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Role of Cognitive Radio on 4G Communications A Review

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ABSTRACT

There is a rapid advancement in wireless communication technology providing the network services anywhere and anytime. 4G communication systems are being developed to solve the various problems the current communication systems (3G, 2.5G) are facing.4G will be an intelligent technology that will reduce the number of different technologies to a single global standard. Cognitive Radio (CR) is the key enabling technology for next generation networks. Cognitive Radio techniques provide the capability to use or share the spectrum in an opportunistic manner. With the use of CR, 4G wireless networks will support global roaming across multiple wireless and mobile networks. In this paper, the Role of CR in 4G Communications is reviewed. The recent research being done on Cognitive Radio and 4G technologies is identified. The main possibilities of implementing Cognitive Radios in 4G Communication Systems are surveyed. IEEE 802.22 networks are cognitive technology based networks which will enhance the performance of 4G Communication systems. IEEE 802.16h (WiMAX) provide extensions to support unlicensed coexistence.

Keywords: *Cognitive Radio (CR), WiMAX, 4th Generation (4G)*

1. INTRODUCTION

Without spectrum, no wireless telecommunication or wireless internet services would be possible. Cognitive Radio is not only a radio technology; it also includes a revolutionary change in how the spectrum is regulated. Cognitive Radio and 4G are two complementary developments that will reframe the world of wireless communications. 4G networks employing cognitive radios are a solution that revolutionizes the telecommunication industry, significantly changing the way we design our wireless systems and services.

Ideal CR is still a challenge i.e. making a machine with the ability to intelligently make decisions based on its own situational awareness. Researchers expect intelligent reconfigurable CR prototypes to emerge within next five years. Some devices available already have some elements of CR e.g. WLAN, Military follower Jammers.

In spite of the increased complexity, future networks should be easily maintainable and there capabilities should be continuously improved and upgraded by relying as little as possible on human intervention. In order to meet this demand, the networking research community proposed a new paradigm of networking: the cognitive network [1], [2]. It is generally agreed that cognitive networks have the ability to think, to learn and to remember.

Fourth Generation (4G) Technology will offer many advances to the wireless market, including downlink data rates over 100 megabits per second (Mbps), low latency, very efficient spectrum use and low cost implementations. With flexible network connections, efficient use of spectrum and impressive user applications, 4G will offer what consumers want [3] as shown in Figure 1.

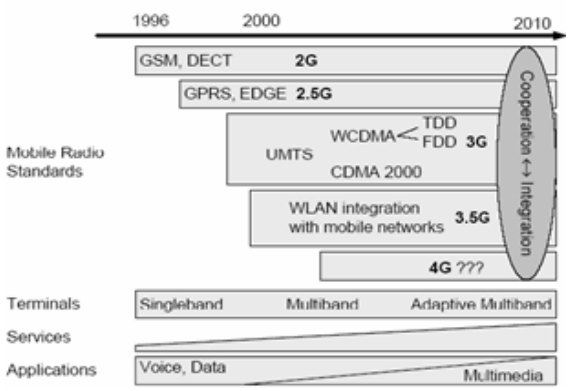

Figure 1: Evolution of 4G [17]

4G promises to offer a vast range and diversity of converged devices, services and networks to revolutionize the way we communicate. 4G would influence today's networking architecture where the inter user communication is realized with the help of third party communication infrastructure. 4G would not only offer ultra high data rates but would also enable a ubiquitous computing paradigm. [4]

2. COGNITIVE RADIO TECHNOLOGY

Recent studies and measurements have shown that, with the traditional spectrum access approach, the radio spectrum assigned to primary (licensed) users is vastly underutilized. Actual measurements conducted by the FCC's spectrum Policy Task Force which has determined that, in some locations or at some times of a day, about 70 percent of the allocated spectrum may not be in use [5]. Measurements in [6] reveal that spectrum utilization is often heavy in unlicensed bands while low in TV bands or medium in some cellular bands. These observations on

actual spectrum usage have challenged approaches to the radio spectrum management and fueled interests in the opportunistic spectrum access problem. Opportunistic spectrum access has been enabled by cognitive radios. Unlike conventional radios, CRs have the capability to sense their surroundings and actively adapt their operation mode to maximize the quality of service for secondary users while minimizing interference to primary users. Hence, CRs must carry out spectrum sensing to identify white spaces or spectrum holes which are bands of frequencies assigned to primary users, but, at a particular time and specific geographic location, these bands are not being utilized by those users [7] as shown in Figure 2.

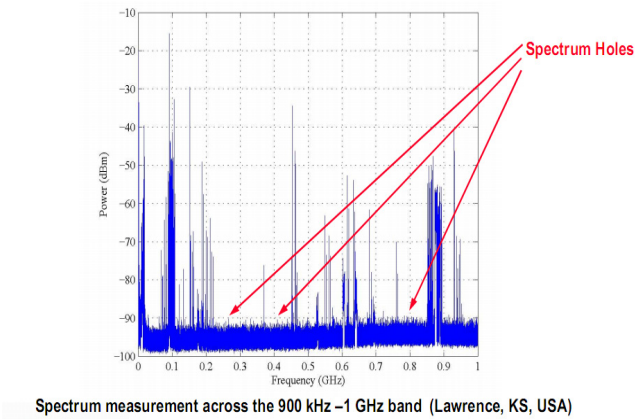

Figure 2: Frequency Spectrum showing White Holes

The CR Technology will enable the users to [8]:

- Determine which portions of the spectrum are available and detect the presence of licensed users when a user operates in a licensed band(spectrum sensing)
- Select the best available channel(spectrum management)
- Coordinates access to this channel with other users (spectrum sharing)
- Vacate the channel when licensed user is detected(spectrum mobility)

3. IMPORTANT RESEARCH ON COGNITIVE RADIO

Several entities including DARPA, the SDR Forum, IEEE and the FCC have done some important researches on cognitive radio.

3.1 DARPA

Currently, DARPA is exploring many aspects of cognitive radio as a part of the XG (Next Generation) program and other ongoing programs.

The most notable anticipated activity from DARPA is the launching of the **W**ireless **A**daptive **N**ode **N**etwork (WANN) project. It is hoping to achieve significant gains in throughput and network scalability through the incorporation of intelligence in the radios [9].

3.2 SDR Forum

Some activities:

- Technical committee on cognitive radio
- Also groups on secondary spectrum access testing, meta-language for mobility work, and possibly security
- Various Projects are currently being worked on.

3.3 IEEE

The IEEE P1900 Standards Committee was established in 2005 by the IEEE Communications Society (ComSoc) and EMC (Electromagnetic Compatibility Society). It was reorganized further as SCC 41(Standards Coordinating committee).IEEE SCC 41 will develop standards related to dynamic spectrum access networks, focusing on improved use of spectrum as of the year 2009.

Currently, the 1900 working groups and their focuses:

- 1900.1- Standardize definitions and terminology related to cognitive radio and next generation radio systems.
- 1900.2- Interference and coexistence analysis.
- 1900.3- Conformance evaluation of SDR software modules.
- 1900.4- Architectural Building Blocks Enabling Network Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks.
- 1900.5- Managing Cognitive Radio for Dynamic Spectrum Access applications.
- 1900.6- Spectrum sensing interfaces and data structures for dynamic spectrum access and advanced radio communications.[10]

3.4 FCC

The FCC released its R&O for TV Whitespace on November 4, 2008 allowing unlicensed radio transmitters to operate in the broadcast television spectrum at locations where that spectrum is not being used given they use CR / DSA capabilities. Recently, FCC defined provisions that allow unlicensed devices to operate in the licensed bands so long the unlicensed devices do not create interference for licensed services [11].

3.5 Other Institutions

Several other institutions are also currently pursuing cognitive radio research including Virginia Tech, International Telecommunication Union (ITU), European Radio Spectrum Policy Group (ERSPG), U.K. Ofcom (consultation on DySPAN), Japan's Ministry of Internal Affairs and Communication (MIC)

4. 4G FEATURES

4G is the stage of broadband mobile communications that will supersede the 3G. While neither standards bodies nor carriers have concretely defined or agreed upon what exactly 4G will be, it is expected that end-to-end IP and high quality streaming video will be among 4Gs

distinguishing features.4G networks are likely to use combination of WiMAX and WiFi technologies[13].

Table 1: Series of mobile generation and their features [12]

Technology	1G	2G	2.5G	3G	4G
Design began	1970	1980	1985	1990	2000
Implementation	1984	1991	1999	2002	2012?
Services	Analog voice	Digital voice	Higher capacity, packetized data	Higher capacity, broadband data up to 2 mbps	Completely IP based, speed up to hundreds of mbs
Standards	NMT, AMPS, CDPD	GSM, iDEN, D-MPS	GPRS, EDGE etc	WCDMA, CDMA2000	Single Standard
Data Bandwidth	1.9 kbps	1.4 kbps	384 kbps	2 Mbps	200 Mbps
Multiplexing	FDMA	TDMA, CDMA	TDMA, CDMA	CDMA	CDMA?
Core Network	PSTN, PSTN	PSTN,	PSTN, Packet network	Packet network	Internet

5. ROLE OF COGNITIVE RADIO(CR) IN 4G

When fully implemented, 4G is expected to enable pervasive computing, in which simultaneous connections to multiple high speed networks provide seamless handoffs throughout a geographical area. The network Operators may employ technologies such as cognitive radio and wireless mesh networks to ensure connectivity and efficiently distribute both traffic and spectrum [13]. Multiple standards of 3G make it difficult to roam and interoperate across various networks, whereas 4G provides global standard that provides global mobility. This is possible with the help of cognitive radio. As a support of Mobility Management the communication between different systems should be established through generic interfaces. Multimode terminals are the one aspect considered for 4G systems.

4G systems will prove to be far cheaper than 3G, since they can be built atop existing networks and won't require carriers to purchase costly extra spectrum. In addition to being a lot more cost efficient, so carriers can do more with less [12].

With 4G systems there will be a need to design a single user terminal that can operate in different wireless networks and overcome the design problems such as limitations in size of the device, its cost and power consumption. This problem can be solved using Software Defined Radio/Cognitive Radio approach i.e user terminal adapts itself to the wireless interfaces of the network.

Another important role of Cognitive Radio in 4G communications is that the 4G devices are expected to be more visual and intuitive rather than today's text and menu based systems. They will be able to interact with the envoirnment around it and act accordingly.

Typical key applications scenarios of cognitive radio:

- CR technologies are useful for the internal optimization of the networks, which are essential in solving the every-serious spectrum resource scarcity problem while the current 3G telecommunications networks are evolving to the all IP-based 4G telecommunications networks aiming at providing seamless, ubiquitous, end-to-end, and quality-guaranteed services inside a specific operator and carrier[14]
- CR technologies lend themselves to the application in heterogeneous communications networks [15] encompassing different service providers and radio standards like WiMAX, BWA (World-wide Interoperability for Microwave Access Broadband Wireless Access), e.g. 802.16e/h, 3G/B3G/4G 3GPP mobile operators (e.g., UMTS/HSDPA/LTE/DVB-H).
- CR technology can become a key enabler for true heterogeneous communication environment where data-aided mitigation techniques, such as physical or logical layer cognitive pilot channel (CPC) will be implemented for optimal sharing of the spectrum and coexistence with least interference among various radio access nodes. These ideas gain in importance especially with respect to the vision of Future Internet or Internet of Things, where a multitude of different devices are expected to communicate seamlessly and rearrange their network configuration in an autonomous fashion in order to route/exchange the information in most efficient way. The cognitive and reconfigurable radio paradigms with CPC and cognitive routing schemes are expected to contribute greatly to the realization of this vision, as forecasted by the Future Internet Assembly and reflected in the 7th Framework Program (2007-2013) of the European Community for research, technological development and demonstration activities.

Standards which incorporate this research:

1. **Stand-alone CR systems(to be standardized and developed) – IEEE 802.22** is currently the only candidate .This standard foresees a Wireless

Regional Area Network(WRAN) to access white spaces in TV bands.

2. **Cognitive capabilities built in to other standards- IEEE 802.16 e/h/m** present a good example of this approach, focusing on the coexistence of WiMAX systems in unlicensed bands.

5.1 IEEE 802.22

IEEE 802.22 defines air interface for use by license-exempt devices on a non- interfering basis in VHF and UHF (54-862 MHz) bands which are also referred to as the TV White Spaces.

This 802.22 standard utilizes cognitive radio technology to ensure that no undue interference is caused to television services using the television bands. In this way 802.22 is the first standard to fully incorporate the concept of cognitive radio. This new standard, which will operate in the TV bands, makes use of techniques such as spectrum sensing, incumbent detection and avoidance, and spectrum management to achieve effective coexistence and radio resource sharing with existing licensed services. [16]

Table 1: IEEE 802.22 WRAN system capacity and coverage [12]

1.	RF channel Bandwidth	6MHz
2.	Average Spectrum Efficiency	3 bit/s/Hz
3.	Channel capacity	18Mbit/s
4.	System capacity per subscriber(forward)	1.5Mbit/s
5.		384 kbit/s
6.	System capacity per subscriber(Return)	3.9
7.	Forward/return ratio	50
8.	Over subscription ratio	600
9.	Number of subscribers per channel	90subs
10.		3 bit/s/Hz
11.	Minimum number of subscribers	1800 subs.
12.		2.5 persons
13.	Assumed early take up rate	4500 persons
14.	Potential number of subscribers	98.3 W
15.	Assumed number of persons per household	30.7 km
16.		1.5 person/km^2
17.	Total number of persons per coverage area	OFDM
18.	WRAN base station EIRP	Spectrum Sensing to identify free channels
	Radius of coverage for WRAN system	
	Minimum population density covered	
	Modulation	
	Methodology	

5.2 IEEE 802.16e/h/m

IEEE 802.16-based WiMAX is also gaining attention as a 4G solution. It uses OFDMA-based multicarrier modulation, MIMO, and other advanced features along with cognitive radio technology to greatly improve the mobile wireless services.

WiMAX supports either manual or automatic selection of networks based on user preference and defines protocols to support this. This is said to be done with the help of cognitive radio technique.

802.16 Family

802.16	LOS 10-66 GHz
802.16a	2-11 GHz (superceded by 802.16-2004)
802.16c	2-11 GHz (superceded by 802.16-2004)
802.16d	Combined 802.16, 802.16a, 802.16c into 802.16-2004
802.16e 2006	Approved Dec 7 2005Published Feb
802.16f	Network Management Information Base (MIB) Published Dec 1, 2005
802.16g 2006	Network management plane Draft Feb
802.16h	Coexistence with license-exempt 802.16 protocols (Draft)
802.16i	Mobile Management Information Base (explicitly to handle updates from 802.16e) –
802.16j	Mobile Multihop Relay
802.16k	Network Management/Bridging
802.16m	4G WiMAX

5.2.1 IEEE 802.16 e

In 2005 The IEEE announced the approval of IEEE 802.16e (Mobile WirelessMAN) that will facilitate the global development of mobile broadband wireless access (BWA) systems. The standard specifies a system for combined fixed and mobile BWA supporting subscriber stations moving at vehicular speeds in licensed bands under 6 GHz [17].

5.2.2 IEEE 802.16 h

Main features of IEEE 802.16h:

- Improved Coexistence Mechanisms for License-Exempt Operation
- Basically, a cognitive radio standard
- Incorporates many of the hot topics in cognitive radio
  - Token based negotiation
  - Interference avoidance
  - Network collaboration
  - RRM databases

- Coexistence with non 802.16h systems Regular quiet times for other systems

5.2.3 IEEE 802.16 m

IEEE is now working on a new wireless standard called 802.16 m and it is said to deliver 1Gbps transfer rates. The standard also has a high mobility mode which allows for 100 Mbps rates.

It is under the process of standardization. The new standard will use MIMO technology [17].

The new standard will be compatible with future 4G networks. The goal for the long-term evolution of WiMAX is to achieve 100 Mbit/s mobile and 1 Gbit/s fixed-nomadic bandwidth as set by ITU for 4G NGMN (Next Generation Mobile Network).

6. CONCLUSION

Current Communication systems are reaching a point where traditional network management and maintenance technologies will no longer able to cope with increasing system complexity. In this paper we surveyed the cognitive radio capabilities. The various research activities being done by various groups on cognitive radio have been reviewed. Furthermore, the role of cognitive radio on 4G communication systems has been emphasized in this paper. The various application scenarios and the standards incorporating them have been reviewed. Internet is a driving force for higher data rates and high speed access for mobile wireless users. 4G systems will give value added services but still they will offer a lot many challenges till they get fully implemented.

4G systems will depend upon the various issues of spectrum management, cost reduction, global roaming facility and mobility between various systems and that these are prime candidates for the implementation by Cognitive Radios.

The growth of 4G technology will be enhanced with the development of the open standards.

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