Emerging Applications of Cognitive Radios

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***Abstract*— As per recent Federal Communications Commission (FCC) report, it has been observed that licensed spectrum bands are not being fully utilized by licensed users. Instead of exploring new spectrum bands at higher Giga hertz range, white spaces in existing frequency bands can be utilized for communication. Recently, cognitive radios have been introduced as being capable of increasing the spectral efficiency by opportunistically access both the licensed and unlicensed spectrum bands. In this literature, we have targeted some important applications of cognitive radios and surveyed the challenges facing by cognitive users in these applications.**

Keywords- cognitive radios; cognitive radio applications; CR emerging application

I. Introduction

Cognitive radios are one of the computer-intensive systems which are also called to be "radio with a computer inside or a computer that transmits" [1]. Due to increasing use of wireless systems and scarce of the conventional static spectrum, policies have been formulated for unlicensed wireless devices by the Federal Communications Commission to opportunistically use spectrum holes in licensed bands, most importantly, the void spectrum spaces of TV band spectrum [2]. The expanding Cognitive Radio (CR) technology has proved itself a reliable technique of enhancing the spectral efficiency by employing the features of time, frequency, and space domains having harmless interference with previous systems.

The CR technology has equipped wireless radios and has given them a new dimension, they have the capacity to alter and modify several parameters to work with more intelligence and take decisions [3]. Cognitive radios are fully capable of choosing its own frequency in bandwidth rather than using predefined channels in accordance with the spectrum and network needs at hand. CRs are capable of cooperating very efficiently towards the possible use of the frequency band, as well with the presence of several cognitive radios and old system, non-cognitive, radios.

CR technology plays a major part in coming up with the appropriate use of the limited frequency band. It turns to help in contributing the ever increasing facilities for growing wireless appliances, like the TV spectrum through a smart grid, citizen safety, GSM network and body area network band for medical equipment. To take greater advantage of newly born opportunities, several standards, like "IEEE 802.22, IEEE 802.11af, ECMA 392, IEEE SCC41, and ETSI RRS)" are either in the development phase or are being finalized [7]. CR technology can use both licensed and unlicensed frequency bands for communication. The FM/AM, TV, GSM and satellite band spectrum, HAP control spectrums are a few examples of licensed frequency bands. License holder has the power to control the given spectrum; therefore he can independently monitor and control noise factors present in the way of user equipment to ultimately achieve the quality of service (QoS).

Improvement in overall spectrum utilization for cognitive radios is achieved through active adjustment and adaptation to localized band availability [8]. It equips the secondary users (unlicensed users) to utilize the unused frequency band possessed by the primary users (licensed users) in the interference range which is below a certain threshold level. The Cognition Cycle (CC) plays a central role in making each SU to observe and learn, and will help to make the right decision at the right time for optimal performance of the network or close to optimal at all time. In particular, the network wide performance is significantly enhanced because of the cognition cycle as it enables the secondary users to use under-utilized spectrum opportunistically while maintaining the interference levels to a minimum for primary users.

In recent years, many advancements in CR technology have been evolved, for example, in addition to the licensed frequency band the unlicensed portions of the spectrum has also been reserved which could be used without any license by radios following a predefined set of rules. There can be a number of parameters to define that rule, one of that might be maximum power radiated per hertz (power spectral density) [6]. The prime advantage of utilizing the unlicensed spectrum is twofold, first to minimize the cost of purchasing licensed bands through auctioning which ultimately builds the burden on consumer end and hence the use of technology is finally discouraged. The other big gain is that it promotes innovation as the designers have the inherent constraint to use the same band for their cognitive radio architectures. These unlicensed bands have been shown to play an important role in wireless communications. This is reflected in the 2.4 GHz unlicensed systems such as Bluetooth, cordless phones and Wi-Fi-802.11b/g/n. Despite all the benefits of unlicensed bands, there is a limit to which we can further use them as if all the devices start using these bands then there would be too much interference that no communication would be possible.

Cognitive radios can be categorized into three main network paradigms: underlay, overlay, and interweave [6]. In case of underlay network paradigm, cognitive users are only allowed to operate if and only if the level of interference caused towards non-cognitive users is below a threshold. In overlay systems, cognitive radio uses excellent signal processing and coding to maintain or improve the communication of non-cognitive radios and at the same time get some extra bandwidth for their own communications. Finally, for interwoven systems, cognitive radio uses cunning strategy for exploiting spectral holes opportunistically without interfering with other transmissions.

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The paper is structured as follows; Section II will cover the trending applications of cognitive radios and it is the core section of the paper. The applications which have been covered are; application of cognitive radios in wifi scenario, TV band devices, wireless broadband access, medical body area networks, smart grid networks, cellular networks, military applications and public safety networks. Finally, at the end, Section III will draw the paper conclusion.

II. Cognitive Radio Application Areas

Even though there is sound assurance of the fact that cognitive radio is an intelligent, smart and self-conscious technology, a variety of other interesting applications are also sprouting up stretching from commercial to health related; from Dynamic Spectrum Access (DSA) to interoperability applications towards the concept of universal transportable devices. However, the most preferred and favorite for technology developers right now is Dynamic Spectrum Access (DSA) and they see it as an extremely important application of CR technology [5].

A. *Improvement in Spectrum Utilization for Wifi*

CR techniques provide an appealing as well as fascinating strategy to dynamic spectrum allocation (DSA) [5]. As shown in Figure 1 a surprisingly simple and straightforward scenario exhibits 20 dB SINR betterment for wireless LAN (WLAN) employing cognitive radio strategies in an interference atmosphere setup over that offered by the existing IEEE 802.11a physical layer standard.

The experiment [5] narrows down to the license-free band 5.8 GHz ISM (industrial, scientific, and medical) to make the assessment of technique effectiveness with reference to frequency-band utilization of IEEE 802.11a/g PHY- layer with the CR model of such a WLAN radio. Through the proposed experimental setup, a typical standardized OFDM physical layer of 802.11a/g WLAN was developed and afterwards simulation was successfully done to assess the exploitation of the spectrum for both the cases; fixed channel assignment strategy vs dynamic spectrum allocation technique based on cognitive radio concept. It can be considered as the simplest application of cognitive radios.

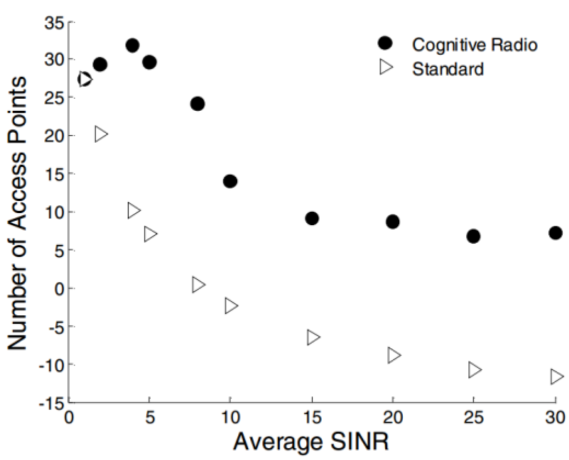

Fig. 1. *Enhancement* of *SINR* relating to standard technique and CR

B. *TV Band Devices*

The TV band devices (TVBDs) can be classified into two main categories: fixed and portable [7]. Maximum power radiated by Fixed TVBDs is not greater than 4W; possessing PSD of 16.7 mW/100 kHz from a fixed pre identified location. They're expected to either use geo location functionality or be appropriately setup in a predefined never moving spot and possess the ability to extract a summary of accessible channels from an authorized list of channel bank. Frequency channels which are permitted to be used for fixed TVBDs cannot exist adjacent to primary user operating channels ranging from channels between 2 and 51 apart from channels 3, 4 and 37 which are an exception case. In case of portable TVBDs, they are allowed to use channels between 21 and 51 excluding channel 37 and maximum power constraint for radiation is set to be 100 mW with the power spectral density of 1.67 mW/100 kHz in non-adjacent frequency channels while PSD constraint for adjacent frequency channels is 0.7 mW/100 kHz. Portable devices are furthermore divided into two additional modes of operation: mode-I and mode-II. Mode-I devices don't require geo location functionality or permission to access a database. Mode II devices require geo location functionality as well as the way to approach a database for listing of accessible channels.

A sensing-only device is some type of handheld TVBD, which makes use of RF spectrum detection to acquire and pull out a listing of accessible television stations. The sensing-only equipment like the one mentioned will be able to broadcast on any number of readily accessible channels within the band of frequencies ranging from 512-608 MHz (corresponding TV channels 21-36) and 614-698 MHz (corresponding TV channels 38-51), and generally are limited to an utmost transmission power of 50 mW with a power spectral density of 0.83 mW/100 kHz on non-adjacent channels and 40 mW with a power spectral density of 0.7 mW/100 kHz on adjoining channels [7]. Aside from that, a sensing-only device is required to make sure with an exceptionally higher level of assurance that it will not contribute to local radio transmissions of the primary users. The necessary power levels for detecting the signals are: NTSC Analog TV: -114 dBm, mean value across a 100 kHz frequency band; ATSC digital TV: -114 dBm, mean value across a 6MHz frequency band; Low power wireless microphone signals: -107 dBm, mean value across a 200 kHz frequency band. A TVBD might start working over a TV station when there is no TV; it takes only a time period of 30 seconds to identify the cordless microphone as well as any other below average power auxiliary equipment transmitting signals over the threshold range. A TVBD is required to accomplish in service supervision of the working station at the very least one time after every 60 seconds period. All transmissions are brought to a halt as soon as the TV, a cordless microphone or similar lower power auxiliary gadget signal is detected over the TVBD in service channel.

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TABLE 1. PARAMETERS & APPLICATIONS

	Fixed device	Sensing only
Channels	Channels ranging from 2 to 51 except 3, 4 and 37. Only Non-adjoining channels	Channels 21 to 51 excluding 37
Power constraints	4 W	50 mW
Prospective applications of CR	Cellular backhaul (base station, relay stations), Smart grid stations	Public safety, Femto-cell

C. Wireless Broadband access in TV bands

Cognitive Radio (CR), a present day technology has already been prevailed as a central framework in increasing wireless access methods, including the IEEE 802.22 also known as Wireless Regional Area Networks (WRANs) [2]. An excellent utilization of IEEE 802.22 is the wireless broadband internet connection in non-urban as well as far off areas, offering results are very much similar to existing broadband access systems such as cable modems and digital subscriber line (DSL). WRAN networks are expected to take advantage of the infrequently employed ultra high frequency (UHF) TV band spectrum, providing wireless solutions including data, speech, and video traffic maintaining satisfying levels of quality of service (QoS).

D. Medical Body Area Netwroks

In the past few years we have seen accelerating curiosity pertaining to supervision of medical patients in hospitals for crucial indicators such as human body temperature, blood oxygen, blood pressure, and ECG. Generally most of these vitals are supervised by on-body receptors which are then hooked up to cable connections to a bedroom screen. The MBAN is an appealing substitute for getting rid of these electrical wires, consequently enabling sensors to easily and reasonably obtain a number of needed parameters immediately and communicate the observing details wirelessly which would mean that doctors can react exponentially fast.

Typically, the 2.4 GHz ISM frequency spectrum is not well suited for life-critical healthcare systems because of the interference and bottleneck caused by wireless IT systems' medical facilities. By making use of 2360 to 2400 MHz frequency band specified for body area networks on alternative basis, Quality of Service (QoS) for such life-crucial monitoring devices could perhaps be much better ensured. Furthermore, the frequency band ranging from 2360 to 2400 MHz is specifically next to the 2.4 GHz frequency band wherein a number of wireless systems are already available right now which may often be used again for MBANS like IEEE 802.15.4 standard devices [7]. This certainly will end up in cheap implementations owing to economies of scale, and finally result in larger arrangements of medical body area networks(MBAN) and as a consequence, there would be immense advancement in patient health-care.

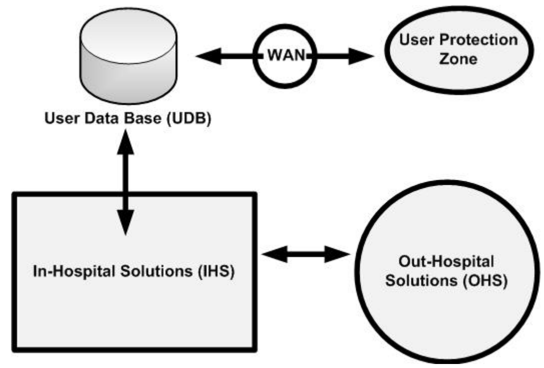

Fig. 2. MBANs Basic Architecture

Transmissions from body area network devices would likely to be of data only (without voice). It is strongly recommended that the frequency band ranging from 2360 to 2400 MHz should be classified into two categories: band-I in the frequency range 2360 to 2390 MHz and band-II in the frequency range 2390 to 2400 MHz while in the 2360-2390 MHz frequency range, body area networks operation is confined for indoor use exclusively. And for the frequency range 2390 to 2400 MHz, body area network operation is permitted pretty much anywhere [7]. A contention-based protocol, which is unrestricted, is proposed for gaining access to the medium. The maximum amount of emission of bandwidth for body area networks is allowed to be 5 MHz. The utmost transmission power should not meet or exceed 1 mW.

E. Smart Grid Networks

Remodeling of the previous century power grid right into an intelligent smart grid will probably be advocated by many nations as a means of handling electrical power self-reliance and durability, global warming and catastrophe challenges. The smart grid constitutes 3 abstract-level tiers, from a technological innovation point of view: the physical electrical power tier, communication networking tier, together with the application layer [5]. The smart grid manages the electrical power in a manner in which electric power is produced, transported, used up and charged. Putting intellect through the entire freshly networked power grid boosts grid durability, enhances demand management and responsiveness, and incorporates distributed sources of energy, and also essentially lowers expenses towards the customers and service provider.

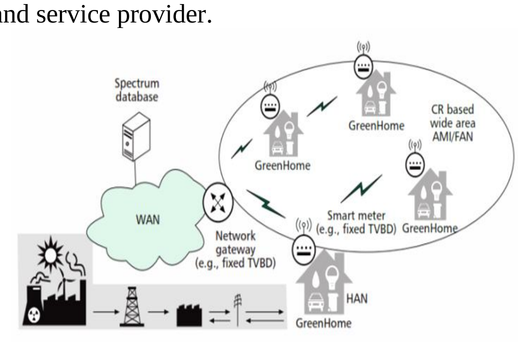

Fig. 3. Smart Grid Network

A smart grid network has normally three building blocks:

- The home area networks (HANs) which generally connect on-premise devices and intelligent meters, dispersed alternative sources and plug-in electric powered automobiles.
- The field area networks (FANs) or advanced metering infrastructure (AMI) which assists transmit data linking sites (through intelligent metering) together with a network gateway, that might be a power substation, a utility rod-fitted appliance, or just a transmission tower system.
- The wide area networks (WANs) that function as being the central resource for interaction among utility data center and the aggregation points/network gateways.

F. Cellular Networks

In the last decade, usage of the cellular networks has increased considerably, with consumers always hoping of staying connected regardless of their different locations and time. Beginning of smart phones and social networking era , increasing usage of multimedia websites which includes daily motion, facebook, YouTube, and flicker, releasing of innovative gadgets for example e-readers etc have additionally enhanced the dramatical improvement in the usage of mobile networks for conventional data services , e.g., web surfing and electronic mail. Now this offers not only new possibilities for innovative businesses but at the same time it's a real challenge for cellular operators. The increasing number of data services creates an opportunity as they add to the overall revenue. But, it becomes challenging as in some geological regions, mobile networks have become congested because of the limited bandwidth acquired by cellular operators. Recent studies indicate that the broadband internet bandwidth shortfall is anticipated to come closer to 300 MHz by 2014 [7].

For applications requiring access to the network, two scenarios are usually kept in view. Primarily are hotspots, like in airports and game stadiums, mainly because people arrive in massive numbers at majority of these spots. Let us consider the scenario of an athletic ground, participants in this modern age possess smart phones which have cameras by means of which they can easily take photographs of the proceedings of the sporting activity and share them with their friends through social media sites. This kind of video and graphic data adds massive load on mobile phone network. During a research investigation by Cisco, it is concluded that this picture and video data can cause up to 60 percent increase [7]. These days a fraction of the multimedia content could be very easily diverted to ISM (industrial, scientific, and medical) band used in WiFi networks. Nevertheless, because of the huge amount of information produced within a smaller region, both ISM band Wifi networks as well as cellular networks are likely to be jammed. If this particular type of multimedia content (images, video etc) can be side tracked to some other extra channel, for example TVWS, then the_mobile network may possibly be utilized for other speech services offered by the network with a significantly more effective manner, and as a result reaping the benefits for both the user as well as cellular operator.

Femto-cell can be seen as the second access network application. These days many cellular operators provide miniaturized base stations whose visual appearance is just like a Wi-Fi router or access point, individuals can purchase them and install them within their houses. These mini base stations also called Femto-cells which can be used in areas having bad coverage areas like basements. These femto-cells and cellular operators use the same frequency range [7].

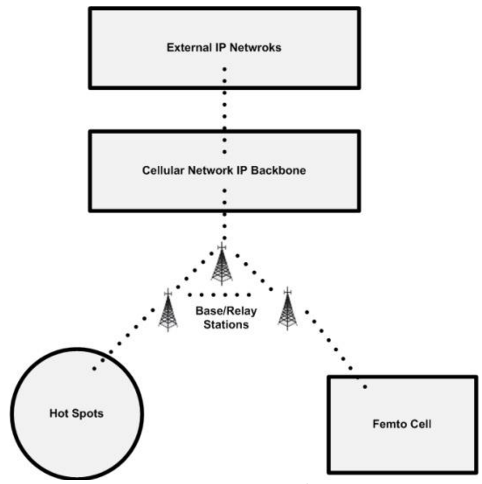

Fig. 4. Basic Architecture of Cellular Network

G. Military

The capability to improve interoperability connecting several dissimilar radio standards, combined with the ability to observe the existence of interferers, CR device has turned into a must-have technology gadget. This cutting edge technology provides you with added benefits by means of safeguarding and shielding the ongoing communications, recognizing the adversary transmissions, as well as revealing of tracks of opportunity.

The U.S. Department of Defense (DoD) has dedicated lots of energy and efforts to revolutionary state-of-the-art wireless applications over the last few years and has now developed packages for instance, Joint Tactical Radio System (JTRS), SPEAKeasy radio system, and Next Generation (XG) to make it possible for the development of an intelligent and a smart communication agent [5].

H. Public Safety Networks

General consumer protection and crisis situation feedback is nevertheless an additional sphere where exactly CRs have acquired loads of interest and attention. For quite a few years public safety and security organizations have desperately needed a whole lot more spectrum share to help ease frequency over-crowding and greatly improve interoperability. Equipped with spectrum sharing functionality, CRs can show their usefulness simply by using a portion of the pre-existing spectrum which is not frequently used at the same time help in taking care of call priority and response time. On top of that, Cognitive Radios may play a significant part in further enhancing interoperability by allowing gadgets to bridge communications between areas by making use of separate frequencies and modulation forms.

Public safety high-risk workers have become considerably important turning out to be backed up with wifi enabled mobile computing devices, laptop systems, together with mobile camcorders to enhance most of the functionality and capability to instantaneously team up making use of centralized control, co-workers, in conjunction with other groups [7]. Specified cordless support services relating to community protection and safety stretch out ranging from web surfing, speech to text messaging, electronic mail, database accessibility, graphic transmission, video media buffering, along with other wideband features. Video monitoring spy cameras coupled with sensor devices are increasingly becoming immensely important resources to enhance the eyes and ears concerning general public protection and security organizations. Correspondingly, information rates, integrity, as well as lag time specifications differ from service to service.

In comparison, RF band frequencies designated for the consumer's safety and security purpose are increasingly becoming jam-packed, particularly in metropolitan areas. Aside from that, primary users originating from various areas and associations usually are not able to connect in the course of crisis situation. As shown in Figure 5, these kinds of cognitive devices could possibly be positioned in a number of ultra-powerful crisis responders' automobiles coupled with wireless routers or access points. This approach elevates the strain from mobile handheld devices to acquire cognitive ability to lessen the situation in which various critical responders might use several radios nowadays and most probably in the foreseeable future to a greater extent.

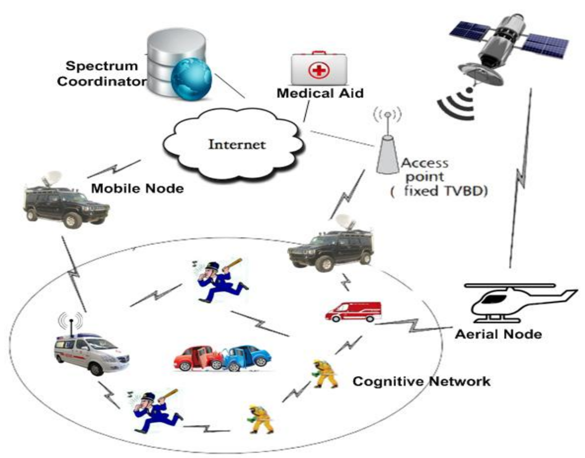

Fig. 5. Public Safety Network

CR was indeed recognized as a promising solution to supercharge effectiveness and usefulness of RF band. Equipped with Cognitive Radios, customer safety operators can make use of a whole lot more RF band for day-to-day operations from area to area and time to time. By working with the appropriate spectrum collaborating partners, public security personals are also able to get access licensed RF bands and professional operator networks. For instance, the public protection people might possibly roam on wireless networks in 700 MHz frequency range and possibly several other frequency bands throughout the spots in which public security wireless services are inaccessible and the places where there exists at the moment a working public coverage network, however considerably more data capacity is needed to respond proficiently and resourcefully for a critical situation.

So it will remain to be witnessed the way in which Cognitive Radio concept will assist the top priority distribution and routing of data packets by means of its very own specialized network together with the general public wireless networks, consequently safeguarding time-critical priority data packets from losses or postponement caused by network over-crowding. This goes beyond the borders of spectrum recognition to content recognition, from the PHY layer towards the App layer.

III. Conclusion

CR technology can play an important role in order to make an excellent use of the limited spectrum to compliment the rapidly growing desires and needs pertaining to wireless applications, such as the common man basic safety, intelligent power grid, and the wireless broadband internet, mobile networks to even healthcare applications. At the same time, challenges continue to exist due to the fact that CR-enabled networks are expected to exist together with incumbents as well as cognitive users and are required to minimize interference in a manner that they will more effectively facilitate these kinds of applications from end to end.

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