Research Gaps in Cognitive Radios Networks

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Abstract— **Cognitive radio (CR) technology has great potential to alleviate spectrum scarcity in wireless communications. It allows secondary users (SUs) to opportunistically access spectrum licensed by primary users (PUs) while protecting PU activity. All of the radio spectrum is allocated to different services, applications and users, observation provide evidence that usage of the spectrum is actually quite low. In order to overcome this problem and improve spectrum utilization, cognitive radio concept has been proposed. This paper provides an overview of cognitive radio for opportunistic spectrum access and related research topics.**

Keywords— **: Cognitive Radios(CR) , SDR, Spectrum Sensing, Cognitive Cycle**

Introduction

In the past decade, Software Defined Radio (SDR) and Cognitive Radio (CR) technology has revolutionized our view of opportunities in wireless communications to a great extent[1-5]. The key motivation behind this technology is *to increase spectral utilization* and *to optimize the use of radio resources.* As SDR and CR are clearly emerging as a strong technological opportunity. Research and development is being promoted rapidly throughout the wireless industry and in the academic research arena. Correspondingly, the standardization, regulation and certification activities are also being initiated in many parts of the world including IEEE 802.22, Wireless Innovation Forum and ETSI[6-20]. However, the security issues on SDR and CR is still under research especially for commercially viable prototypes and future products and its implications on standardization. According to FCC, several parts of the fixed spectrum are under-utilized while some spectrum bands are heavily used and subject to high interference. Temporarily unused spectrum bands also known as spectrum holes can be used by opportunistic radios to improve the overall spectrum utilization. The underutilization of some frequency bands opens up the opportunity to identify and exploit spectrum holes.

Measurement studies have shown that in both the time and frequency domains that spectrum is underutilized. Underutilized part of spectrum is now accessed by secondary user's (shown in Fig.1)

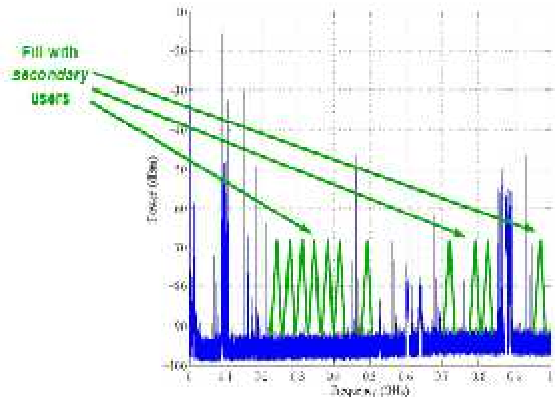

Fig 1: Example of spectrum being utilized by secondary users[2]

SDR and CR technology implements radio functionalities like modulation/ demodulation, signal generation, signal processing and signal coding in software instead of hardware as in conventional radio systems. The software implementation provides a higher degree of flexibility and re-configurability and many benefits including the capability to change the channel assignments, to change the provided communication services or modify the transmission parameters or communication protocols. SDR is also considered a technology enabler for CR, which are "intelligent" radios, which can learn from the environment and adapt their transmission/reception frequencies and parameters to improve spectrum utilization and communication efficiency.

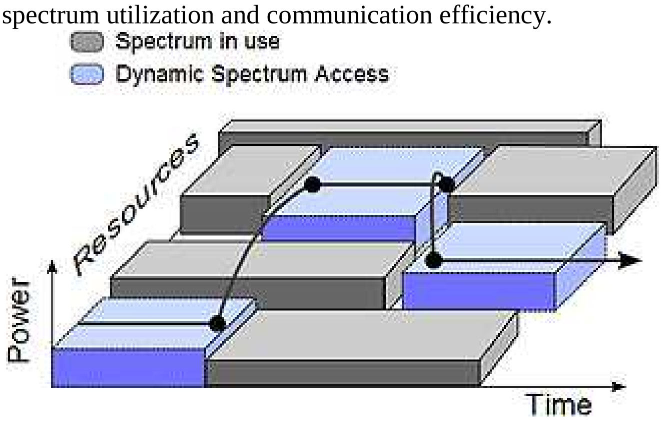

Fig 2: Dynamic Spectrum Access in Cognitive Radios Network [5-6]

SDR and CR technologies are fundamental blocks to provide a more flexible approach to spectrum management in comparison to the conventional approach where radio frequency spectrum bands are statically allocated by spectrum regulators. This flexible approach, known as Dynamic Spectrum Access (DSA) or Dynamic Spectrum Management (DSM), is considered a potential solution for the "spectrum shortage" problem as shown in Fig. 2.

The definitions of cognitive radio are still being developed by industry, academia and standardization bodies. A cognitive radio is assumed to be a fully re-configurable radio device that can "cognitively" adapt itself to the communications requirements of its user, to the radio frequency environment in which it is operating and to the various network and regulatory policies which apply to it [14]. Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment and uses the methodology of understanding by building to learn from the environment and adapt its internal states to statistical variations in the incoming radio frequency stimuli by making corresponding changes in certain operating parameters in real time, with two primary objectives: highly reliable communications whenever and wherever needed and efficient utilisation of radio spectrum [10]. Fully capable cognitive radio is unlikely to be achieved in the next 20 years, but certain cognitive radio features will be gradually implemented in radio equipment in the future years. In order to achieve these objectives, cognitive radio is required to adaptively modify its characteristics and to access radio spectrum without causing excessive interference to the primary licensed users. Cognitive cycle of cognitive radio operation as secondary radio system is shown in Fig. 3. Steps of the cognitive cycle are: spectrum sensing, spectrum decision, spectrum sharing and spectrum mobility [15].

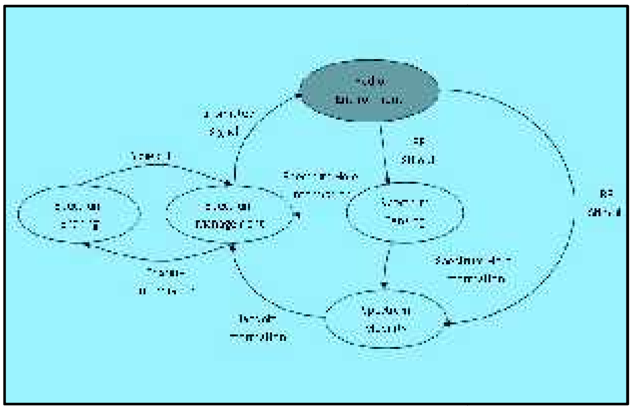

Fig 3. Cognitive cycle of cognitive radio [10-15]

The cognitive radio technique generally includes four main functions: -

a) Spectrum Sensing

Spectrum sensing detects and shares the available spectrum without detrimental interference with other users. It is critical for cognitive radio network to find spectrum holes. And the most efficient and effective way to detect spectrum holes is to detect primary users.

b) Spectrum Management

Spectrum management captures the best available spectrum to meet the needs of the communication requirement among users. Cognitive radio users should select the best spectrum band to satisfy the Quality of Service (QoS) requirements over all available bands, which necessitate the spectrum management functions such as spectrum analysis and spectrum decision for cognitive radio users.

c) Spectrum Sharing

Spectrum sharing provides the fair spectrum scheduling mechanism. It exhibits some similarities of the classical media access control MAC problems in current wireless systems. Spectrum sharing can be classified as centralized and distributed; non -cooperative and cooperative; overlay and underlay in terms of different criteria as architecture, allocation behavior and access technique respectively.

d) Spectrum Mobility

Spectrum mobility is defined as a process that a secondary user vacates or switches to other channels than the one it is using when current channel conditions become worse or a primary user appears. Cognitive radio networks utilize the spectrum in a dynamic manner by allowing the radio terminals to operate in the best available frequency band, maintaining seamless communication requirements during the transition to better spectrum.

A. Literature Review

A comprehensive review of the work reported by various researchers in the potential QoS Provisioning, Channel Allocation/Assignment strategies (DSA) & Power Control of Cognitive Radios is presented in tabular form as follows and briefly described thereafter.

Table 1: Literature Review

Particulars	**References**
Quality of Service Provisioning in Cognitive Radio Networks.	C. K. Siew et al.[1989],P. Letteri et al.[1998], E. Shih et al.[2001], N. Han et al.[2006], S. Gao et al. [2008], Y. C. Liang et al.[2008], F. Wang et al.[2008], Y. Wu et al.[2009], R. Kannan et al.[2010], F. R. Yu et al. [2011], Yakim Y. Mihov[2012], Hyoung-Jin Lim et al.[2012]
Channel Assignment Strategies	J.Mitola[1999], S. Haykin[2005], I. F. Akyildiz et al.[2006], Q. Zhao et al. [2007], C. Zou et al.[2008], F. F. Digham[2008], S. Huang et al. [2009], R. Xie et al. [2010], K. Liu et al.[2010], Y.-C. Liang et al. [2011] , L. Lai et

	al.[2011] , Q. Chen et al.[2011], Xiao Yu Wang et al.[2012], Antonio De Domenico et al.[2012]
Power Controlled(Green) CR Networks	L. Cao et al. [2008], A. T. Hoang et al.[2009], Y. Chen et al.[2009], Q. D. Vo et al. [2010], R. Xie et al.[2010], H. Su et al.[2010], S. Maleki et al.[2011], Phond Phunchongharn et al.[2012],

B. Research Gaps in Cognitive Radios Networks

The Various key issues and research gaps retrieved from the literature are as follows:

- Detecting interference at primary receiver - primary goal of cognitive radio is to protect primary system from interference, up to now there is not feasible method of detecting influence of cognitive radio at primary receiver due to its passive nature,
- Increasing the sensing time allows an increase of the number and the quality of the detected spectrum opportunities. However, in order to limit the sensing overhead, a cognitive user can observe only a limited part of the radio resource. Interestingly, only few MAC protocols implement a criterion (see, for instance [13]) to choose probing channels. Thus, this problem needs to be further investigated to improve spectrum sensing effectiveness.
- Cooperative sensing arises as a mean to greatly enhance the effectiveness of primary users detection in wireless fading channel. As stated in [22], [23] collaborative detection is, however, limited by the effects of spatially correlated shadowing. For a given SNR, a larger number of correlated sensing nodes is needed to achieve the same detection probability of few independent users. Future MAC protocols should consider correlation impact to develop more efficient cooperative sensing schemes.

- Speed and reliability of detection - complete cognitive cycle of cognitive radio is happening in real time, therefore it is essential to develop reliable and fast methods of spectrum awareness, A major misconception in CR literature is that detecting primary transmitter signal is equivalent to discover spectrum opportunities [14][15][35]. On the contrary, even when primary signals can be perfectly detected, spectrum opportunities discovery is affected by three main problems: the hidden transmitter, the exposed transmitter, and the hidden receiver. A hidden transmitter is outside the sensing range of the cognitive sender but it is placed close to the cognitive receiver. An exposed transmitter is a primary sender that is located in the proximity of the cognitive transmitter, while the licensed receiver is outside the secondary transmitter interfering range. A hidden receiver is a primary receiver that is located in the interfering range of cognitive transmitter while the primary transmitter is outside the detection range of the cognitive users. While the hidden transmitter problem has been solved by performing spectrum sensing at both transmitter and receiver side, there are still no feasible solutions for the latter problems. In order to solve these issues, a cognitive user should be able to detect the presence of a neighbour primary receiver. In [35], the authors present a sensor which is able to locate a RF receiver measuring its Local Oscillator leakage power. However, this approach is only suitable in the detection of TV receivers [5].

- Spread spectrum detection - primary users using spread spectrum are difficult to detect as the power of the primary user is distributed over a wide frequency range, possibly hidden in the noise,
- Hidden node problem - there is danger of not detecting working primary system due to possible shadowing effect or multipath fading in propagation between primary transmitter and sensing receiver,
- The interference temperature model was an interesting but unsuccessful idea. Thus, in order to successfully implement the underlay transmission access paradigm new metrics that represent the performance degradation experienced by the primary system should be investigated.
- Strategies based on interference temperature metric ([2], [28]), most of CR MAC protocols follow the interweave paradigm transmitting only on spectrum holes. Exploiting adaptive modulation and coding (AMC) and power control techniques, new MAC protocols can be designed according to the underlay paradigm in order to improve the overall system capacity and efficiency. Furthermore, in order to jointly profit the advantages and mitigate their drawbacks we believe that hybrid transmission schemes should be investigated.
- Learning and intelligence - appropriate models of artificial intelligence, bio inspired intelligence and machine learning methods have to be embedded in cognitive radio in order to fulfil its demanding tasks,
- Multi-multi environment - most of cognitive radio will have to autonomously work in multi-service, multitechnology and multi-user environment, it remain to be seen how cognitive radio can work and adapt in this challenging environment without causing chaos, disorder and anarchy,
- Vertical and horizontal sharing of radio spectrum - cognitive radio has to protect the operation of primary licensed radio services (vertical sharing) and also to overcome the problem of co-existence with other secondary use devices (cognitive devices and others),
- Spectrum space opportunities - cognitive radio is primarily focusing on frequency efficiency, but to achieve efficient usage of natural resources, all

dimensions of radio spectrum space as a theoretical hyperspace have to be used efficiently,

- Spectrum mobility - cognitive radio have to vacate spectrum when primary user begins to transmit, therefore cognitive radio have to switch its operating frequency from one spectrum hole to another while preferably not interrupting data transmission,
- Transmission power control - have to find right balance between cognitive radio self-goal of achieving maximum data rate and altruistic network or community goal leaving enough opportunities for other secondary devices,
- Hardware requirements - cognitive radio must be capable of spectrum sensing and operating over wide radio spectrum range, emulate many radio technologies and different modulation schemes, which causes various hardware challenges.
- A common control channel facilitates interaction and coordination among secondary users in a cognitive network. The common channel may however saturate when the number of secondary users or traffic load increase. Additionally, independent nodes may not observe the same spectrum availability and they may not be able to share the same channel. Additional dynamic strategies should be developed to realize a reliable exchange of signalling information, and permit synchronization within a neighbour cognitive radios.
- When an incumbent(PU) is detected, cognitive users interrupt transmission and hop in a new available channel to continue data transfer. Limiting packet loss and delay during the spectrum mobility process is a challenge. The backup channels list, introduced in [24] and [25-27], reduces latency and avoid performance degradation during the spectrum handoff. This solution should, however, be further investigated to increase the number of available channels and introducing QoS criteria to protect priority users.
- Classically, researchers have tried to develop bandwidth efficiency systems to deal with spectrum scarcity without consider the energy costs related to this approach. However, recent studies showed how scarcity is almost due to the static spectrum allocation strategies and that cognitive radio can be the way to improve the spectrum usage. Thus, *green* cognitive approaches should be investigated in order to save power consumptions, reduce interference, and improve battery life of customer's devices.
- Most of CR literature deals with opportunistic ad-hoc networks. However the impact of cognitive paradigms on cellular networks should be explored. In particular, we think that a cognitive approach is necessary to realize the coexistence of femtocells with macrocell users [33]. (Femtocells are low power access points introduced by the evolution of cellular systems to enhance indoor coverage).
- In order to optimize the radio resource management in CR networks, several DSA algorithms have been proposed. Few MAC protocols, however, include these complex algorithms in their functionalities (see, for instance [34-35]). Hence, further investigations on DSA-based protocols to enhance the spectral usage in both primary and secondary network would form object for future research.

C. Conclusion

Radio system founded on cognitive radio technology is challenging and promising concept, leading to new directions in developments of wireless communications and leap progress in radio spectrum usage efficiency. It is seen as a groundbreaking and founding technology of future wireless systems. In this paper, we have presented motivation for developments of opportunistic spectrum access, an overview of cognitive radio systems and major technical and research issues in cognitive radio.

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