COGNITIVE RADIO NETWORKS

RAHUL CHUMBLE & S. S. GUNDAL

Department of Electronics Engineering, Pune University, Maharashtra, India

ABSTRACT

Cognitive radio networks (CRN) are intelligent networks that can automatically sense the environment and adapt the communication parameters accordingly. These types of networks have applications in dynamic spectrum access, coexistence of different wireless networks, interference management, etc. They are touted to drive the next generation of devices, protocols and applications. Clearly, the cognitive radio network paradigm poses many new technical challenges in protocol design, power efficiency, spectrum management, spectrum detection, environment awareness, new distributed algorithm design, distributed spectrum measurements, Quality of Service (QoS) guarantees, and security. Overcoming these issues becomes even more challenging due to non-uniform spectrum and other radio resource allocation policies, economic considerations, the inherent transmission impairments of wireless links, and user mobility.

Cognitive radio has been considered as a key technology for future wireless communications and mobile computing. We note the cognitive radios can form cognitive radio networks (CRN) by extending the radio link features to network layer functions and above. We categorize CRN architecture into several structures and classify the unidirectional links in such structures.

KEYWORDS: Cognitive Radio Networks (CRN), Quality of Service (QoS) Guarantees

INTRODUCTION

The wireless communication systems are making the transition from wireless telephony to interactive internet data and multi-media type of applications, for desired higher data rate transmission. As more and more devices go wireless, it is not hard to imagine that future technologies will face spectral crowding, and coexistence of wireless devices will be a major issue.

Considering the limited bandwidth availability, accommodating the demand for higher capacity and data rates is a challenging task, requiring innovative technologies that can offer new ways of exploiting the available radio spectrum [1]. Cognitive radio is the exciting technologies that offer new approaches to the spectrum usage.

Cognitive radio is a novel concept for future wireless communications, and it has been gaining significant interest among the academia, industry, and regulatory bodies. Cognitive Radio provides a tempting solution to spectral crowding problem by introducing the opportunistic usage of frequency bands that are not heavily occupied by their licensed users. Cognitive radio concept proposes to furnish the radio systems with the abilities to measure and be aware of parameters related to the radio channel characteristics, availability of spectrum and power, interference and noise temperature, available networks, nodes, and infrastructures. An interconnected set of cognitive radio devices that share information is defined as a Cognitive Radio Network (CRN).

Cognitive Radio Networks aim at performing the cognitive operations such as sensing the spectrum, managing available resources, and making user-independent, intelligent decisions based on cooperation of multiple cognitive nodes.
In order to be able to achieve the goals of the cognitive radio concept, cognitive radio networks need a suitable wireless technology that will facilitate collaboration of the nodes.

**COGNITIVE RADIO NETWORKS**

When we look at the evolution of wireless standards and technologies, it can be seen that the adaptive features and intelligent network capabilities are gradually adapted as the hardware and software technologies improve. Specially, with the recent trend and interest in software defined radio based architectures, cognitive radio and cognitive networks attracted more interest. In addition to these, the increasing demand for wireless access along with the scarcity of the wireless resources (specifically the spectrum) bring about the desire for new approaches in wireless communications. Therefore, even though cognitive networks and cognitive radio terms have recently become popular, it is actually a natural evolution of the wireless technologies [10]. With the emergence of cognitive radio and cognitive network concepts, this evolution process has been more formalized and structured.

Especially, the emergence of cognitive networks (with cooperative functions and cognitive engine concepts) is a promising solution for the barrier that arises from the flaws of the conventional layered design architecture.

For many researchers and engineers, the cognitive radio concept is not limited to a single intelligent radio, but it also includes the networking functionalities. Cognitive networks can be defined as intelligent networks that can automatically sense the environment (individually and collaboratively) and current network conditions, and adapt the communication parameters accordingly. Among the special features of cognitive networks, the leading ones are advanced interference management strategies, efficient use of wireless resources, safe and secure wireless access methodologies, and excellent Quality of Service (QoS).

**Architecture for Cognitive Radio Networks**

Current wireless network environment employs heterogeneity in terms of both spectrum policy and communication technologies. Hence, a clear description of the cognitive radio network architecture is crucial for development of communication protocols [6].

![Figure 1: Co-Operative Communications for Cognitive Radio Networks](image_url)

The components of the cognitive radio network architecture, as shown in Figure. 10 can be classified in two groups as the primary network and the cognitive network. Primary network is referred to as the legacy network that has an exclusive right to a certain spectrum band.
In order to address these challenges, we provide a directory for different functionalities required for spectrum management in CR networks. The spectrum management process consists of four major steps:

**Spectrum Sensing**

A CR user can only allocate an unused portion of the spectrum. Therefore, the CR user should monitor the available spectrum bands, capture their information, and then detect the spectrum holes [7].

**Spectrum Decision**

Based on the spectrum availability, CR users can allocate a channel. This allocation not only depends on spectrum availability, but it is also determined based on internal (and possibly external) policies.

**Spectrum Sharing**

Since there may be multiple CR users trying to access the spectrum, CR network access should be coordinated in order to prevent multiple users colliding in overlapping portions of the spectrum [4].

![Figure 2: Spectrum Sharing Primary and Cognitive Networks](image)

**Spectrum Mobility**

If the specific portion of the spectrum in use is required by a primary user, the communication needs to be continued in another vacant portion of the spectrum. The spectrum management framework for CR network communication is illustrated in Figure 4. It is evident from the significant number of interactions that the spectrum management functions necessitate a cross-layer design approach. Thus, each spectrum management function cooperates with application, transport, routing, medium access and physical layer functionalities with taking into consideration the dynamic nature of the underlying spectrum.

**Spectrum Sensing for Cognitive Radio Networks**

A cognitive radio should monitor the available spectrum bands, capture their information, and then detect the spectrum holes. Hence, spectrum sensing is a key enabling technology in cognitive radio networks. In spectrum sensing, the detection accuracy has been considered as the most important factor to determine the performance of cognitive radio networks.
However, in reality, RF frontend of CR users cannot differentiate the primary user signals and CR user signals. In case of the energy detection, widely used in spectrum sensing, transmission and sensing cannot be performed at the same time. Thus, during the sensing (observation time), all CR users should stop their transmissions and keep quiet. Due to this hardware restriction, CR users should sense the spectrum periodically with sensing period $T_s$ and observation time $t_s$, as described in Figure 3[8].

SYSTEM ANALYSIS ON CRN

Spectrum Decision Framework for Cognitive Radio Networks

In cognitive radio (CR) networks, unused spectrum bands will be spread over a wide frequency range including both unlicensed and licensed bands. These unused spectrum bands detected through spectrum sensing show different characteristics according to the radio environment.

Since CR networks can have multiple available spectrum bands having different channel characteristics, they should be capable of selecting the proper spectrum bands according to the application requirements, called spectrum decision.

In Cognitive Radio Networks, a QoS aware spectrum decision framework is proposed to determine a set of spectrum bands by considering the application requirements as well as the dynamic nature of spectrum bands. Specifically, for real-time applications, a minimum variance-based spectrum decision (MVSD) is proposed so as to minimize the capacity variance of the decided spectrums subject to the capacity constraint. Furthermore, a maximum capacity-based spectrum decision (MCSD) is proposed for the best effort applications where spectrum bands are decided to maximize the total throughput.

Inter-Cell Spectrum Sharing in Cognitive Radio Networks

Cognitive radio (CR) networking achieves high utilization of the scarce spectrum resources without causing any performance degradation to the licensed users. Since the spectrum availability varies over time and space, the infrastructure-based CR networks are required to have a dynamic inter-cell spectrum sharing capability.
This allows fair resource allocation as well as capacity maximization and avoids the starvation problems seen in the classical spectrum sharing approaches. A joint spectrum and power allocation framework is proposed that addresses these concerns by (i) opportunistically negotiating additional spectrum based on the licensed user activity (exclusive allocation), and (ii) having a share of reserved spectrum for each cell (common use sharing).

Our algorithm accounts for the maximum cell capacity, minimizes the interference caused to neighboring cells, and protects the licensed users through a sophisticated power allocation method.

Figure 5: Inter-Cell Spectrum Sharing Framework for CRN

Infrastructure-based CR networks are required to provide two different types of spectrum sharing schemes: intra-spectrum sharing and inter-spectrum sharing. In order to share spectrum resource efficiently, CR networks necessitate a unified framework to support cooperation among inter- and intra-cell spectrum sharing schemes and other spectrum management functions. Figure 5 shows the framework for spectrum sharing in infrastructure based CR networks, which consists of inter-cell spectrum sharing, intra-cell spectrum sharing, and event monitoring.

Spectrum Mobility for Cognitive Radio Networks

As CR networks have capability to support flexible usage of wireless radio spectrum, cognitive radio (CR) techniques have attracted increasing attention in recent years. In CR networks, secondary users may dynamically access underutilized spectrum without interfering with primary users, which is called *spectrum handoff* [5]. Spectrum handoff refers to the procedure invoked by the cognitive radio users when they users wish to transfer their connections to an unused spectrum band. Spectrum handoff occurs

- When primary user is detected or
- Current spectrum condition becomes worse.

The cognitive radio users monitor the entire unused spectrum continuously during the transmission. If spectrum handoff occurs, they move to the "best matched" available spectrum 18 band. However, due to the latency caused by spectrum sensing, decision and handoff procedures, quality degrades during spectrum handoff. Hence, spectrum handoff method focuses on the seamless transition with minimum quality degradation.

Spectrum Aware Routing Protocol for Cognitive Radio Networks

Routing constitutes a rather important but yet unexplored problem in CR networks, especially when a multi-hop architecture is considered. The activity of the primary users (PUs) affects the channels of the licensed bands differently. This renders the channels unusable for the CR network to different geographical extents around the PU. In such a situation, the key decision is switching the channel in portions of the route, thus incurring a switching delay, or passing through entirely different regions altogether, thus increasing the latency. In addition, the frequently changing primary user (PU)
activity and the mobility of the users make the problem of maintaining optimal routes in ad-hoc CR networks challenging. A geographic forwarding based Spectrum Aware Routing [3] protocol for Cognitive Ad-hoc networks (SEARCH) has developed, that:

- Jointly undertakes path and channel selection to avoid regions of PU activity during route formation.
- Adapts to the newly discovered and lost spectrum opportunity during route operation.
- Predicts node mobility and takes corrective measures to maintain end-to-end performance.

We consider a three-dimensional system, with the x-y plane representing the physical space where the CR network and the PUs are located [11]. The z-axis shows the frequency scale and also the different channel bands. The shaded regions in the Figure show that a single PU may affect several channels (frequencies) around its location.

![Figure 6: Joint Route and Spectrum Discovery](image)

Moreover, the channels may be affected to different geographical extents, depending upon their frequency separation with the PU's transmission channel. SEARCH attempts to find paths which circumvent the PU coverage regions (Path 1 and 2) and link them together, whenever a performance benefit is seen [13].

**Cognitive Mesh Networks**

The Wireless Mesh Network (WMN) paradigm is envisaged to be a key technology that allows ubiquitous connectivity to the end user. A typical WMN consists of mesh routers (MRs) forming the backbone of the network, interconnected in an ad-hoc fashion. Each MR can be considered as an access point serving a number of users or mesh clients (MCs) under it. The MCs could be mobile users, stationary workstations or laptops that exchange data over the Internet. The COGgnitive Mesh NETwork (COMNET) architecture, takes the first step in leveraging the benefits of cognitive radio technology in the area of WMNs [12].

![Figure 7: Cognitive Mesh Network Architecture](image)
The Following Key Challenges in a Cognitive Radio Enabled Mesh Scenario

- Enabling MCs to monitor the primary channel while continuing normal operation in the 2.4 GHz ISM band.
- Devising a theoretical framework for identifying primary transmitter frequencies through time domain sampling.
- Proposing theoretical models for estimating power injected in the primary band channels due to the presence of secondary users.
- Allowing a decentralized computation framework at each MR for load sharing between the primary and secondary bands, based on the above models.

CONCLUSIONS

Cognitive radio is an immature but rapidly developing technology area. In terms of spectrum regulation, the key benefit of CR is more efficient use of spectrum, because CR will enable new systems to share spectrum with existing legacy devices, with managed degrees of interference. There are significant regulatory, technological and application challenges that need to be addressed and CR will not suddenly emerge.

Cognitive radio networks are being studied intensively. The major motivation for this is the currently heavily underutilized frequency spectrum. The development is being pushed forward by the rapid advances in SDR technology enabling a spectrum agile and highly configurable radio transmitter/receiver. A fundamental property of the cognitive radio networks is the highly dynamic relationship between the primary users having an exclusive priority to their respective licensed spectrum and the secondary users representing the cognitive network devices. This creates new challenges for the network designs which have been addressed applying various approaches as has been discussed in the previous sections.

The fundamental problems in detecting the spectrum holes are naturally mostly related to signal processing at the physical layer. From the traffic point of view careful attention must be paid in order to guarantee an efficient usage of the wireless medium while simultaneously providing fairness between competing users and respecting the priority of the primary users.

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