Cognitive Radio

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Abstract- The radio frequency spectrum is a scarce natural resource and its efficient use is of the utmost importance. The spectrum bands are usually licensed to certain services, such as mobile, fixed, broadcast, and satellite, to avoid harmful interference between different networks to affect users. Most spectrum bands are allocated to certain services but worldwide spectrum occupancy measurements show that only portions of the spectrum band are fully used. Moreover, there are large temporal and spatial variations in the spectrum occupancy. In the development of future wireless systems the spectrum utilization functionalities will play a key role due to the scarcity of unallocated spectrum. Moreover, the trend in wireless communication systems is going from fully centralized systems into the direction of self organizing systems where individual nodes can instantaneously establish ad hoc networks whose structure is changing over time. Cognitive radios, with the capabilities to sense the operating environment, learn and adapt in real time according to environment creating a form of mesh network, are seen as a promising technology. Cognitive radio is a new technology that allows spectrum to be dynamically shared between users.

Key-Words: - Cognitive Radio, Spectrum, Intelligent, Adaptive

I. INTRODUCTION

Cognitive Radio is an intelligent radio that is aware of its environment capable of using its radio ability to interact with the environment, learning about the environment and using the learned knowledge to improve communication. The primary objectives of the cognitive radio are to provide highly reliable communications whenever and wherever needed and to utilize the radio spectrum efficiently. The key issues in the cognitive radio are awareness, intelligence, learning, adaptivity, reliability, and efficiency. The goals of adaptation include maximizing spectral efficiency, minimizing interference to other user’s coexistence of licensed and unlicensed users, battery energy efficiency and autonomously adjusts its operation to achieve designated objectives.

Cognitive Radio is based on Software Defined Radio, which is a radio communication system which can potentially tune to any frequency band and receive any modulation across a large frequency spectrum by means of as little hardware as possible and processing the signals though software. A Cognitive Radio is a Software defined Radio that is aware of its environment, internal state and location

II. COGNITIVE RADIO FEATURES

The idea of a cognitive radio extends the concepts of a hardware radio and a software defined radio (SDR) from a simple, single function device to a radio that senses and reacts to its operating environment. A Cognitive Radio incorporates multiple sources of information, determines its current operating settings, and collaborates with other cognitive radios in a wireless network. The promise of cognitive radios is improved use of spectrum resources, reduced engineering and planning time, and adaptation to current operating
conditions. Some features of cognitive radios include:

Sensing the current radio frequency spectrum environment: This includes measuring which frequencies are being used, when are they used, estimating the location of transmitters and receivers, and determining signal modulation. Results from sensing the environment would be used to determine radio settings.

Policy and configuration databases: Policies specifying how the radio can be operated and physical limitations of radio operation can be included in the radio or accessed over the network. Policies might specify which frequencies can be used in which locations.

Self-configuration: Radios may be assembled from several modules. For example, a radio frequency front-end, a digital signal processor, and a control processor. Each module should be self-describing and the radio should automatically configure itself for operation from the available modules. Some might call this “plug-and-play.” Typical mission requirements might include operation within buildings, substantial capacity, operation over long distances, and operation while moving at high speed. Mission-oriented configuration involves selecting a set of radio software modules from a library of modules and connecting them into an operational radio.

Adaptive algorithms: During radio operation, the cognitive radio is sensing its environment, adhering to policy and configuration constraints, and negotiating with peers to best utilize the radio spectrum and meet user demands.

Distributed collaboration: Cognitive radios will exchange current information on their local environment, user demand, and radio performance between themselves on a regular bases. Radios will use their local information and peer information to determine their operating settings.

Security: Radios will join and leave wireless networks.

III. COGNITIVE RADIO FUNCTIONS

i) Spectrum Sensing: It refers to detect the unused spectrum and sharing it without harmful interference with other users. It is an important requirement of the Cognitive Radio network to sense spectrum holes, detecting primary users is the most efficient way to detect spectrum holes. Spectrum sensing techniques can be classified 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 approaches proposed:
  - matched filter detection
  - energy detection

- Cooperative detection: It refers to spectrum sensing methods where information from multiple Cognitive radio users are incorporated for primary user detection.

- Interference based detection.

ii) Spectrum Management: It is the task of capturing the best available spectrum to meet user communication requirements. Cognitive radios should decide on the best spectrum band to meet the Quality of Service requirements over all available spectrum bands, therefore spectrum management functions are required for Cognitive radios, these management functions can be classified as:

- spectrum analysis
- spectrum decision

iii) Spectrum Mobility: It is defined as the process when a cognitive radio user exchanges its frequency of operation. Cognitive radio networks target to use 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

iv) Spectrum Sharing: It refers to providing the fair spectrum scheduling method, one of the major challenges in open spectrum usage is the spectrum sharing.

How can CR improve ?

- Enable unlicensed users when spectrum not in use.
- Assist secondary markets with frequency use, implemented by mutual agreements.
- Negotiate frequency use between users.
- Provide automated frequency coordination.
- Overcome incompatibilities among existing communication services.
IV. COGNITION CYCLE

A cognition cycle by which cognitive radio may interact with the environment.

![The Cognition Cycle Diagram]

Conceptual Operation

OODA Loop: (continuously)
- Observe outside world
- Orient to infer meaning of observations
- Adjust waveform as needed to achieve goal
- Implement processes needed to change waveform

Other processes: (as needed)
- Adjust goals (Plan)
- Learn about the outside world, needs of user,…

This cycle implements the capabilities required of iCR in a reactive sequence. Stimuli enter the CR as sensory interrupts, dispatched to the cognition cycle for a response. Such an iCR continually observes (senses and perceives) the environment, orients itself, creates plans, decides, and then acts.

Observe (Sense and Perceive)

The iCR senses and perceives the environment (via “observation phase” code) by accepting multiple stimuli in many dimensions simultaneously and by binding these stimuli—all together or more typically in subsets—to prior experience so that it can subsequently detect time-sensitive stimuli and ultimately generate plans for action. Thus, iCR continuously aggregates experience and compares prior aggregates to the current situation. A CR may aggregate experience by remembering everything. This may not seem like a very smart thing to do until you calculate that all the audio, unique images, and emails the radio might experience in a year takes up only a few hundred gigabytes of memory, depending on image detail. So the computational architecture for remembering and rapidly correlating current experience against everything known previously is a core capability of the CRA. A novelty detector identifies new stimuli, using the new aspects of partially familiar stimuli to identify incremental-learning primitives. In the six-component (user SP, environment, effectors, SDR, sys-apps, and cognition) functional view of the architecture defined in the CR Node Functional Components subsection (see p. 433), the observe phase comprises both the user SP and the environment (RF and physical) sensor subsystems. The subsequent orient phase is part of the cognition component in this model of architecture.

Orient

The orient phase determines the significance of an observation by binding the observation to a previously known set of stimuli of a “scene.” The orient phase contains the internal data structures that constitute the equivalent of the short-term memory (STM) that people use to engage in a dialog without necessarily remembering everything with the same degree of long-term memory (LTM). Typically, people need repetition to retain information over the long term. The natural environment supplies the information redundancy needed to instigate transfer from STM to LTM. In the CRA, the transfer from STM to LTM is mediated by the sleep cycle in which the contents of STM since the last sleep cycle are analyzed both internally and with respect to existing LTM. Matching of current stimuli to stored experience may be achieved by “stimulus recognition” or by “binding.” The orient phase is the first collection of activity in the cognition component.

Stimulus Recognition

Stimulus recognition occurs when there is an exact match between a current stimulus and a prior experience. The CR1 prototype is continually recognizing exact matches and recording the number of exact matches that occurred along with
the time measured in the number of cognition cycles between the last exact match. By default, the response to a given stimulus is to merely repeat that stimulus to the next layer up the inference hierarchy for aggregation of the raw stimuli. But if the system has been trained to respond to a location, a word, an RF condition, a signal on the power bus, or some other parameter, it may either react immediately or plan a task in reaction to the detected stimulus. If that reaction were in error, then it may be trained to ignore the stimulus, given the larger context, which consists of all the stimuli and relevant internal states, including time. Sometimes the orient phase causes an action to be initiated immediately as a “reactive” stimulus–response behavior. A power failure, for example, might directly invoke an act that saves the data (the “immediate” path to the act phase). A non recoverable loss of signal on a network might invoke reallocation of resources (e.g., from parsing input to searching for alternative RF channels). This may be accomplished via the path labeled “urgent”

Binding

Binding occurs when there is a nearly exact match between a current stimulus and a prior experience and very general criteria for applying the prior experience to the current situation are met. One such criterion is the number of unmatched features of the current scene. If only one feature is unmatched and the scene occurs at a high level, such as the phrase or dialog level of the inference hierarchy, then binding is the first step in generating a plan for behaving in the given state similar to the last occurrence of the stimuli. In addition to number of features that match exactly, which is a kind of hamming code, instance-based learning (IBL) supports inexact matching and binding.

Plan

Most stimuli are dealt with “deliberatively” rather than “reactively.” An incoming network message would normally be dealt with by generating a plan (in the plan phase, the “normal” path). Such planning includes plan generation. In research quality or industrial-strength CRs, formal models of causality must be embedded into planning tools. The plan phase should also include reasoning about time. Typically, reactive responses are preprogrammed or defined by a network (i.e., the CR is “told” what to do), whereas other behaviors might be planned. A stimulus may be associated with a simple plan as a function of planning parameters with a simple planning system.

Decide

The decide phase selects among the candidate plans. The radio might have the choice to alert the user to an incoming message (e.g., behave like a pager), or to defer the interruption until later (e.g., behave like a secretary who is screening calls during an important meeting).

Act

Acting initiates the selected processes using effector modules. Effectors may access the external world or the CR’s internal states.

Learning

Learning is a function of perception, observations, decisions, and actions. Initial learning is mediated by the observe phase perception hierarchy in which all SP are continuously matched against all prior stimuli to continually count occurrences and to remember time since the last occurrence of the stimuli from primitives to aggregates. Learning also occurs through the introduction of new internal models in response to existing models and case-based reasoning (CBR) bindings.

Applications of Cognitive Radio

Traffic Control: Traffic is a big problem especially in big cities during the mornings and in the evenings. Under such situations, the local traffic control can transmit the congested traffic location, the predicted traffic delay and an alternate route to the mobile user. Cognitive intelligence can be applied on traffic signals themselves as well to determine how long the red or green signal may remain on depending on the traffic volume in each direction. This traffic information can be gathered at each signal location by cognitive sensors. The appropriate decision can be taken locally or via a central control.

INTEROPERABILITY: Interoperability is a powerful tool in CR domain that enables intelligent wireless communication across any boundary and over any dimension. This ubiquitous connectivity can define the ultimate adaptive system over heterogeneous networks, varied spectrums, diverse geographical boundaries, and over different
communication policy and regulations. Achieving the ideal interoperable system may still be a long way from reality. Some of the cognitive applications that can set the way are CR ability to operate over legacy systems, intelligent policy management methods, utilizing network knowledge, cross layer optimization, and various multi-antenna configurations. Cognitive traits of frequency agility and protocol independence can allow CR to build SDR platforms that are potentially capable of solving radio and system interoperability problems. These platforms can provide seamless system operation in a highly fragmented and in a multiterminal/ multi-frequency heterogeneous communication environments.

An immediate implementation of interoperability at present can be the public safety first responders and military applications. The role of interoperable devices, services, networks, and spectrums are extremely critical for these applications. In other sectors, such as in consumer applications, CRs can offer interoperability across licensed, unlicensed, and semi-licensed spectrum services and over diverse networks. Figure below represents a coalesce of interoperable devices, services, and networks for a visual understanding of interoperable wireless system.

CONCLUSION

Cognitive radio introduces a new level of sophistication to wireless communications technology. It is a new and exciting technology that, has the potential to unlock the spectrum necessary for the deployment of next generation high data rate systems. However, for this concept to become a practical technology, research into the processing, transmission, and spectrum sensing are necessary which are going on. CR applications are on the horizon due to enabling technologies of Artificial Intelligence and Software Defined Radio. These applications range from Biometric Authentication for Security, Medical Services, Traffic Control, Military etc. Cognitive Radio will enable significant efficiencies in the use of radio spectrum but there are a number of significant technical and regulatory challenges that need to be overcome before we can realize “full” cognition in a radio system.

References


