Integrated Intelligent Research (IIR)

International Journal of Computing Algorithm
Volume: 07, Issue: 01, June 2018, Page No.11-18
ISSN: 2278-2397

Cognitive Radio Technology – An Intelligent Radio Approach

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Abstract — The obtainability of spectrum is limited for wireless communication. The inefficient usage of spectrum leads to the evolution of a new technology known as Cognitive Radio Networks. With the fixed spectrum assignment policy, most of the spectrum remains unused and remains as vacant white spaces all the time. This leads to an approach known as spectrum sensing. Spectrum sensing is the process of detecting the presence of the primary users (PUs) in a licensed spectrum and is considered as fundamental problem for cognitive radio. It is an intelligent radio communication approach where a cognitive radio device will sense the environment and carry communication using the unutilized spectrum bands. Cognitive radio technology potentially satisfies the increasing users in future. This paper provides an insight of cognitive radio knowledge-architecture, cognition cycle, functions, different spectrum sensing methods and various applications of CR.
Keywords: Spectrum Sensing, PU, SU, CRWSN, Dynamic spectrum access.

I. Introduction

With the spontaneous growth in wireless communication, an extensive amount of growth in demand for wireless radio spectrum has been experienced with the rapid growth of wireless communication in the last few decades. The organization, Federal Communications Commission (FCC) takes into consideration of promoting competitions, innovations, investment and regulations in radio spectrum. In recent years, Cognitive Radio has become most prominent technology and has become a solution for the spectrum scarcity problem in wireless communication. The terminology “Cognitive Radio” was coined in 1999 by Joseph Mitola. Cognitive Radio [1] acts as a transceiver which can automatically sense the available channels in wireless spectrum and change its transmission or reception parameters accordingly. This process is also known as dynamic spectrum management. In the current spectrum framework, the spectrum bands are allocated to licensed users. The licensed users are also known as primary users (PUs). But, the utilization in the allocated spectrum is partial. This insufficient and unsatisfactory utilization of spectrum leads to the need of Dynamic Spectrum Access Techniques (DSA). DSA allows secondary users (SUs) to use the spectrum temporally for a particular period of time. When the primary users reemerge, secondary users have to leave the connection. But, for ulizing the spectrum, secondary users needs to constantly sense for the available spectrum. Spectrum sensing has become a recent topic of research and many techniques have been put forward. After sensing the spectrum, CRs [10] allocate the spectrum to the SUs and the SUs need to adapt and reconfigure themselves in order to use the newly assigned spectrum.

II. Ease of Use Architecture of Cognitive Radio

A. Sensors

In CR implementing DSA, sensors collect the information from the external environment to identify fallow spectrum.

B. Radio Platform

The Cognitive Radio Platform which includes the digital signal processing unit and the software control acts as an interface to communicate with the RF, sensors, policy reasoners and the information source and sink. It can be classified into two categories based on Universal Software Radio Peripheral (USRP) and Non-USRP. Software Radio Peripheral acts as a signal processing software platform. It has several advantages such as very high flexibility, use of general high level language (such as C/C++) for software development, low cost, strong extendibility and portability and short development cycle.

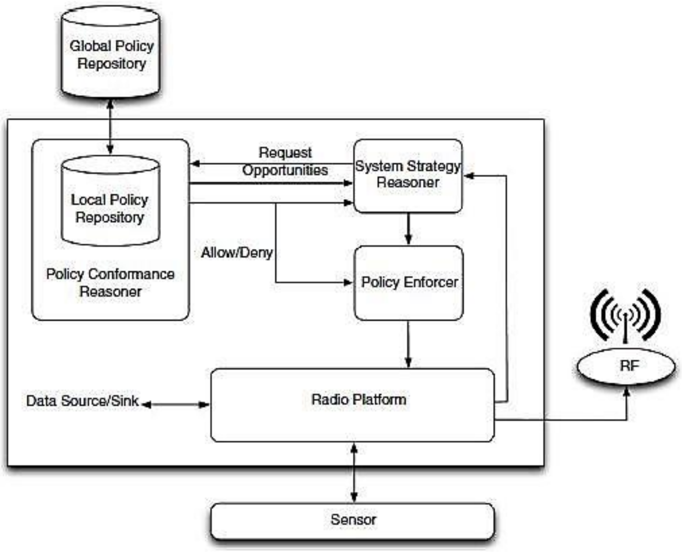

Fig 1. Architecture of Cognitive radio

C. System Strategy Reasoner (SSR)

The SSR acts as a crossing point for transmitting and receiving signals. The SSR determines the available spectrum by interacting with the PR. Based on its current state and collected sensory information, a transmission strategy is formulated by SSR. This data is sent to PR in the form of a transmission request. The process of the cognitive radio is controlled by the strategies formed by the System Strategy Reasoner (SSR).

D. Policy Conformance Reasoner

The Policy Conformance Reasoner [9] is a platform independent module which works as a local policy decision unit for every XG Radio. Policy Conformance Reasoner receives requests from the SSR and estimates them based on the Active Policies. Once the evaluation is complete, the Policy Conformance Reasoner returns a response which is either to allow, deny or incomplete transmission. In case if the transmission request is being denied or incomplete, the Policy Conformance Reasoner returns opportunity restraints, which if satisfied by the radio, will allow transmission.

E. Policy Enforcer (PE)

The Policy Enforcer acts as a gate keeper linking the Radio Platform and the SSR. The main function of PE is to guarantee that all the transmission decisions that are sent from SSR to the Radio Platform comply with the active policy.

F. Global Policy Repository

The Global Policy Repository, which is shared across the network, stores all the policies and specific subsets configured for specific networks.

G. Local Policy Repository

The Local Policy Repository is present within the SSR. It downloads the policies from the Global Policy Repository through an interface. Though a radio node can store multiple sets of policies, only one set of policy can be active at any time.

III. COGNITION CYCLE

Cognition cycle [12] is a cycle that deals with the environment. In the initial stage, stimuli enter the cognitive radio and it is sent to the OOPDA cycle for processing. The Cognitive radio, the self adjusting and intelligent radio, constantly monitors the atmosphere, Orient itself, create plans, decides and then acts accordingly. In these phases machine learning is used for learning. During wake period, a new cognition cycle is generated when the cognitive radio sensor senses the stimuli. Here the CR continuously monitors and senses the environment. It also includes radio broadcasts monitoring. For power down conditions it undergoes sleep period. Pattern recognition and learning are done in dream period when the CR is in long sleep state. Machine learning algorithms are used for learning. Prayer period occurs for interacting with higher officials when there is an unresolved problem.

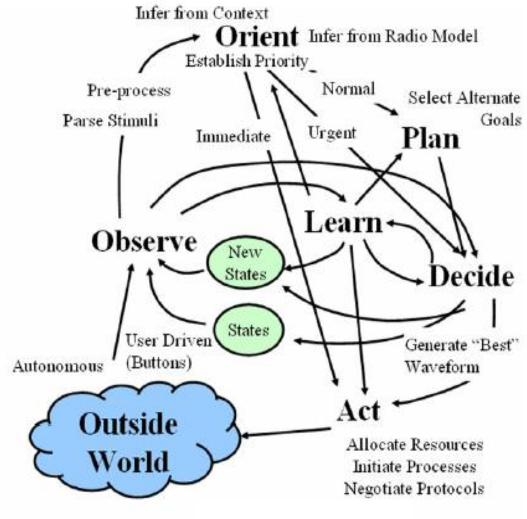

Fig 2. Cognition cycle

A. Observe

The Observe phase senses and perceives the environment by accepting multiple stimuli simultaneously from many directions and then binding them all together. This is done to detect the exact current stimuli so that it can be compared with the previous stimuli and plans can be generated accordingly. In observe phase, CR reads the location information, temperature information, and light level sensors information, etc. to gather the user's communications context. The Observe phase which consists of the user SP and environment can be sensed using various sensors.

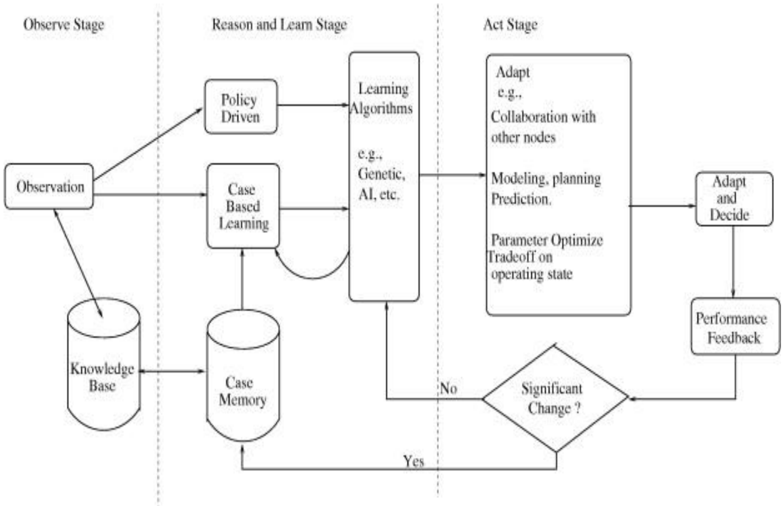

Fig 3. Operation of Cognition cycle

B. Orient

By comparing the incoming stimuli with the formerly observed set of stimuli, Orient phase analyze the prominence of the incoming stimuli, which can be named as a scene. The orient phase scrutinizes the stimuli during the sleep period. There are two ways to compare and match the stimuli: Stimulus recognition and binding. Stimulus recognition: Stimulus recognition occurs when there is an exact matching between the existing and previously experienced stimuli. Along with this total number of matched stimuli will be noted as well. Binding: Binding occurs when there is a near exact matching between the existing and previous stimuli. If the number of unmatched stimuli is extra in comparing a current and previous scene, then that scene will be

International Journal of Computing Algorithm
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allotted with low priority thus the binding becomes less effective. If the binding is more effective (i.e.,) less number of matchless stimuli, then it is assigned with a higher priority.

C. Plan

Several plans are generated based on the input stimuli. This is called plan generation. The cognitive radio can instantly respond to the current situations or emergency situations only if the plans are preprogrammed considering the future situations. Only some plans can be preprogrammed while others plans are generated instantly. Many parameters such as the weather, topography and natural calamities are to be considered for plan generation.

D. Decide

For every single situation, there may be a lot of plans generated or preprogrammed. This is because if one plan fails, the other alternative can be considered for that situation. The decide phase selects one plan, among the set of available plans, which suits the current situation. Decide phase also helps cognitive radio to defer the disruption until later.

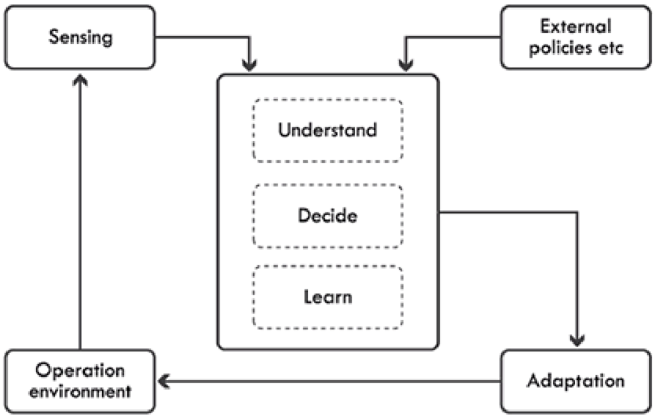

Fig 4. Srensing in Cognition cycle

E. Act

Act uses different modules to initiate the process selected by the decide phase. Cognitive Radio’s internal state or external world may be accessed using the effectors. Actions are of two types namely

- Externally oriented actions
- Internally oriented actions

1) *Externally oriented actions*

With the use of different languages such as: Knowledge Query and Manipulation Language (KQML), Web Ontology Language (OWL), Radio Extensible Markup Language (RXML), Radio Knowledge Representation Language (RKRL) or some other language, external world can be accessed using messages which can be either spoken into the neighboring environment or expressed in the form of text from local environment to another cognitive radio or cognitive network.

2) Internally oriented actions

Internally oriented actions include controlling the machine controllable resources. The contents of the model can be affected by either adding a new model or by removing a model or by removing a model from the existing model.

IV. FUNCTIONS OF COGNITIVE RADIO

A. Spectrum Sensing

To achieve synchrony with each type of primary license similar to that required for coherent detection, a dedicated circuitry will be needed by cognitive radio. So, the implementation cost and intricacy will rise based on the upsurge in amount of primary bands being opened for opportunistic access. More sophisticated feature detectors may be employed to address the issue of its incapability to discriminate between causes of received energy, at the cost of increased impediment. The secondary users will be unaware of the recurring primary users and so, harmful interference may occur ensuing in delay and degradation in quality of service (QoS). Sensing has to be interleaved with data transmission as it is not possible to communicate on a license band [4] and sense it at the same time. A sensing-based system has to certify that a primary receiver is always shielded from the harmful interference of the secondary user. Receiving low signal strength doesn't mean that the primary system is positioned out of the interference range of the secondary user. The primary signal might also be severely shadowed by obstacles or experience a deep fade. The precision with which a noise power can be predictable estimated is limited by factors such as calibration errors and change in thermal noise. Thus noise uncertainty is the major challenge faced by Spectrum sensing [5]. Thus different spectrum [2] users results can be considerately used to spot the licensed spectrum occupancy.

Table I. Classification of White Space Identification Models

	Infrastructure cost	Legacy compatibility	Transceiver complexity	Positioning	Internet connection	Continuous monitoring	Standardized channel
Database registry	High		Low	X	X		
Beacon signals	High		Low	X			X
Spectrum sensing	Low	X	High			X	

B. Spectrum Sharing

All wireless channels have shared nature which requires coordination in transmission. The main challenge in spectrum sharing is that the existence of both licensed users and unlicensed (CR) users and also the wide spectrum range. To deal with these challenges spectrum sharing is classified based on the following ways: (a) architecture, (b) spectrum allocation behavior, (c) spectrum access technique and scope. But finally sharing focus mainly on two types: (a) Internetwork spectrum sharing (2) Intranetwork spectrum sharing [3].

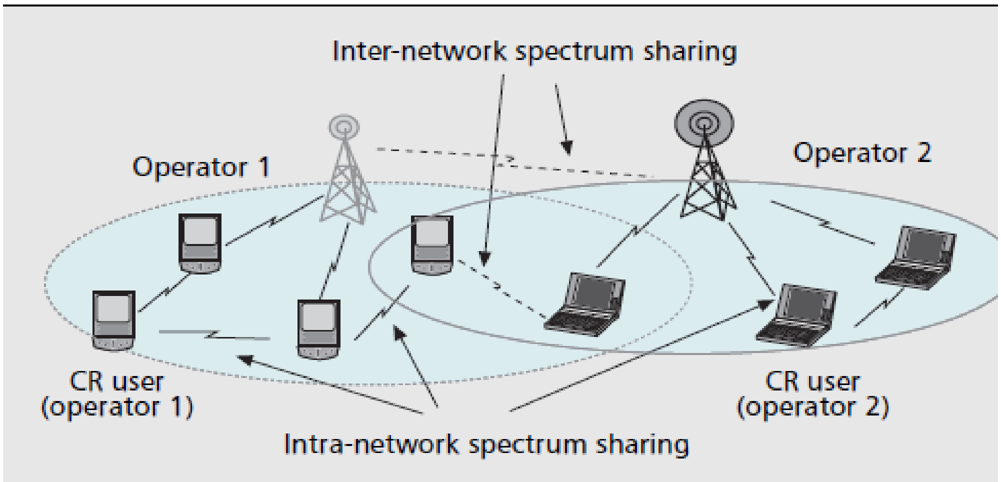

Fig 5. Spectrum Sensing in Cognitive radio

In case of Intranetwork spectrum sharing the spectrum allocation will happen between the entities of the CR network. It does not cause interference to the licensed users and uses only the available spectrum. In Internetwork, spectrum sharing can be implemented using two or more CR networks involved in sharing. It deploys multiple users in the overlapping region and spectrum of two different users. This gives the broader view of spectrum sharing by certain operating policies. Some of the spectrum challenges are as follows: i) Common control challenges facilitate many sharing functions. However when a primary user chooses the

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spectrum the unlicensed user must vacate the spectrum. ii) Dynamic radio range: Radio range and operating frequency are always interdependent of each other. iii) Spectrum unit: Always channel is considered as a basic spectrum unit. iv) Location information: When the location and power of the primary user is identified, the interference information can be calculated.

C. Spectrum Mobility

Spectrum mobility mainly aims at seamless channel switching without interrupting the on-going secondary unit (SU) communication. The two processes of spectrum mobility are spectrum handover and connection management. The process of transferring the on-going data transfer from one channel to another is called spectrum handling. There occur several challenges during spectrum sharing that affects the communication. To compensate such unavoidable conditions, connection management adjusts the protocol stack parameters. Primary users are the accredited users to use the spectrum band.

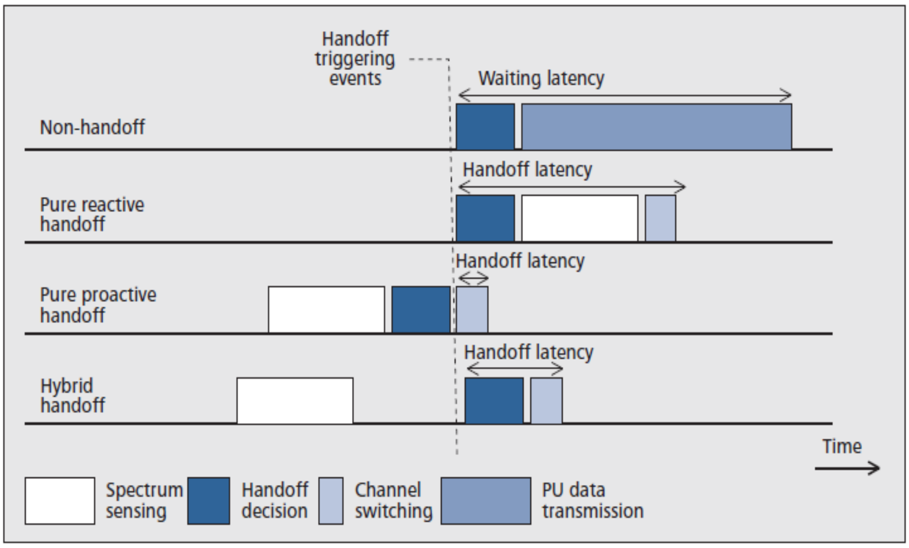

Fig 6. Handoff latency factors

Strategy	Non-handoff	Pure reactive	Pure proactive	Hybrid
Main idea	Stay and wait	* Reactive sensing * Reactive action	* Proactive sensing * Proactive action	* Proactive sensing * Reactive action
Advantages	Very low PU interference	Accurate target channel selection	* Fastest response * Smart target channel selection	Fast response
Disadvantages	Very high SU interference	Slow response	* Outdated target channel selection * High computational requirement	Outdated target channel selection
Handoff latency	Unpredictably high latency	Medium latency	Very low latency	Low latency
Dependency	PU activity	Spectrum sensing	* Backup channel relevancy * Accurate PU traffic model	Backup channel relevancy
Best suited environment	Short data transmission PU network	General PU network	Well-modeled PU network	General PU network

Fig 7. Comparison of spectrum handoff strategies

Secondary users use the licensed band in the absence of PUs. When the primary users arrive back to their band the secondary users are forced to leave the band and shift to another band and this process is called spectrum handoff. Thus during handoff many challenges such as wireless link layer delay, wireless link error and interference occurs affecting the SU communication [8] performance. During handoff, the SU should ensure that the new path to be chosen is not occupied by any other primary user (PU); the channel path is free from link errors and delays and that no other signal should interfere with this signal. The new channel chosen should have better functionalities than SU's past channel. To maximize the throughput, multiple channels are used to transmit data. A SU should sense the PU continuously to know the changes in PU so that it can adapt itself according to it. Link maintenance is also very important in spectrum mobility and its related issues are spread over the network, MAC layers and the physical layers. A cross layer approach between physical and MAC layer or between network and MAC layer is performed to solve the link maintenance issues. Energy efficiency is another major challenge here because most of the energy is used for spectrum sensing and spectrum information update.

V. APPLICATIONS OF COGNITIVE RADIO

A. Military and Public Security Applications

There are number of applications for conventional wireless sensor networks. One of the most important applications is CBRN investigation. CBRN stands for chemical biological radiological and nuclear. CBRN attack detection and investigation is carried out through WSN. The other applications include command control, battlefield surveillance, targeting, monitoring and intelligence assistant.Jamming the signals in the battlefield by enemies/jammers are common. In those situations, CR-WSNs [7] can handoff frequencies for a wide range. CR-WSNs can use different frequency bands.

B. Health Care

Wearable body sensors are being used increasingly in a health care system, such as telemedicine. On the body of patients wireless sensor nodes are placed by the remote monitoring techniques of WSN to get data. Data related to medicine are crucial and it should be error sensitive. So that accurate data plays a major role. If the operating spectrum band is crowded in "telemedicine with BAN", the QoS may not be achieved at a satisfactory level. These problems can be mitigated by the use of 'CR wearable body wireless sensors'. This improves reliability.

C. Indoor Applications

For the achievement of QoS applications a huge WSNs environment is required. Reliable communication is one of the most important challenges in WSN because indoor areas ISM bands are very teeming. Some examples of the indoor applications of WSNs are

- Intelligent buildings,
- Home monitoring systems,
- Factory automation and personal entertainment.

D. Bandwidth-Intensive Applications

There are many challenging applications which require huge bandwidth requirement. These applications includes

- On-demand or live video
- Audio
- Still images

These applications require large bandwidth. It is possible for CR-WSN [11] secondary users to access multiple channels whenever available. For bandwidth constraint applications, CR-WSN is very suitable.

E. Real-Time Surveillance Applications

There are number of real time scrutiny applications such as traffic checking, biodiversity plotting, habitat checking and environmental condition checking that affect crops and livestock, irrigation, underwater WSNs, vehicle tracking, inventory tracking, disaster relief operations, bridges or tunnel monitoring, require minimum channel access and communication delay. Some real-time surveillance applications [7] are delay profound and

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require high reliability. Delays occur due to the link catastrophes. Channel accumulation and the use of multiple channels concurrently are possible in CR-WSNs to surge the channel bandwidth.

VI. Conclusion

Cognitive radio is a novel approach that basically increases the utilization efficiency of the radio spectrum when the primary users (PUs) are not using it. This paper presents an extensive study of cognitive radio in terms of architecture, OOPDA cycle, functions of CR and applications of CR. Dynamic spectrum sharing becomes a promising approach to improve the efficiency of spectrum usage. CR uses the available spectrum in an efficient way by fully utilizing the scarce spectrum resources. Most important element of cognitive radio is sensing the available spectrum and making it used by secondary users in the absence of primary users. In CR, the new spectrum management technology, licensed/primary users can share their spectrum to the secondary users, unlicensed users. This approach of sharing is known as Dynamic Spectrum Access (DSA). For making CR an open research area, there are numerous tough issues still need further analysis, Challenges includes: (a) flawless spectrum handovers; (b) hands-on spectrum selection; (c) interference avoidance; (d) energy competence; and (e) alternatives to the common control channel. It can be concluded CR will confine the WSN (wireless sensor networks) and IOT (Internet of Things) technologies to a higher level in near future.

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