CognitiveRadio

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Abstract—
A cognitive radio is an adaptive, intelligent, multi- dimensionally aware, software defined and autonomous, radio and network technology .Since the concept of cognitive radio originated one and half decade ago a lot of advancements have been made and plenty are yet to be done. This is still a very fresh and captivating research topic, therefore many technical research questions still need to be answered. This paper introduces the characteristics of cognitive radio technology, functions of cognitive radio network, existing research challenges of cognitive radios technology and its applications. This paper is going to be a future reference for all those who want to research deeper in this section.

Keywords -
Cognitive; autonomous; challenges; deployment

Introduction

Cognitive radios offer the promise of being just this disruptive technology innovation that will enable the future wireless world. A fundamental problem facing the future wireless systems is where to find suitable spectrum bands to meet the demand of future services. While essentially 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 consumption, cognitive radio concept has been proposed. Cognitive radios are fully programmable wireless devices that can sense their environment and dynamically adapt their transmission waveform, channel access method, spectrum use, and networking protocols as needed for good network and application performance. In cognitive radio cycle a cognitive radio monitors spectrum bands, captures their information and then detects the spectrum spaces. The characteristics of the spectrum spaces that are detected through spectrum sensing are estimated. Then, the appropriate spectrum band is chosen according to the characteristics and user requirements. Once the operating spectrum band is determined, the communication can be performed over this spectrum band. A CR "monitors its own performance continuously", in addition to "reading the radio's outputs"; it then uses this information to "determine the RF environment, channel conditions, link performance, etc.", and adjusts the "radio's settings to deliver the required quality of service subject to an appropriate combination of user requirements, operational limitations, and regulatory constraints".

Cognitive Radio Characteristics

The dramatic increase of service quality and channel capacity in wireless networks is severely limited by the scarcity of energy and bandwidth, which are the two fundamental resources for communications. Therefore, researchers are currently focusing their attention on new communications and networking paradigms that can intelligently and efficiently utilize these scarce resources. Cognitive radio (CR) is one critical enabling technology for future communications and networking that can utilize the limited network resources in a more efficient and flexible way. It differs from traditional communication paradigms in that the radios/devices can adapt their operating parameters, such as transmission power, frequency, modulation type, etc., to the variations of the surrounding radio environment. Before CRs adjust their operating mode to environment variations, they must first gain necessary information from the radio environment. This kind of characteristics is referred to as cognitive capability, which enables CR devices to be aware of the transmitted waveform, radio frequency (RF) spectrum, communication network type/protocol, geographical information, locally available resources and services, user needs, security policy, and soon. After CR devices gather their needed information from the radio environment, they can dynamically change their transmission parameters according to the sensed environment variations and achieve optimal performance, which is referred to as reconfigurability.

Cognitive Radio Functions

The main functions of cognitive radios are:

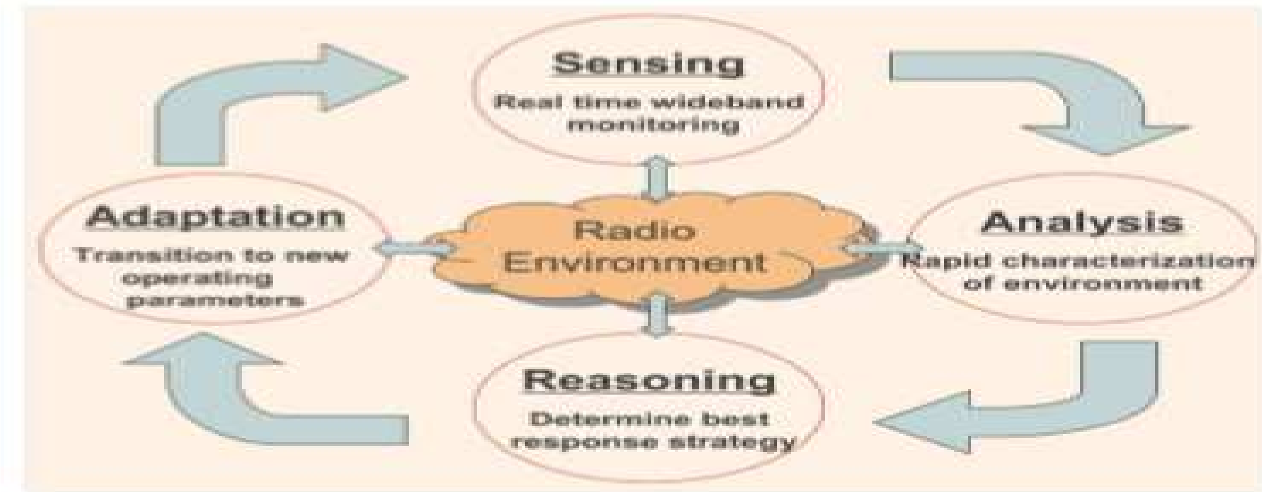
- *Power Control*: Power control is used for both opportunistic spectrum access and spectrum sharing CR systems for finding the cut-off level in SNR supporting the channel allocation and imposing interference power constraints for the primary user's protection respectively.
- *Spectrum sensing*: Detecting unused spectrum and sharing it, without harmful interference to other users; an important requirement of the cognitive-radio network to sense empty spectrum. Detecting primary users is the most efficient way to detect empty spectrum. Spectrum-sensing techniques may be grouped into three categories:
    - *Transmitter detection*: Cognitive radios must have the capability to determine if a signal from a primary transmitter is locally present in a certain spectrum. There are several proposed approaches to transmitter detection:
    - Matched filter detection
    - Energy detection: Energy detection is a spectrum sensing method that detects the presence/absence of a signal just by measuring the received signal power. This signal detection approach is quite easy and convenient for practical implementation. To implement energy detector, however, perfect noise variance information is required. And surprisingly when there is noise uncertainty, there is an SNR wall below which the energy detector cannot reliably detect any transmitted signal. This algorithm does not suffer from SNR wall and outperforms the existing signal detectors (see for example and its USRP implementation
    - Cyclostationary-feature detection: This type of spectrum sensing algorithms are motivated because most of manmade communication signals such as BPSK, QPSK,AM, OFDM ex hibit cyclostationary behavior. However, noise signals (typically whitenoise) do not experience this behavior. These detectors are robust against noise variance uncertainty. The aim of such detectors is to exploit the cyclostationary nature of manmade communication signals buried in noise. Cyclostationary detectors can be either single cycle or multicycle cyclostationary.
        - Single Cycle detectors: These detectors exploit the existence of the transmitted

signal just by considering one cyclic frequency location.

- Multicycle detectors: In this detector, many cyclic frequency locations are examined to detect the presence or the absence of transmitted signals. As this detectors considers many possibilities, it usually give better performance compared to that of the single cycle detector. But this is at the expense of additional complexity

- Moment based detector: Like in the Cyclostationary detectors, different man made signals such as BPSK, QPSK, Mary QAM signals also have different n>2th moment values than that of white noise. The moment based detector exploits this behavior to check the presence or absence of the transmitted signal.
- Wideband spectrum sensing: It refers to spectrum sensing over large spectral bandwidth, typically hundreds of MHz or even several GHz. Since current ADC technology cannot afford the high sampling rate with high resolution, it requires revolutional techniques, e.g., compressive sensing.

- Cooperative detection: Refers to spectrum-sensing methods where information from multiple cognitive-radio users is incorporated for primary-user detection
- Interference-based detection



- Null-space based CR: With the aid of multiple antennas, CR detects the null-space of the primary-user and then transmit within this null-space, such that its subsequent transmission causes less interference to the primary-user

- Spectrum management: Capturing the best available spectrum to meet user communication requirements, while not creating undue interference to other (primary) users. Cognitive radios should decide on the best spectrum band (of all bands available) to meet quality of service requirements; therefore, spectrum-management functions are required for cognitive radios. Spectrum-management functions are classified as:

- Spectrum analysis
- Spectrum decision

The practical implementation of spectrum-management functions is a complex and multifaceted issue, since it must address a variety of technical and legal requirements. An example of the former is choosing an appropriate sensing threshold to detect other users, while the latter is exemplified by the need to meet the rules and regulations set out for radio spectrum access in international (ITU radio regulations) and national (telecommunications law) legislation.

Research Challenges

The purpose of this section is to briefly describe the core issues which are yet open and current under debate in the research of CR networks.

- Architecture - The potential for Cognitive radio is a novel efficient methodology, extension of software- defined radio, to transmit and receive information over various wireless communication devices. According to the existing operators in the environment, Cognitive radio chooses the best available option based on performance for each application. The different performance measuring parameters include frequency, power, antenna, transmitter bandwidth, modulation and coding schemes etc. This means that the radio has to deal with different radio frequencies spectrum and baseband varieties at the same time, thus requiring a more robust, efficient and reconfigurable hardware and software architecture.

- Signaling - It represents a key research issue as both CRs and CRNs need to configure lower level parameters or networking devices, respectively, and therefore the underlying infrastructure needs to provide software reconfiguration and programming, thus requiring SDR or SAN technology. The requirement for programmable devices leads to two main challenges. First, because of the limitations of the layering principle, in order to provide efficient operation, programmable devices should offer cross-layer interfaces suitable for adaptation and optimization. Specific signalling architectures are needed in order to enable internal or network-wide exchange of information and commands between cognitive devices or among distributed devices constituting a single cognitive entity. Second, while the debate on cross-layering has already gained maturity even with conflicting ideas it is worthwhile to address signalling architecture as a relevant point to support cross-layer or in general optimization solutions. Indeed, several signalling architectures are available which can be classified on the basis of the different types of interaction among protocol at different layers inter-layer signalling, or network- wide signalling.

- Cross Layer Design - The flexibility of cognitive radios has significant implications for the design cross layer algorithms which adapt to changes in physical link quality, radio interference, radio node density, network topology or traffic demand may be expected to require an advanced control and management framework with support for cross-layer information. Spectrum handoff and mobility management will face some new challenges which are required to do a cross-layer design, especially when required providing the necessary capabilities in terms of quality of service at the same time.

- Security - Most of the work has been concentrated on denial-of-service (DoS) attacks that will affect the design of authentication protocols. Although it is essential to build on these initial forays to develop secure protocols for spectrum access by the SUs, it also important to consider other aspects of security like authorization. First, CRNs inherently assume that PUs and SUs are distinguishable. Confirming PU and

SU is especially important since they have unequal privileges. Although, this may be fairly straightforward for centralized architectures by making the SUs sign using a centralized authority, this is harder to achieve in a distributed secondary network where a centralized authority cannot always be implemented. Second, in the context of CNs, there is a unique authorization requirement called conditional authorization. It is conditional because the SUs are authorized to transmit in licensed bands only as long as they do not interfere with PU communications in that band. As it is difficult to pinpoint exactly which of the secondary users is responsible for harmful interference to the PU transmission, this type of authorization is hard to enforce and even more so in a distributed setting. Hence conditional authorization poses a unique challenge in OSA. So far several researchers have begun working on security implications for CRNs, however this area is still in its infancy.

- Spectrum Sharing Strategies - Spectrum sharing is allocation of an unprecedented amount of spectrum that could be used for unlicensed or shared services. Opportunistic communication with interference avoidance faces a multitude of challenges in the detection of sharing in multi-user cognitive radio systems. Because of the presence of user priority (primary and secondary), they pose unique design challenges that are not faced in conventional wireless systems. A major issue in a multiple secondary user environment is sharing, a topic that has generated a lot of research interest in the recent past.

Applications

First, the capacity of military communications is limited by radio spectrum scarcity because static frequency assignments freeze bandwidth into unproductive applications, where a large amount of spectrum is idle. CR using dynamic spectrum access can alleviate the spectrum congestion through efficient allocation of bandwidth and flexible spectrum access. Therefore, CR can provide military with adaptive, seamless, and secure communications.

Moreover, a CR network can also be implemented to enhance public safety and home land security. A natural disaster or terrorist attack can destroy existing communication infrastructure, so an emergency network becomes vital to aid the search and rescue. As a CR can recognize spectrum availability and reconfigure itself for much more efficient communication, this provides public safety personnel with dynamic spectrum selectivity and reliable broadband communication to minimize information delay. Moreover, CR can facilitate interoperability between various communication systems. Through adapting to the requirements and conditions of another network, the CR devices can support multiple service types, such as voice, data, video, and etc.

Another very promising application of CR is in the commercial markets for wireless technologies. Since CR can intelligently determine which communication channels are in use and automatically switches to an unoccupied channel, it provides additional bandwidth and versatility for rapidly growing data applications. Moreover, the adaptive and dynamic channel switching can help avoid spectrum conflict and expensive re- deployment. As CR can utilize a wide range of frequencies, some of which has excellent propagation characteristics, CR devices are less susceptible to fading related to growing foliage, buildings, terrain and weather. When frequency changes are needed due to conflict or interference, the CR frequency management software will change the operating frequency automatically even without human intervention. Additionally, the radio software can change the service bandwidth remotely to accommodate new applications. As long as no end-user hardware needs to be updated, product upgrades or configuration changes can be completed simply by downloading newly released radio management software. Thus, CR is viewed as the key enabling technology for future mobile wireless services anywhere, any- time and with any device.

Conclusion

Cognitive radio technology has been proposed in recent years as a revolutionary solution towards more efficient utilization of the scarce spectrum resources in an adaptive and intelligent way. It is seen as a groundbreaking and founding technology of future wireless systems. Nevertheless, cognitive radio is not a magic wand which will instantly solve radio spectrum scarcity problems, liberate all the frequency bands and abrogate radio spectrum regulation. As we look in the future, we see that cognitive radio has the potential for making a significant difference in the way how the radio spectrum can be accessed and used by wireless systems.Given the complexity of the topic and the diversity of existing technical approaches, our presentation is by no means exhaustive. In this paper we introduced the characteristics of cognitive radio technology, functions of acognitiveradionetwork and some existing research challenges of cognitive radios technology.

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