Cognitive Radio : A Solution for Issues in Network Convergence

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Abstract: While planning for strategic communication no nation or organisation can ignore the problems of dynamic radio resource allocation and interference. Among lot number of technologies as a solution Cognitive Radio (CR) is the best one, which helps to overcome the problem of interference, and also allow efficient and dynamic radio resource allocation. Applying Cognitive Radio Networks (CRN) to strategic communications as a solution, this roadmap has been proposed by nations and organizations. For fast network deployment it is mandatory to overcome traffic problem in spectrum, increase communication reshaping mechanism and also strategic radio should act as multi-functional Radio-Frequency(RF) Unit, these are the themes for which CRN is the choice. Wireless Sensor Networks(WSNs) present day have many challenges, if it get clubbed with CR, many problems can be solved. Theme of our research is to empower CRN, so that it will help to solve above problems and also help to manage traffic in network convergence services without ignoring or compromising security.

Keywords: *CR, CRN, DSA, SDR, SR-WSN, Cyber EM, CR-MANET, RF, WSN*

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I. INTRODUCTION

Mobile communication technologies have been a process of discovering and utilizing new radio resource dimensions to improve spectrum efficiency. Cellular technology in 1970s made frequency multiplexing possible and expanded the space of spectrum resources. The digitalization process beginning in 1980s enabled resources to be extended in time dimension. At the turn of the century, Multiple Input Multiple Output (MIMO) technology was introduced, marking the utilization of space dimension of resources. The discovery of these three resource dimensions has greatly driven the development of mobile communication technologies [10].

With growing demands for the amount of data transferred in wireless networks, spectrum shortage problems become tremendous. Measures are needed to overcome problem of interference, improve system-wide spectral efficiency and allow full fledge and flexible spectrum resource utilization. CR is widely considered as a promising technology for providing the measure to solve the spectrum resource challenge in the current inflexible spectrum allocation policy. CR, which have environment sensing and transmission adaptation capabilities, can address the dynamic nature of the network, offering new possibilities to enhance the performance of modern strategic communication system [1]. Many organizations have put forward a roadmap for applying CRN to strategic communications.

II. WHAT IS?

A. *CR and CRN*

The term "Cognitive Radio" (CR) was first coined by Dr. Joseph Mitola in 1999. CR systems can dynamically access new frequency bands, and at the same time protect higher priority users on the same bands from harmful interference. In addition to the ability to adapt, the concept of CR allows for the radio to "learn" in order to make good performance choices for the user's objectives [23]. Haykin provided a comprehensive definition for CR [2]:

"Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit power, carrier frequency, and modulation strategy) in real-time, with two primary objectives in mind: highly reliable communication whenever and wherever needed; efficient utilization of the radio spectrum."

CR is a radio that can change its transmitter parameters based on the environment in which it operates [3]. A CR needs knowledge, or awareness of the environment to make decisions. Knowledge can be gathered from policies and rules, sensors, the radio network infrastructure, propagation data, and the like. Knowledge might be gathered by the CR itself, obtained from a central controller, or from peer CRs. Sensing data from other CRs may be gathered and fused locally, or data might be fused by a central controller and distributed in distilled format. Some of the key features that are typically associated with CR [4] are ***Senses, Collaborates, Adapts, Reasons, Learns & Anticipates.***

CRs shall form Cognitive Radio Networks (CRN) to complete the packet deliveries [5]. A CRN is generally a multi-hop wireless heterogeneous network, meaning it allows peer-to-peer communications and may include different types of radios. When CRs are connected and form a CRN, they may share knowledge, that is, the information gathered at each node, and decisions may be made in a distributed manner. In an abstract sense, the cognition then becomes a function of the network, rather than the individual radio.

B. Terminal capability of CRN

The capabilities of CRs as nodes of CRN can be classified according to their functionalities [7].

a) Cognitive capability: A CR sense the environment, consists of *Spectrum Sensing, Spectrum Sharing, Location Identification, Network/System Discovery and Service Discovery.*

b) Self-organized capability: A CR analyze and learn sensed information, *consists of Spectrum/Radio Resource Management, Mobility and Connection Management and Trust/Security Management.*

c) Reconfigurable capabilities: A CR adapts to the environment, consists of *Frequency Agility, Dynamic Frequency Selection, Adaptive Modulation/Coding, Transmit Power Control and Dynamic System/Network Access.*

C. Commercial CRN and Strategic CRN

In the commercial world, CRs are radios that use locally available spectrum, which is allocated but unused by the licensed user, in a homogeneous and predictable manner to provide services that would not otherwise be available. IEEE 802.22 WRAN standard, under development, that aims to reuse vacant Television (TV) bands. There is a clear distinction of primary users(PU) and secondary users(SU). The aim of strategic CRs is to use the existing spectral allocations more efficiently and to improve communications support when changing location and network topology to support operations. There may be no clear distinction of PU and SU.

III. CR WITH OTHER TECHNOLOGIES

A. Cognitive Radio and Dynamic Spectrum Access (DSA)

DSA is the real-time adjustment of spectrum utilization in response to changing circumstances and objectives [6]. DSA allows a group of radios to share spectrum, as a radio may locate vacant frequency bands and occupy them for the duration of a transmission, then release the spectrum resource. When the available spectrum is already licensed for use by a particular set of radios, DSA allows unlicensed (secondary) users to exploit the spectrum in an opportunistic manner, under the condition that the secondary users vacate the spectrum within a predetermined time if the primary user needs it. A CR may or may not be capable of DSA. The sufficient aspects for CR are the context-awareness and decision-making, not a particular algorithm, such as fixed vs. dynamic spectrum access. A CR will be more capable if it performs DSA. Thus DSA is viewed as a key component of CR.

B. Cognitive Radio and Software Defined Radio (SDR)

SDR is a type of radio in which some or all of the physical layer functions are software defined. This is in contrast to hardware radio, in which changes in communications capabilities may only be achieved through changes to the hardware, or equivalently by software that is programmed once in the factory and cannot be changed due to radio architecture inflexibility. SDR enables adaptation and reconfiguration. CR is seen by many as the next step in reconfiguration flexibility, after SDR.

C. Cognitive Radio and Multi - Dimension Cooperative Communications

To enhance a system's cognitive capability and reduce cognitive costs, cooperative means must be adopted, the combination of CR with multi- dimension cooperative communications have become an inevitable trend. Cognitive Engine (CE) defines the architecture and mechanism for a CR system to sense and analyze environmental information, as well as to reason and learn to adjust its own work mode. The main components of CE are an environmental monitor module, and reasoning and learning module [24]. Cooperative sensing allows multiple cognitive users to exchange sensed information, thus dramatically improving spectrum interception and sensing capabilities. The cross-layer design for joint sensing between physical layer and Media Access Control (MAC) layer can also greatly enhance spectrum sensing capability. Cognitive Wireless Networks (CWNs) have been commonly recognized as a development trend of CR technology in research and industrialization.

Cooperative communication technologies are based on full knowledge of contextual information such as user' service types and radio environment characteristics. Only after contextual information is acquired, can intelligent cooperation among different elements be achieved. The sensing and

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collection of contextual information can only be done with CR and CWN technologies. Therefore, future multi-dimension mobile cooperative communications have a natural need for CR technologies. Cooperative communication technology can considerably improve the efficiency in sensing spectrum and contextual information, enhancing sensing reliability and reducing the cost. With basic information provided by Common Spectrum Coordination Channels (CSCCs), cognitive terminals can work with the network to sense wireless contextual information, and return the sensed information and service traffic characteristics to the network. The network, in turn, will use this information for joint resource management among different wireless access technologies, for load sharing and mobility optimization. Ultimately, it will achieve optimal system performance and provide an excellent user experience [25, 26]. The combination of CR and cognitive networks with multi-dimension cooperative communications is of great significance theoretically and pragmatically.

D. Cognitive Radio Wireless Sensor Network (CR-WSN)

A CR-WSN is one of the candidate areas where cognitive techniques can be used for opportunistic spectrum access. Communications in Wireless Sensor Networks (WSNs) are event driven. Whenever an event triggers wireless sensor (WS) nodes generate tremendous traffic. WSNs consist of hundreds of WS nodes deployed throughout the sensor field and the distance between two neighboring WS nodes is generally limited to few meters. Recently, cognitive techniques have been used in wireless networks to circumvent the limitations imposed by conventional WSNs.

If CR can be integrated with wireless sensors, it can overcome the many challenges in current WSNs. CR has the ability to know the unutilized spectrum in a license and unlicensed spectrum band, and utilize the unused spectrum opportunistically. The incumbents or primary users (PU) have the right to use the spectrum anytime, whereas secondary users (SU) can utilize the spectrum only when the PU is not using it [8]. CR allows unlicensed users to access multiple licensed channels opportunistically. This nature of CR gives potential advantages to WSNs by increasing the communication reliability and improving the energy efficiency. When wireless sensor nodes with cognitive capabilities are introduced to an entire network, it gives exciting new opportunities to researchers and industry to develop algorithms, hardware and software that can overcome the limitations imposed by current wireless sensor design techniques. CR-WSNs can be deployed in number of fields like facility management, machine surveillance and preventive maintenance, precision agriculture, medicine and health, logistics, object tracking, telemetries, intelligent roadside, security, actuation and maintenance of complex systems, monitoring of indoor and outdoor environments [8].

IV. ARCHITECTURES OF CRN

A CRN is not just an interconnection of CRs – CRNs are composed of various kinds of communication systems and networks, and can be viewed as a sort of heterogeneous network [11]. The heterogeneity exists in wireless access technologies, networks, user terminals, applications, and service providers. The CRNs can be deployed in different architectures, and serve the needs of both licensed and unlicensed applications. The basic components of CRNs are mobile station (MS), base station/access point (BSs/APs) and backbone/core network. These three basic components compose three kinds of network architectures in CRNs: infrastructure-based, ad-hoc and hybrid architectures.

A. Infrastructure-based architecture

The secondary user network is infrastructure-based, network consists of cells; each cell is managed through a central BS/AP which controls the medium access and the secondary MS. The observations and analysis performed by each MS feeds the BS, so that it can make decisions such as how to avoid interfering with primary users. According to the decision, each MS reconfigures its communication parameters. Each MS connects to a BS/AP with a direct link. MSs in the transmission range of the same BS/AP (one cell) communicate with each other through the BS/AP. Communications between different cells are routed through backbone/core networks. A good example of a cognitive, infrastructure-based network is that of the IEEE 802.22 standard [12] which follows a cellular architecture.

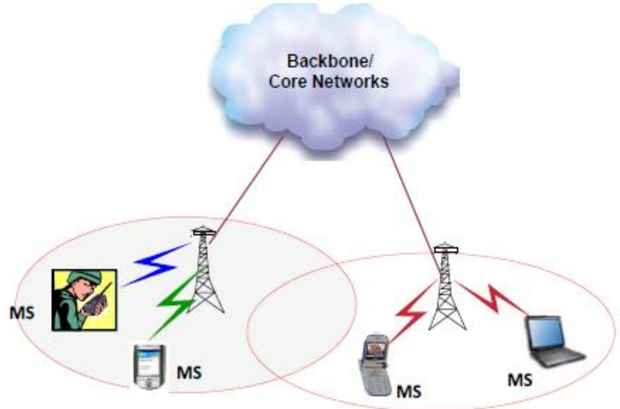

Figure 1: *Infrastructure-based network architecture*

B. Ad-hoc architecture

There is no central BS to manage the decision making. Each MS needs to have all the CR capabilities and is responsible for determining its actions based on the local observations. Two MSs who are within communication range can exchange their information directory; while those who are not within direct communication range can exchange information over multi-hop relay nodes. To eliminate the limitation of the local observation of each MS, collaborative algorithms [13] are

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usually used for this type of architecture, where the local observation results are exchanged among the MSs to broaden the knowledge on the network. We call this type of network Cognitive Radio Mobile Ad hoc Networks (CR-MANETs) [13].

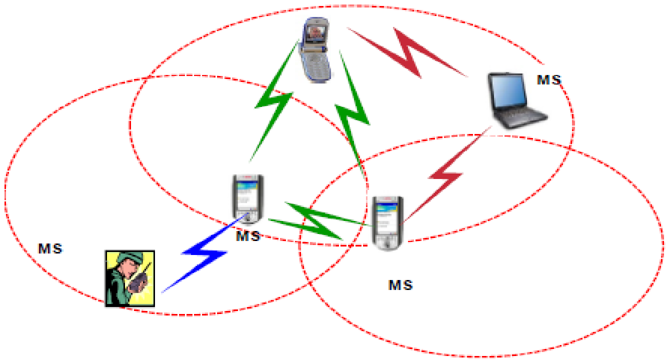

Figure 2: *Ad-hoc network architecture*

C. Hybrid architecture

This architecture is a combination of the infrastructure and ad-hoc architectures, with wireless connections between the BSs/APs. The BSs/APs work as wireless routers and form a wireless backbone network. The MSs can either access the BSs/APs directly, or use other MSs as multi-hop relay nodes.

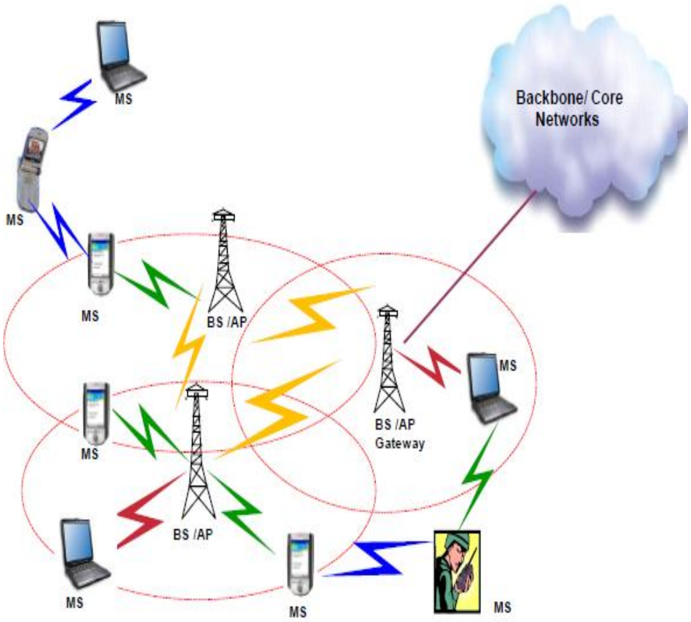

Figure 3: *Hybrid (infrastructure/ad-hoc) network architecture*

V. Challenges

A. Dynamic Spectrum Access (DSA)

CR is often associated with DSA. One significant challenge to the use of DSA is the implementation of spectrum sensing [9]. It is due to the limitations on conventional signal detection techniques. The classical energy detector does not reliably predict the presence of a legacy radio signal when the signal to noise ratio (SNR) of that signal is low, or negative. Another reason spectrum sensing is challenging is the nature of the wireless propagation channel [14]. It has been suggested that it might be possible to avoid sensing and just monitor one's own received signal quality. This strategy is related to the idea of interference-tolerance in radio networks [15].

B. Security

There are some differences between a traditional wireless network and the CR network in terms of network security [16], like the potential of far reaching and long-lasting impact of an attack is higher in CR networks and some simple spectral manipulation, such as generation of signals, can cause a profound effect on network performance and behavior in CR networks. Different attacks possible in CRN are

a) *Incumbent Emulation (IE) attacks*
b) *Spectrum Sensing Data Falsification (SSDF) attacks*
c) *Common Control Channel Jamming (CCCJ) attacks*

C. Electronic and cyber warfare in CRN

CRN provide opportunity to integrate communications & electronic warfare information in ways that enhance the capabilities of both communications & EW functionality [22].

VI. CRN Security Solutions

A. Cross layer security framework

The basic security functions including authentication and intrusion detection can be integrated into a security sub-layer and the results can be used for different layers.

B. Trust-based security schemes

The nodes must share information about their state and the state of the world around them without burdening the network with too much system traffic. Trust is an important feature in the design and analysis of secure distribution systems. Trust and Security in CRNs are always interlinked.

C. Novel physical layer authentication schemes

Verifying signal characteristics through novel physical layer authentication techniques can help counter Incumbent Emulation (IE) attacks.

D. Distributed authentication with threshold cryptography

Threshold cryptography is generally used to let some or all network nodes share a network master key and collaboratively provide security services such as issuing private keys. In CR-MANETs, identity (ID)-based cryptography with threshold cryptography is a popular approach for the security design because it uses a simple key management scheme compared to Public Key Infrastructure (PKI) [17].

E. Distributed monitoring and consensus algorithms

In CRN with no central authority, secondary users need to cooperatively sense the spectrum to detect the presence of primary users. Consensus algorithms are usually constructed

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based on local communication of neighboring agents, they have low implementation complexity and good robustness, and the overall system may still function when local failure occurs.

F. Robust communications and game theory

Game theory provides a powerful mathematical tool for problems with a large number of players and can be applied for CR-MANET security [18].

G. Anti-jamming CR techniques

Interference-resilient communications systems need to be designed, for instance to decode the received signals in very low SNR regimes or to detect the primary signal buried in a jammer's signal [19].

VII. SUGGESTED ROAD MAPS

There is tremendous need for an evolutionary path to gradually realize the goal of faster, smarter, and more secure communications. The first step towards each aspect of this path is to understand and address the current heterogeneous network. Strategic wireless communication requires a mixture of wireless communication technologies with different characteristics in terms of bandwidth, range, transmission frequency, and modulation schemes.

A. Introduce dynamic spectrum access (Fast deployment)

Spectrum management is a key component of CR, addressing the spectrum scarcity problem as well as the burden of deploying radio networks with detailed spectrum allocation plans for multi-national missions. Use of a centralized spectrum broker entity, or coordinated dynamic frequency management enables coordinated distribution of spectrum in accordance with a defined measure of the benefit to the system of all radio nodes.

B. Introduce cognition (Smarter communication)

CRs can learn and mitigate interference situation because communications are towards denser networks [20], and given spectrum is usually quite crowded in a densely populated theater, cognition will eventually be needed.

C. Support cyber EM (More resilient communication)

It has long been thought that the increased situational awareness gained by merging EW and communications sensor information would be beneficial [21]. The argument only becomes stronger when considering CRNs, which rely on situational awareness in the spectrum domain, augmented with signal detection and classification, for decision making. Our future forces will require CRNs that are hardened to attack, and that may intelligently and covertly disable adversarial CR networks.

VIII. CONCLUSION

CR has the ability to sense the environment in which it is operating, measure the performance it is achieving, and assess whether it is able to perform additional tasks to better accomplish the user's or the network manager's objectives. The need to gradually introduce DSA for fast network deployment and to ease spectrum congestion, the benefit of CRN to increase communication system intelligence in dynamic, heterogeneous environments, and the role of the CR as a multi-functional RF unit, capable of integrating communications and EW information to support coordinated Cyber EM operations. It has long been thought that the increased situational awareness gained by merging EW and communications sensor information would be beneficial.

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