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Realisation of Cognitive Radio: Issues and Challenges

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Abstract

For last two decades, the demand for wireless spectrum has been increasing rapidly with tremendous developments in the telecom industry. There also has been huge growth in flow of multimedia traffic over the last decade. Thus, the demand for additional bandwidth is increasing exponentially despite the fact that the electromagnetic spectrum is a finite resource. On the other hand, spectrum occupancy is found to be quiet low in most of the allocated bands. Thus, the under-utilization of the precious spectrum is unaffordable if persistent growth of new and existing wireless services are to be sustained. Cognitive radio (CR) is a future technology initiated by many research organizations and academic institutions to increase the spectrum utilization of underutilized spectrum channels to ameliorate scarcity problem of valuable electromagnetic spectrum. There exists number of issues and challenges in designing and implementation of the cognitive radio. These issues need to be rigorously resolved before a cognitive radio is realised.

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Keywords

Cognitive radio, Spectrum sensing, Spectrum management, Spectrum mobility, Spectrum sharing, Primary user, Secondary user.

Introduction

The spectrum is a valuable electromagnetic resource that is controlled by government in order to manage complex issues. Presently, spectrum is allocated to service providers by adopting the policy of fixed allocation in which transmission power is regulated and different frequency bands are assigned for different services and applications. There has been tremendous growth of wireless users and applications over the last decade. The total number of users worldwide was 3.2 billion in 2009 and it was projected to increase by 100 folds by 2013[1]. These new applications require more spectrum allocation,but it is difficult to find the new spectrum as most of the spectrum bands are allocated by a policy of fixed allocation. This policy has created a situation where there appears an artificial scarcity of the spectrum. The spectrum utilization report provided by Federal Communications Commission (FCC)[2] spectrum task force indicates that utilization of the allocated spectrum varies between15% to 85% and is a function of space and time. Other spectrum occupancy measurements conducted have revealed that the average utilization in New York

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City[3] was at 5.2% while in Chicago[4] at 17.4%. Several other countries spectrum occupancy measurement studies, such as Spain[5], Singapore[6], Germany[7,8], New Zealand[9] and United Kingdom[10] also confirmed that spectrum is heavily under-utilized . The authors of[11] have proposed the framework for future spectrum occupancy measurements covering the frequency range from 700 to 2700 MHz in India. Thus, the persistent increase in demand of spectrum cannot be fulfilled until a new scheme is not found to control the limited spectrum. This new scheme is the dynamic spectrum access (DSA)[12-14] in which secondary users (SUs) can use the idle licensed channels opportunistically known as spectrum hole or white space with only constraint of minimum interference to primary users (PUs) or licensed users. If spectrum is utilized on time or frequency basis, the spectrum opportunities appear in the form of holes as shown in Fig.1. In time domain, it is the period of time during which the PU in not transmitting and in frequency domain, it is the frequency band in which SU can use the frequency band for its transmission allotted to PU with no or minimum interference. The technology that will make the DSA a reality is the Cognitive Radio (CR). CR is a smart device having the capability to sense the entire spectrum in order to find the idle channels and utilizing these idle channels opportunistically for communication as and when required. The opportunistic usage of these idle channels can increase the utilization of precious spectrum. CR can enable the SUs to utilize licensed channels of PUs either on negotiated or opportunistic basis. It can provide a basis for efficient wireless communication between users wherein nodes have the capability to alter any of its transmission or reception parameters in order to adapt to continuously changing environment.

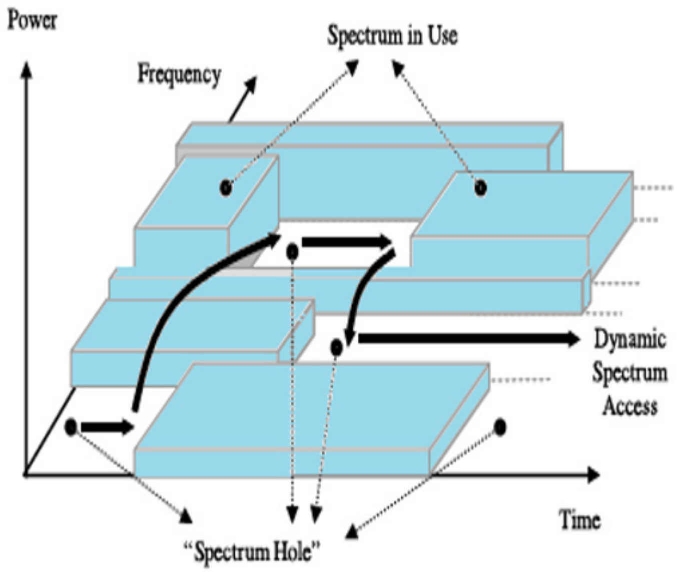

Fig. 1: Spectrum hole concept (reproduced from[14])

Capabilities and Features

The smart device like CR can have the capabilities to model its location and time varying environment so that the suitable frequency channels, protocols and interfaces are selected in order to have the best communication. Cognitive cycle proposed by Mitola[15] is shown in Fig. 2.

Theproposed cognition cycle is described as under:

Observe

CR has the capability to sense the environment so that it has complete knowledge about the environment.

Orient
The importance of the collected information is assessed.

Plan
On the basis of collected information, CR determines all its available options for resource optimization.

Decide
Amongst the available options, the best course of action is decided.

Act
The best course of action is implemented by CR for resource optimizations. The changes are then reflected in the interference profile by CR.

Learn
During this process, the CR uses all its previous observations and decisions to improve upon its future decisions using learning techniques.

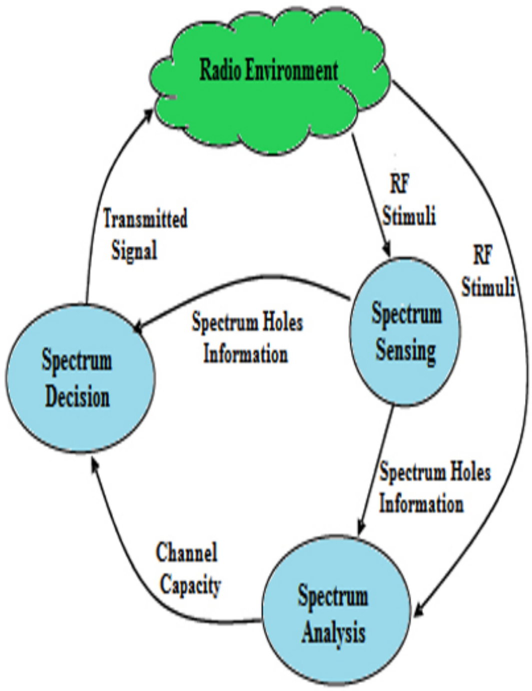

Fig. 2: Basic cognitive cycle (reproduced from[27])

Spectrum As A Resource
Spectrum is a group of electromagnetic radiations used for wireless communications. Chunks of these different ranges of frequencies are allocated for different applications for dedicated, successful and secure service provisioning. Different spectrum bands are allocated for different services and applications in order to guarantee interference free operation of the users. But, fixed allocation of the spectrum bands has created poor utilization scenario of allocated bands that has resulted in wastage of valuable natural resource. With the increase in wireless applications and its users, the service providers have been at loggerhead with each other for acquiring more spectrum. The regulatory agencies have faced a tough time for spectrum distribution especially during past one decade. Every nation has its right for unbounded use of the spectrum. At the international level, International Telecommunication Union (ITU) has been assigned the responsibility of allocation of spectrum for various countries in world radio communication conference. Considering the difficulties in spectrum allocation, authorities like Federal Communications Commission (FCC), Telecom Regulatory Authority of India (TRAI) emphasizes the need for change in spectrum regulatory policy from fixed to dynamic spectrum allocation.

Spectrum Allocation in India: Present Scenario
In order to facilitate the hardware compatibility, standardization; the specific spectrum bands are allocated for a particular use. Allocation of different spectrum bands for different services and applications in India[16] is shown in Table 1.

Government of India under ministry of communications created the wireless planning and co-ordination wing (WPC) in 1952 that acts as the National Radio Regulatory Authority. WPC is being assigned the responsibility of management of spectrum in India. Standing Advisory Committee on Frequency Allocation (SACFA) is one of the section of WPC. Main function of SACFA is to make recommendations regarding allocation issues and sort out other issues referred to it by wireless users. Wireless communication refers to the transmission of electromagnetic waves with range from 3 Hz to 300 GHz. The electromagnetic waves transmitted at different frequency ranges have different characteristics, such as interference, path loss, wireless link errors, link layer delay etc., necessitating the use of unique applications for specific frequency bands.

Table 1: Spectrum allocation in India for different services (reproduced from[16])

Frequency Band (MHz)	Services
0-87.5	Mobile, Aeronautical Navigation, Cordless Phones
87.5-108	FM Radio Broadcast
109-173, 230450	Broadcast Vans, Aeronautical Navigation
585-698	TV Broadcast
806-960	GSM and CDMA Mobile Services
960-1710	Aeronautical and Space Communication
1710-1930	GSM Mobile Services
1930-2010	Reserved for Defence Forces
2025-2110, 2170-2300	Satellite and Space
2400-2483.5 (Unlicensed)	Wi-Fi, Bluetooth
2483.5-3300	Space Communication
3600-10000	Space Research, Radio Navigation
10000 onwards	Satellite Broadcasts, DTH Services
174-230, 450585 699-805, 2010-2025 2110-2170, 2300-2400 3300-3600	Not Allocated

Issues Of Cognitive Radio

The main purpose of the CR is to realize dynamic access to the idle spectrum in order to have communication. However, implementation of a cognitive radio is a challenging task. A typical cognitive radio scenario consists of SUs that co-exist with the PUs. PU has a priority to use the spectrum as they have legacy rights for the spectrum access. SU opportunistically access the spectrum when they find that PU is not using the spectrum or underlay access to the spectrum, when both PU and SU co-exist, with strict constraint over non-interference among the users. The main issues of CR are as under[14,17,18]:

- Spectrum Sensing
- Spectrum Management
- Spectrum Mobility
- Spectrum Sharing

Spectrum Sensing

Spectrum sensing is the important function of the CR. The CR (or SU) has to sense the radio environment in order to detect the idle channels (or spectrum hole) and use these idle channels for its communication. The sensing operation should also be able to detect the PU's arrival on the frequency band presently occupied by SUs instantly and accurately[19]. This function can be further divided as under:

Primary Transmitter Detection

The CRs should have the capabilities to detect even weak signals from any primary transmitter through its local observations. This function can be further divided as under:

Matched Filter Detection

In this scheme, the CR has the prior knowledge of the some characteristics of the PU signal and is able to detect the presence or absence of PU with high accuracy[20]. However, the disadvantage is the requirement of knowledge of some features of primary signal such as operating frequency, modulation scheme, packet format etc[19].

Energy Detector

In this scheme, the CR does not have prior knowledge of any characteristics of the PU's signal. The measured energy of the received signal is compared with the preselected threshold in order to determine the presence or absence of the primary signal[21]. The disadvantage of this scheme is the non-discrimination between noise energy and primary user signal[22].

Cyclostationary Feature Detection

In this scheme, the modulated signals are coupled with other waves such as sine wave carriers, pulse trains, repeated spreading, hopping sequences or cyclic prefixes to create built-in periodicity. These cyclostationary features are detected at the receiver in order to determine the presence or absence of the primary signal. The advantage of this approach is the discrimination between the noise energy and the primary user signal[23,24]. This is a complex technique and takes long time for detection of the PU signal.

Cooperative Spectrum Sensing

In this scheme, the local sensing result from multiple CR users is utilized to draw conclusion on the presence or absence of primary user signal. This approach mitigates the harmful effects of fading, shadowing, noise, interference etc. and results in reduction of miss detection and false alarm probabilities[25,26].

Interference Based Detection

In this scheme, the transmission of CR is allowed only if the interference introduced does not exceed a certain threshold known as interference temperature limit of the licensed receiver[27].

Spectrum Management

Spectrum management helps in finding the best idle channels or hole for the transmission of SU among large number of available spectrum holes. The SU has to interact with different protocol layers of the network to maintain the quality of service (QoS) of an application. Based on the availability of the spectrum, the channel is allocated to the SU. This decision also depends on the internal and external policies as well as other regulatory issues of the spectrum. This function can be further divided as under:

Spectrum Analysis

The spectrum analysis performs the function of the characterization of the idle spectrum or hole found through the spectrum sensing. The characterization of these holes is necessary due to availability of very wide range of spectrum. The characteristics, such as interference, path loss, wireless link errors, link layer delay etc., varies with change in operating frequencies[14].

Spectrum Decision

As per the requirement of the CR user, the appropriate spectrum band is selected for the transmission that satisfies the QoS of the SU. An opportunistic frequency channel skipping protocol[28] is proposed that searches better quality channel based on SNR.

Spectrum Mobility

Spectrum mobility is the process of switching the spectrum band during data transmission due to arrival of PU on that band. The SU has to switch to another frequency band which is not used by the PU at that time in order to continue the transmission[29]. The switching to this idle band should be seamless so that there is minimum QoS degradation of the application running over the SU. As soon as the PU needs the frequency band, the SU has to terminate its transmission and free the frequency band for the PU functioning[30].

Spectrum Sharing

Spectrum sharing is an important functionality of CR as it coordinates the traffic between secondary and primary users. It is a challenging task as it requires high degree of cooperation, understanding and coordination between primary and secondary users. Resource allocation and spectrum access are its two main functions. This function can be further divided as under:

On the Basis of Architecture

Centralized Spectrum Sharing

In this type of sharing, a central entity controls resource allocation and spectrum access functions. A comparative study of centralized and distributed approaches indicates that distributed approaches generally follow the centralized approaches having disadvantage of message exchange[31].

Distributed Spectrum Sharing

In this type of sharing, CR itself manages the functions of resource allocation and spectrum access based on local (or global) policies[32-34].

Spectrum Allocation Behaviour

Cooperative Spectrum Sharing

This type of sharing considers the effect of CR's communication on others. In this case, information is shared among the CRs or among the CRs and the central entity in order to take a decision[32,33,35] .

Non- Cooperative Spectrum Sharing

This type of sharing considers only the communication of a particular CR and thus, adopts a selfish approach. In this case, no information exchange takes place among CRs[34,36].

Spectrum Access Technique

Overlay Spectrum Sharing

In this type of sharing, the CR accesses the spectrum that is not being used by primary user at that time[32,34,35,37].

Underlay Spectrum Sharing

In this type of sharing, both CR and PU transmit in the same frequency band but the transmission of CR is considered noise by the primary user and thus, the interference introduced should be within the tolerable limits. Underlay systems use ultra-wide band[38] or spread spectrum technique[31] for communication.

Conclusion

The present regulatory policies and devices working on fixed spectrum allocation are not suitable for rising service demands and are responsible for under-utilization of spectrum bands. Thus, there is a need to devise newer way of spectrum allocation strategies and new devices that will work efficiently based on dynamic spectrum allocation.The mentioned issues need to be addressed before a practical cognitive radio network is realised.

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