 series standards from which definitions, recommended practices, applications, and polices have been vetted in the community [1]. These definitions serve to bring together various conceptualizations of the distinctions between intelligence (e.g. cognitive) and applications (e.g. radio). Numerous communities have contributed elements such as dynamic spectrum access, networking, software defined radio, and quality of service (QoS) to the concept of a Cognitive radio network. These elements (and others) are formalized in the IEEE 1900 series standards.

CR is an emerging technology which uses intelligent strategies to allow a radio terminal to automatically sense, recognize, and adapt to use of any available radio frequency spectrum at a given time [2]. CR can be viewed as an extension to software defined radio (SDR) where SDR has a predefined frequency band; whereas CR scans a wide range of frequency spectra before deciding which band to use, as shown in Fig. 1. CR opportunistically uses the available (i.e., idle) frequency spectrum for the exchange of information for secondary users (i.e., low priority) and stops using the frequency band at the instant the primary user (i.e., high-priority) needs to use the band. CR seeks to not infringe upon or interfere with the rights of licensed users [3].

II. SPETRUM UTLIZATION MODEL

In recent technical advances resulted improvements in telecommunications, particularly in wireless networking with respect to latency, bandwidth and user friendliness. Many wireless technologies (for example, GSM, GPRS, UMTS, WiMax802.11, 802.15, DVB-H etc) have been developed. While some of these (GSM, GPRS, and UMTS etc) have been wide deployed on an exclusively bought spectrum, many others (802.11, 802.15.1, 802.15.4, etc.) are developed for use in the ISM bands due to free spectrum access. For a range of frequencies - while some frequencies are heavily used others are sparsely used. According to the Federal Communications Commission (FCC), the variations in the spectrum utilization are between 15% to 85% [2]. Defense Advanced Research Projects Agency (DARPA) in its survey reports an average of 6% usage [3]. This shows the articial scarcity - though spectrum is available it is inefficiently used. The spectrum usage however varies spatially and temporally, which makes it hard to put the unused spectrum to use anywhere and every time.

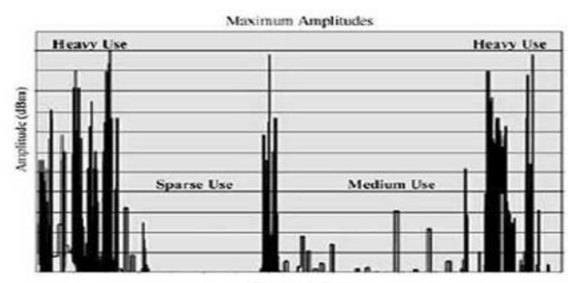

Figure.1 shows the typical spectrum usage

Further, the spectrum use for particular applications such as military, aviation needs to be strictly interference free. Thus there is a need to design newer architectures, and device new technology for increasing the Spectrum utilization.

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III. COGNITIVE RADIO TASKS

Basically, a cognitive radio should be able to nimbly jump in and out of free spaces in spectrum bands, avoiding pre-existing users, in order to transmit and receive signals. [2] The main functions of cognitive radios can be summarized as the following four tasks. [4]

- **Spectrum sensing*:*** Determine which portion of the spectrum is available and detect the presence of licensed users when a user operates in a licensed band.
- **Spectrum management*:*** Select the best available channel (frequency) for communication.
- **Spectrum sharing***:* Coordinate fair spectrum access to this channel with other users.
- **Spectrum mobility***:* Vacate the channel when a licensed user is detected while still maintaining seamless communication requirements during the transition to a better piece of spectrum.

These tasks require a large amount of network (and channel) State information that must be shared *simultaneously* between Multiple OSI layers of the cognitive radio.

The xG network architecture:

The components of the xG network architecture, as shown in Fig. 6, can be classified in two groups as the primary network and the xG network. The basic elements of the primary and the xG network are defined as follows:

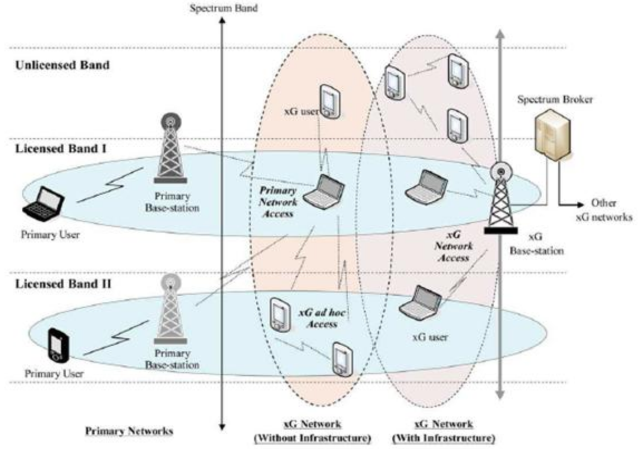


Figure.2 XG Network Architecture

Primary network:

An existing network infrastructure is generally referred to as the primary network; this has an exclusive right to certain Spectrum band. Examples include the common Cellular and TV broadcast networks.

The components of the primary network are as follows:

- **Primary user**: Primary user (or licensed user) has a license to operate in a certain spectrum band. This access can only be controlled by the primary base-station and should not be affected by the operations of any other unlicensed users. Primary users do not need any modification or additional functions for coexistence with xG base-stations and xG users.
- **Primary base-station**: Primary base-station (or licensed base-station) is a fixed infrastructure network component which has a spectrum license such as base-station transceiver system (BTS) in a cellular system. In principle, the primary base-station does not have any xG capability for sharing spectrum with xG users. However, the primary base-station may be requested to have both legacy and xG protocols for the primary network access of xG users, which is explained below.
- **xG network:** xG network (or cognitive radio network, Dynamic Spectrum Access network, secondary network, unlicensed network) does not have license to operate in a desired band. Hence, the spectrum access is allowed only in an opportunistic manner. xG networks can be deployed both as an infrastructure network and an ad hoc network .

The components of an xG network are as follows:

xG user:

xG user (or unlicensed user, cognitive radio user, secondary user) has no spectrum license. Hence, additional functionalities are required to share the licensed spectrum band.

xG base-station:

xG base-station (or unlicensed base-station, secondary base-station) is a fixed infrastructure component with xG capabilities.

xG base-station provides singlehop connection to xG users without spectrum access license. Through this connection, an xG user can access other networks.

Spectrum broker:

Spectrum broker (or scheduling server) is a central network entity that plays a role in sharing the spectrum resources among different xG networks. Spectrum broker can be connected to each network and can serve as a spectrum information manager to enable coexistence of multiple xG networks.

The reference xG network architecture is shown in Fig. 2, which consists of different types of networks: a primary network, an infrastructure based xG network, and an ad-hoc xG network. xG networks are operated under the mixed spectrum environment that consists of both licensed and unlicensed bands. Also, xG users can either communicate with each other in a multihop manner or access the base-station. Thus, in xG networks, there are three different access types as explained next:

• **xG network access**:

xG users can access their own xG base-station both on licensed and unlicensed spectrum bands.

• **xG ad hoc access:**

xG users can communicate with other xG users through ad hoc connection on both licensed and unlicensed spectrum bands.

• **Primary network access**:

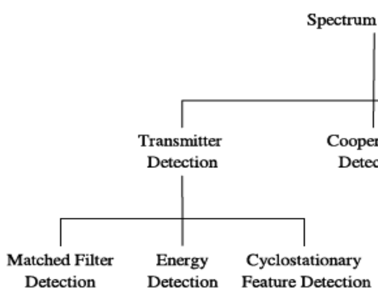
The xG users can also access the primary base-station through the licensed band. According to the reference architecture shown in Fig.2 various functionalities are required to support the heterogeneity in xG networks.

xG network applications:

- Leased network
- Cognitive mesh network
- Emergency network
- Military network.

IV. SPECTRUM SENSING

The spectrum sensing function enables the cognitive radio to adapt to its environment by detecting spectrum holes. The most efficient way to detect spectrum holes is to detect the primary users that are receiving data within the communication range of an xG user. The spectrum sensing techniques can be classified as transmitter detection, cooperative detection, and interference-based detection.



F

igure.3 Spectrum sensing techniques

Transmitter detection

Transmitter detection approach is based on the detection of the weak signal from a primary transmitter through the local observations of xG users.

$$x(t) =$$

Where x (t) is the signal received by the xG user, s(t) is the transmitted signal of the primary user, n(t) is the AWGN and h is the amplitude gain of the channel. H0 is a null hypothesis, which states that there is no licensed user signal in a certain spectrum band On the other hand; H1 is an alternative hypothesis, which indicates that there exist some licensed users Signal.

When the information of the primary user signal is known to the xG user, the optimal detector in stationary Gaussian noise is the matched filter since it maximizes the received signal-to-noise ratio (SNR) [15]. While the main advantage of the matched filter is that it requires less time to achieve high processing gain due to coherency.

Energy detection:

If the receiver cannot gather sufficient information about the primary user signal, for example, if power of the random Gaussian noise is only known to the receiver, the optimal detector is an energy detector [5].

Cyclostationary feature detection:

An alternative detection method is the cyclostationary feature detection.Modulated signals are in general coupled with sine wave carriers, pulse trains, repeating spreading, hopping sequences sequences, or cyclic prefixes, which result in built-in periodicity. These modulated signals are characterized as cyclostationarity since their mean and autocorrelation exhibit periodicity.

These features are detected by analyzing a spectral correlation function. The main advantage of the spectral correlation function is that it differentiates the noise energy from modulated signal energy.

Therefore, a cyclostationary feature detector can perform better than the energy detector in discriminating against noise due to its robustness to the uncertainty in noise power [5].

Cooperative detection

The assumption of the primary transmitter detection is that the locations of the primary receivers are unknown due to the absence of signaling between primary users and the xG users. Therefore, the cognitive radio should rely on only weak primary transmitter signals based on the local observation of the xG user [14, 15].

However, in most cases, an xG network is physically separated from the primary network so there is no interaction between them Cooperative detection among unlicensed users is theoretically more accurate since the uncertainty in a single user's detection can be minimized [14]. Moreover, the multi-path fading and shadowing effect are the main factors that degrade the performance of primary user detection methods [15].However, cooperative detection schemes allow to mitigate the multi-path fading and shadowing effects, which improves the detection probability in a heavily shadowed environment [15].

Interference-based detection:

Therefore recently, a new model for measuring interference, referred to as interference temperature shown in Fig.3 has been introduced by the FCC [14]. The model shows the signal of a radio station designed to operate in a range at which the received power approaches the level of the noise floor.

As additional interfering signals appear, the noise floor increases at various points within the service area, as Indicated by the peaks above the original noise floor. Unlike the traditional transmitter-centric approach, the interference temperature model manages interference at the receiver through the interference temperature limit, which is represented by the amount of new interference that the receiver could tolerate.

The interference is defined as the expected fraction of primary users with service disrupted by the xG operations.

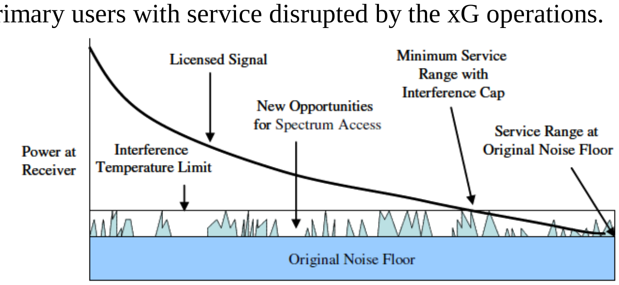


Figure.4 Interference temperature model

This method considers factors such as the type of Unlicensed signal modulation, antennas, ability to detect active licensed channels, power control, and activity levels of the licensed and unlicensed users.

TYPE	TEST STATISTICS	ADVANTAES	DISADVANTAGES
Energy Detector	Energy of the received signal samples	1)Easy to implement 2)Not require prior Knowledge about primary signals	1)High false alarm due to noise uncertainty 2) Cannot differentiate a primary user from other signal sourses.
Feature detector	Cyclic spectrum density functions of the received signal.	More robust against noise uncertainty and better detection in SNR regines than energy detection	Specific Features: Cyclostationary features, must be associated with primary signal
Matched filtering & coherent detection	Projected received signal in the direction of the already known primary signal.	Require less signal samples to achieve good detection	High complexity.

Table.1.Comparision of Spectrum sensing techniques

Spectrum management

In xG networks, the unused spectrum bands will be spread over wide frequency range including both unlicensed and licensed bands. These unused spectrums bands detected through spectrum sensing show different characteristics according to not only the time varying radio environment but also the spectrum band information such as the operating frequency and the bandwidth.

Spectrum mobility

xG networks target to use the spectrum in a dynamic manner by allowing the radio terminals, known as the cognitive radio, to operate in the best available frequency band. This enables ‘‘Get the Best Available Channel’’ concept for communication purposes. To realize the ‘‘Get the Best Available Channel’’ concept, an xG radio has to capture the best available spectrum. Spectrum mobility is defined as the process when an xG user changes its frequency of operation.

Spectrum sharing

In xG networks, one of the main challenges in open spectrum usage is the spectrum sharing. Spectrum sharing can be regarded to be similar to generic medium access control (MAC) problems in existing systems. The coexistence with licensed users and the wide range of available spectrum are two of the main reasons for these unique challenges.

The spectrum sharing process consists of five major steps.

- Spectrum sensing
- Spectrum allocation
- Spectrum access
- Transmitter-receiver handshake
- Spectrum mobility:

V. CONCLUSION

xG networks are being developed to solve current wireless network problems resulting from the limited available spectrum and the inefficiency in the spectrum usage by exploiting the existing wireless spectrum opportunistically. In this survey, intrinsic properties and current research challenges of the xG networks are presented. We investigate the unique challenges in xG networks by a bottom-up approach, starting from the capabilities of cognitive radio techniques to the communication protocols that need to be developed for efficient communication. Moreover, novel spectrum management functionalities such as spectrum sensing, spectrum analysis, and spectrum decision as well as spectrum mobility are introduced. Many researchers are currently engaged in developing the communication technologies and protocols required for xG networks. However, to ensure efficient spectrum-aware communication, more research is needed along the lines Introduced in this survey.

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