A Survey on Conceptualization of Cognitive Radio and Dynamic Spectrum Access for Next Generation Wireless Communications

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***Abstract*— Today's wireless spectrums are characterized by a fixed spectrum assignment policy. However, a huge portion of the allocated spectrum is used spasmodically and geographical variations in the usage of allocated spectrum ranges from 15% to 85% with a high discrepancy in time. We can't create resources but we can reuse the available resources. Cognitive radio (CR) is the enabling technology for supporting dynamic spectrum access. The fixed spectrum allocation of governmental agencies results in unused portions of spectrum, which are called spectrum holes or white spaces. Cognitive radio makes use of these spectrum holes and it addresses the spectrum scarcity problem that is encountered in many countries. It has emerged as a promising technology to exploit the unused portions of spectrum in an opportunistic manner.**

***Keywords*— Cognitive Radio, Dynamic Spectrum Access, Next Generation Wireless Networks, Spectrum Sensing, Software Defined Radio.**

I. INTRODUCTION

The key motivation behind cognitive radio technology is to boost spectrum usage and to improve the use of radio resources. The demand for high data rate is increasing as a result of the transformation from voice-only communications to multi-media type applications. Today's wireless networks are monitored by fixed spectrum assignment policies; i.e., the spectrum is monitored by government agencies and is allocated to license holders on a long term basis for huge geographical regions. According to Federal Communications Commission (FCC) the temporal and geographical variations is 15% to 85% in the utilization of the allocated spectrum [1].In 2002, FCC has proposed several solutions to enhance the licensed spectrum utilization efficiency. These solutions are divided into three categories on the basis of how the unused licensed spectrum channels are utilized. The solutions are spectrum reallocation, spectrum sharing and spectrum leasing [2]. In this application, we need an Ultra Wide Band (UWB) antenna to detect or to sense the spectrum hole (free channel) and another reconfigurable Narrow Band (NB) antenna for communication [3], [4]. According to the information given by the Federal Communication Commission (FCC) in November, 2002 [5]:

- Some of the frequency bands are unoccupied for a longtime;
- Some portion of the spectrum is used moderately;
- Some part of the spectrum is always busy.

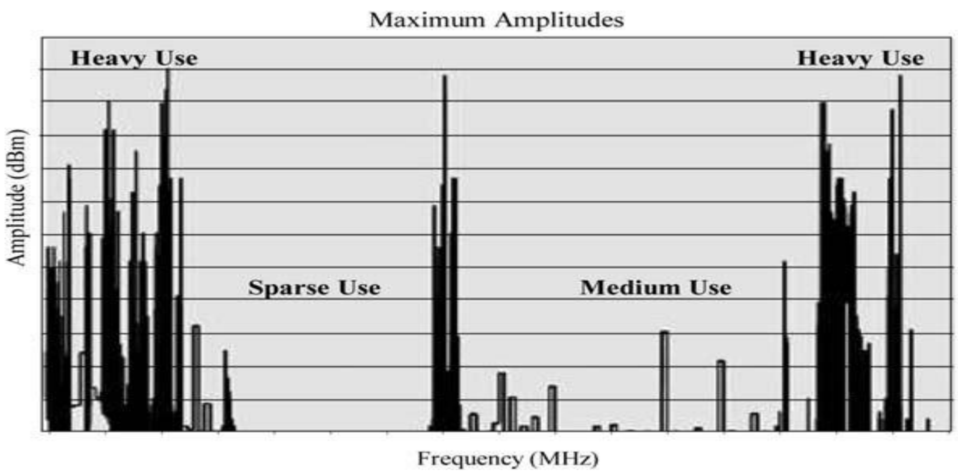

Fig. 1. Spectrum Utilization [5].

To boost the efficiency and usage of the radio spectrum, the dynamic spectrum management model is enforced. Depending upon the usage of bands, spectrum holes are classified into three categories [5].

- **Black Spaces:** they are the part of the spectrum used by primary users, Means they have the high-power “local” interference some of the time.
- **Gray Spaces:** they are the parts of the spectrum which is rarely used by the primary user.
- **White Spaces:** these are parts of the spectrum which are not used by the primary user; it is free of RF interference except the white Gaussian noise.

Usage of Gray and White spaces to boost the spectrum efficiency is known as Dynamic Spectrum Access (DSA) or Dynamic Spectrum Management (DSM), it is considered as a potential solution for the “spectrum shortage” problem. The spectrum shortage and the inefficiency of spectrum usage initiate a new communication technology to exploit the existing wireless spectrum opportunistically. Dynamic spectrum access is recommended to solve these spectrum inefficiency problems. It aims at implementing the intelligent radios known as cognitive radios; the improper usage of the spectrum can be improved through opportunistic access to the licensed bands without interrupting the existing users. Cognitive radio technology provides the capacity to use or share the spectrum in an opportunistic manner. More specifically, this technology will enable the users to decide which portions of the spectrum are available and encounter the presence of licensed users.

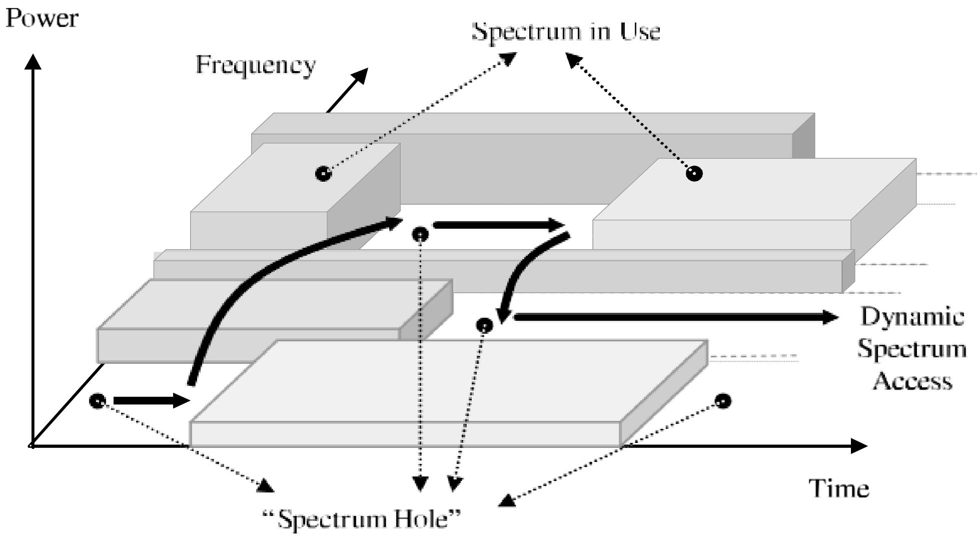

Fig. 2. Spectrum Hole Concept [1].

The cognitive radio enables the usage of temporally unused spectrum, which is referred to as spectrum hole or white space. If this band is further used by a licensed user, the cognitive radio moves to another spectrum hole or stays in the same band, altering its transmission power level or modulation scheme to avoid interference. Cognitive radio is a goal driven framework [6], in which the radio autonomously observes the radio environment, infers context, assesses alternatives, generates plans, supervises multimedia services, and learns from its mistakes.

II. COGNITIVE RADIO AND CLASSIFICATION

The Software Defined Radio (SDR) was invented by Dr. Joseph Mitolain 1992. This radio primarily defined in software, which supports a broad range of frequencies, and its initial configurations can be modified for user requirements. Cognitive radio was invented by the Dr. Joseph Mitola in 1999, by adding intelligence to software defined radio. According to him: ‘‘Cognitive Radio’’ is a radio that can change its transmitter parameters based on interaction with the environment in which it operates with two primary objectives in mind:

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

Depending on transmission and reception parameters, there are mainly two types of cognitive radio [5], [7]:

- **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. It can sense channels that contain signals from a large class of heterogeneous devices, networks, and services.

Depending on the parts of spectrum available, there are two types of cognitive radio:

- **Licensed-Band Cognitive Radio:** It is capable of using bands assigned to licensed users. The IEEE 802.22 working group is developing a standard for wireless regional area network (WRAN), which will operate on unused television channels.
- **Unlicensed-Band Cognitive Radio:** This can only utilize unlicensed parts of the radio frequency (RF) spectrum. One such system is described in the IEEE 802.15

The cognitive engine performs the tasks of sensing, analysis, learning, decision making and reconfiguration. Cognitive radio networks consist of two types of users, primary (licensed) and secondary (unlicensed or cognitive) users. Licensed users have higher priority for the usage of the licensed spectrum; on the other hand unlicensed users can opportunistically communicate in licensed spectrum by changing their communication parameters in an adaptive way when spectrum holes are available

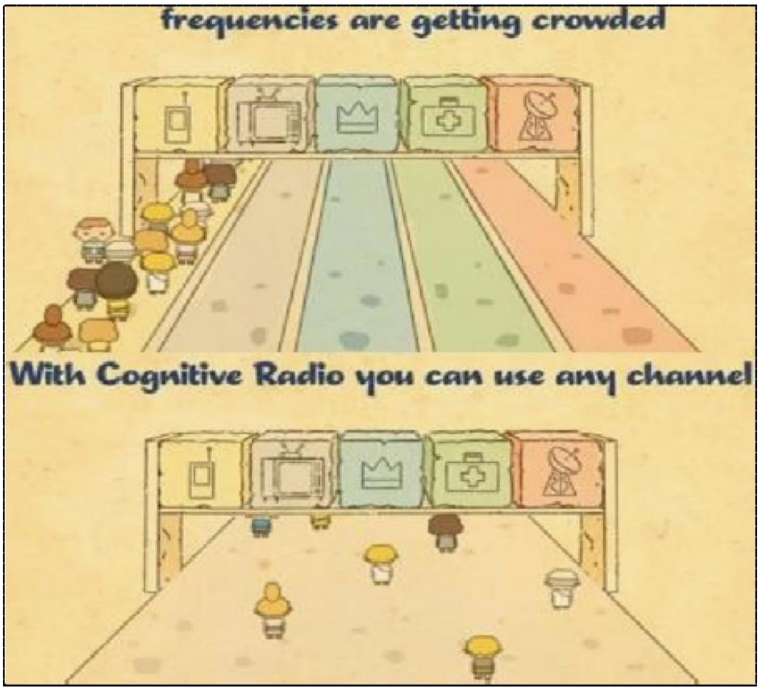

Fig. 3. Frequency utilization in Cognitive Radio Networks [7].

For next generation wireless communications Existing wireless network architectures employ heterogeneity in terms of both spectrum policies and communication technologies [1]. The components of the next generation network architecture are classified in two groups. They are the primary network and the secondary network (next generation network).

A. Primary Network

An existing network infrastructure is generally referred to as the primary network, which has an exclusive right to a certain spectrum band. The basic elements are:

- **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
- **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.

B. Secondary networks

Cognitive radio network or Dynamic Spectrum Access network or secondary network or unlicensed network does not have license to operate in a desired band. Hence, the spectrum access is allowed only in an opportunistic manner.

- **Secondary user:** unlicensed user or cognitive radio user or secondary user has no spectrum license.
- **Secondary base-station:** unlicensed base-station or secondary base-station is a fixed infrastructure component with cognitive radio capabilities. It provides single hop connection to Next generation wireless networks users without spectrum access license.

- **Spectrum broker:** Spectrum broker (or scheduling server) is a central network entity that plays a role in sharing the spectrum resources among different Next generation wireless networks.

III. COGNITIVE RADIO IMPLEMENTATION

A. Cognitive Radio Characteristics

The two main characteristics of the cognitive radio are [1]:

1. **Cognitive capability:** It refers to the ability of the radio technology to capture or sense the information from its radio environment. Through this capability, the portions of the spectrum that are unused at a specific time or location can be identified. i.e., it provides spectrum awareness.
2. **Re-Configurability:** It is the capability of adjusting operating parameters for the transmission on the fly without any modifications on the hardware components. This capability enables the cognitive radio to adapt easily to the dynamic radio environment. The cognitive radio can be programmed to transmit and receive on a variety of frequencies and to use different transmission access technologies. There are several reconfigurable parameters that can be incorporated into the cognitive radio. They are:
   - Operating frequency
   - Modulation
   - Transmission power
   - Communication technology

B. Cognitive Cycle Steps

The steps of the cognitive cycle [1], [8] are as follows:

- **Spectrum sensing:** A cognitive radio monitors the available spectrum bands, captures their information, and then detects the spectrum holes.
- **Spectrum analysis:** The characteristics of the spectrum holes that are detected through spectrum sensing are estimated.
- **Spectrum decision:** A cognitive radio determines the data rate, the transmission mode, and the bandwidth of the transmission. Then, the appropriate spectrum band is chosen according to the spectrum characteristics and user requirements.

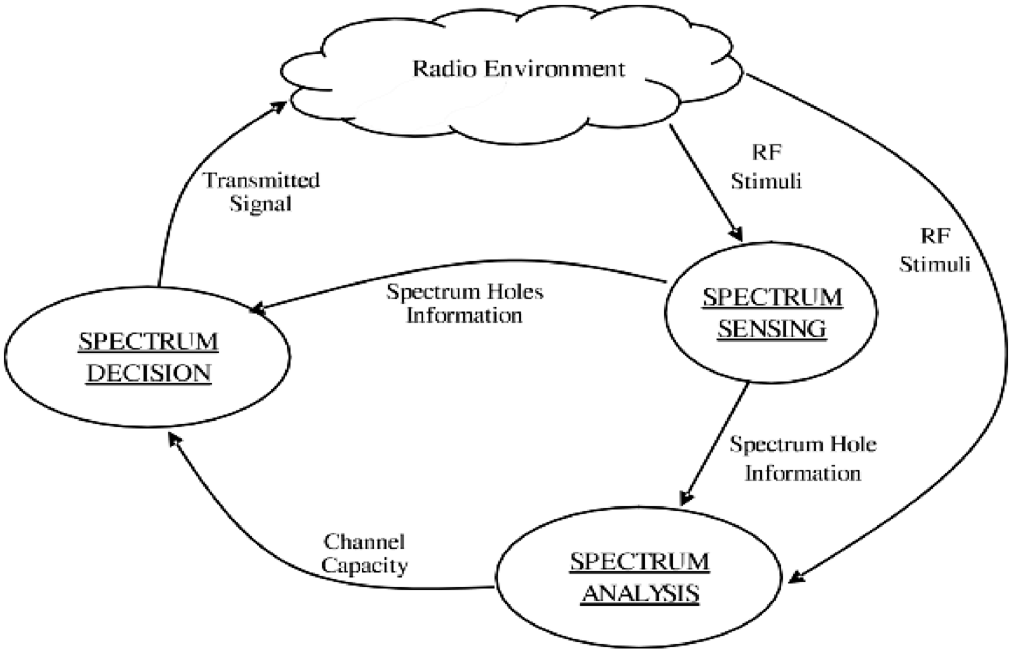

Fig. 4. Cognitive cycle steps [1].

C. Cognitive Functions

The design and deployment of CR and DSA have been investigated in a number of papers starting from the paper of Joseph Mitola. It is recognized that CRs should provide the following functions:

1. **Spectrum Sensing and Methods:** Determine which portions of the spectrum are available and detect the presence of licensed users when a user operates in a licensed band. It can be performed via two different architectures. They are:
   - In the **single-radio architecture**, only a specific time slot is allocated for spectrum sensing. As a result of this limited sensing duration, only certain accuracy can be guaranteed for spectrum sensing results
   - In the **dual- radio sensing architecture**, one radio chain is dedicated for data transmission and reception while the other chain is dedicated for spectrum monitoring.

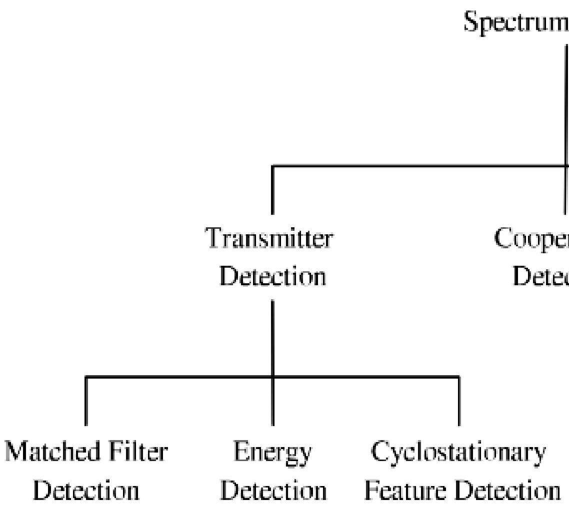

Fig. 5. Spectrum sensing methods [1].

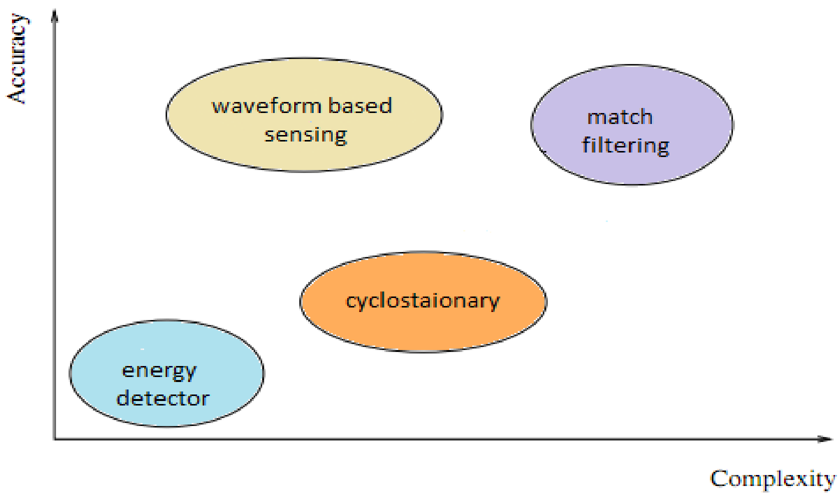

Fig. 6. Different Sensing Methods Comparison in terms of their sensing accuracies and complexities [7].

2. **Spectrum Management**: Select the best available channel for communication. In next generation wireless networks, the unused spectrum bands will be spread over wide frequency range including both unlicensed and licensed bands. These unused spectrum 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. Since next generation networks should decide

on the best spectrum band to meet the QoS requirements over all available spectrum bands, new spectrum management functions are required for next generation networks, considering the dynamic spectrum characteristics.

3. **Spectrum Sharing**: In Next generation wireless networks, one of the main challenges in open spectrum usage is the spectrum sharing. It coordinates access to the channel with other users. The types of spectrum sharing techniques are as follows:
   - Centralized spectrum sharing
   - Distributed spectrum sharing
   - Cooperative spectrum sharing
   - Non-cooperative spectrum sharing
   - Overlay spectrum sharing
   - Underlay spectrum sharing
   - Inter-network spectrum sharing
   - Intra-network spectrum sharing
   - Cooperative intra-network spectrum sharing
   - Non-cooperative intra-network spectrum sharing

4. **Spectrum Mobility and Spectrum Handoff**: Vacate the channel when a licensed user is detected. Next generation wireless 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. In next generation wireless networks, spectrum mobility arises when current channel conditions become worse or a primary user appears. Spectrum mobility gives rise to a new type of handoff in next generation wireless networks that we refer to as spectrum handoff.

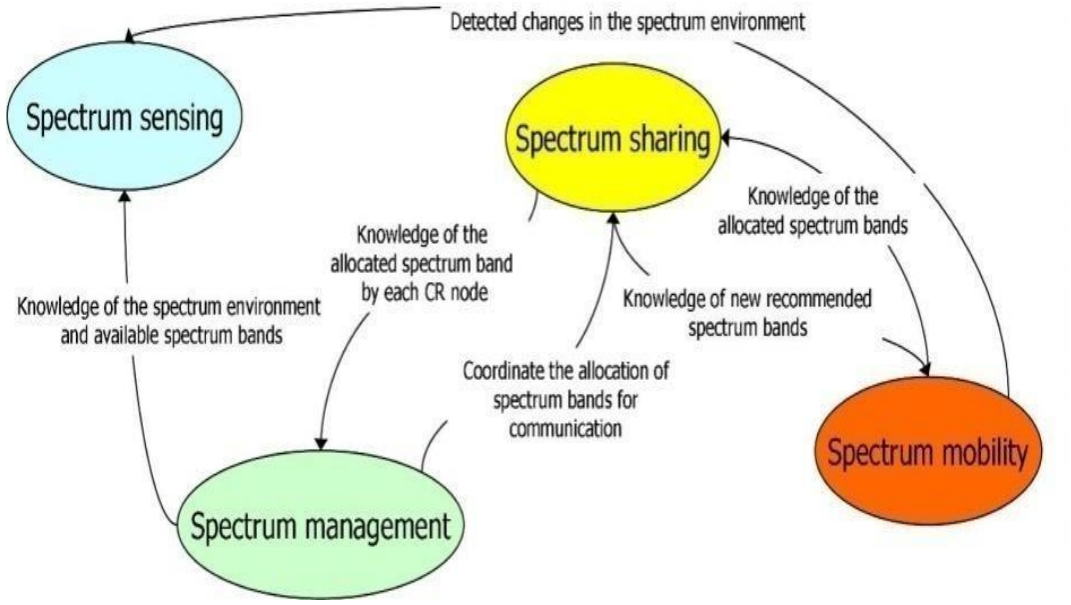

Fig. 7. Dependencies among Cognitive Radio functions [9].

IV. CHALLENGES

The cognitive radio implementation has various challenges. They are [10], [11]:

A. Spectrum sensing challenges:

- Interference temperature measurement
- Spectrum sensing in multi-user networks
- Detection capability
- Accurate detection of weak signals of licensed users over a wide spectrum range.
- Hardware Requirements
- Hidden Primary User-Problem

- Detecting Spread Spectrum Primary Users
- Sensing Duration and Frequency
- Decision Fusion in Cooperative Sensing.
- Security.
- Long term throughput estimation.
- Multiple channel selection.
- Heterogeneous hybrid access.
- A selfish or malicious user can modify its air interface of a primary user. Hence, it can mislead the spectrum sensing performed by legitimate primary users; it is termed as primary user emulation (PUE) attack.

B. Spectrum management challenges:

- Decision model
- Multiple spectrum band decision
- Cooperation with reconfiguration
- Spectrum decision over heterogeneous spectrum bands

C. Spectrum mobility challenges:

- At a particular time, several frequency bands may be available for a next generation wireless networks user. Algorithms are required to decide the best available spectrum based on the channel characteristics.
- Once, the best available spectrum is selected, the next challenge is to design new mobility and connection management approaches to reduce delay and loss during spectrum handoff.
- When the current operational frequency becomes busy (this may happen if a licensed user starts to use this frequency) in the middle of a communication by an next generation wireless networks user, then applications running on this node have to be transferred to another available frequency band.

D. Spectrum sharing challenges:

- Common control channel
- Dynamic radio range

V. THREATS

The threats are as follows [9]:

- Insertion of malicious software.
- Alteration or destruction and Extraction of the configuration data.
- Artificial consumption of resources
- Alteration or destruction and Extraction of waveform data.
- Alteration or destruction of real-time operating system.
- Alteration or destruction of the software framework.
- Alteration or destruction and Extraction of user data.
- Software failure.
- Hardware failure.
- Masquerading as authorized software waveform.
- Unauthorized use of Software Defined Radio services
- Data repudiation.
- Jamming of the channel used to distribute cognitive messages.
- Malicious alteration of cognitive messages
- Masquerading of a primary user.
- Malicious alteration of a cognitive radio node
- Internal failure of cognitive radio node
- Masquerading of a cognitive radio node
- Hidden node problem.
- Unauthorized use of spectrum bands for selfish use
- Unauthorized use of spectrum bands for DoS to primary
- Saturation of the cognitive control channel.
- Eavesdropping of cognitive messages.
- Disruption to the MAC, network layer, or cognitive engine of the cognitive radio network.

VI. SPECTRUM SENSING STANDARDS AND ORGANIZATIONS

A. Spectrum sensing Standards

The main spectrum sensing standards are [10]:

- **IEEE802.11k:** A proposed extension to IEEE 802.11 specification is IEEE802.11k, 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.
- **IEEE 802.22:** IEEE 802.22 is the first worldwide standard based on the cognitive radio technology and is now in the process of standardization. IEEE 802.22 based wireless regional area network (WRAN) devices sense TV channels and identifies transmission opportunities.
- **Bluetooth:** A new feature, namely adaptive frequency hopping (AFH), is introduced to the Bluetooth standard to reduce interference between wireless technologies sharing the 2.4 GHz unlicensed radio spectrum.

B. Organizations

The main organizations working on SDR/CR standards and where security aspects have been addressed [9]:

- Wireless Innovation Forum
- IEEE 802.22
- IEEESCC41
- ETSI TCRRS

VII. CONCLUSION

Next generation wireless networks are being developed to solve current wireless network problems resulting from the limited available spectrum and the inefficiency. Cognitive radio and Dynamic Spectrum Access is the ultimate solution which will provide a spectrum aware communication paradigm in wireless communications. In this paper, intrinsic properties and current research challenges of the next generation wireless networks are presented. The discussions provided in this paper strongly advocate spectrum aware communication protocols that consider the spectrum management functionalities. Cognitive radio is a promising approach to increase the efficiency of spectrum usage, which is one of the efforts to utilize the available spectrum more efficiently through opportunistic spectrum usage. To implement this application, we need an Ultra Wide Band antenna to sense or to detect the spectrum hole and other reconfigurable narrow band antennas for communication.

REFERENCES

[1] Akyildiz, Ian F., et al. "NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey." *Computer networks*, vol. 50, no. 13, pp. 2127-2159, Sep. 2006.

[2] Nella, Anveshkumar, and Abhay Suresh Gandhi. "A survey on planar antenna designs for cognitive radio applications." *Wireless Personal Communications*, vol. 98, no. 1, pp. 541-569, Jan. 2018.

[3] Vinay bankey, N. Anveshkumar, "Design and performance issues of Microstrip Antennas", *International Journal of Scientific & Engineering Research*, vol. 6, no. 3, pp. 1572-1580, Mar. 2015.

[4] Nella, Anveshkumar, and A. S. Gandhi. "A survey on microstrip antennas for portable wireless communication system applications." *In Proceedings of the IEEE International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, Udupi, India, pp. 2156-2165, Sep. 2017.

[5] Jariwala, B., and V. Manilal. "A Survey: A Cognitive Radio for Wireless Communication." *IOSR Journal of Electronics and Communication Engineering*, vol. 9, no. 1, pp. 57-63, Jan. 2014.

[6] Mitola III, Joseph. "Cognitive radio for flexible mobile multimedia communications." *Mobile Networks and Applications*, vol. 6, no. 5, pp. 435-441, Sep. 2001.

[7] Preet, Ayubi, Amandeep Kaur, and Sggswu Fatehgarh Sahib. "Review paper on cognitive radio networking and communications." *International Journal of Computer Science and Information Technologies*, vol. 5, no. 4, pp. 5508-5511, Mar. 2014.

[8] Tawk, Y., J. Costantine, and C. G. Christodoulou. "Cognitive-radio and antenna functionalities: A tutorial [Wireless Corner]." *IEEE Antennas and Propagation Magazine*, vol. 56, no.1, pp. 231-243, Feb. 2014.

[9] Baldini, Gianmarco, et al. "Security aspects in software defined radio and cognitive radio networks: A survey and a way ahead." *IEEE Communications Surveys & Tutorials*, vol. 14, no. 2, pp. 355-379, May 2012.

[10] Yucek, Tevfik, and Huseyin Arslan. "A survey of spectrum sensing algorithms for cognitive radio applications." *IEEE communications surveys & tutorials*, vol. 11, no. 1, pp. 116-130, Mar. 2009.

[11] Tragos, Elias Z., et al. "Spectrum assignment in cognitive radio networks: A comprehensive survey." *IEEE Communications Surveys & Tutorials*, vol. 15, no. 3, pp.1108-1135, Jan. 2013.