*First International Conference on Emerging Trends in Engineering, Management and Scineces"*
*December 28-30, 2014 (ICETEMS-2014) Peshawar, Pakistan*

# Detail Survey of Cognitive Radio Communication System

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## Abstract
Wireless systems facing some fundamental problems in service regarding some suitable spectrum bands so that to meet with the demand in future. Though, essentially all 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 utilization, cognitive radio concept has been proposed. This paper provides an overview of cognitive radio for opportunistic spectrum access and related research topics. Cognitive radio objective is to use inadequate and limited natural resources efficiently without causing excessive interference to the primary licensed users. Consequently, cognitive radio has to sense and understand its spectrum environment, identify temporarily vacant spectrum, transmit adaptively and learn from its behavior. A number of promising concepts for cognitive radio were briefly presented and discussed in this paper in the area of passive and active spectrum awareness, spectrum management and transmit power control.

## Keywords
Opportunistic Spectrum Access, Transmit Power Control, Spectrum Awareness, Spectrum Management, Cognitive Radio.

## Introduction
The wide growth of wireless communications leads to the scarcity of frequency spectra and available radio spectrum is a limited natural resource, being packed full day by day. Many of the pre-allocated frequency bands are paradoxically underutilized and hence the resources there are wasted. It finds that the allocated spectrum is underutilized for static allocation of the spectrum [3].
The unadventurous approach to spectrum management is not bendable. To operate, every wireless operator is assigned a sole license in a certain frequency band. It is difficult to find vacant bands to deploy new services and enhance existing ones. To overcome the situation, we need an improved utilization of the spectrum which will create opportunities for Dynamic Spectrum Access (DSA) [1]. A possible solution is the use of "Cognitive Radio System", it possesses the ability to sense and to be aware of its functioning condition and can regulate its operating parameters. This technique seems like a promising solution for the use of available spectrum on the frequency band efficiently. By analyzing, the Cognitive

radio adjusts to the environment conditions and makes use of this analysis for future assessments. There are mainly two tiers of users in the cognitive radio model. Primary Users (PU) are licensed users, which have the rights of priority in using certain stable frequency band for communications, Secondary Users (SU) are allowed to use the frequency spectra momentarily only if they do not interfere with the PU. So the ability of sensing an idle spectrum and the ability to temporarily utilize a spectrum without interfering with Primary Users are two essential components required for the success of cognitive radios [2].

This work presents short synopsis of cognitive radio systems and corresponding research area. Here we explain concept of spectrum holes for opportunistic spectrum access, present definition of cognitive radio and also explain its basic functions using cognitive cycle concept. Active and passive spectrum awareness as key techniques for identifying spectrum access opportunities is presented. Spectrum sensing algorithms for primary transmitter and receiver detection are investigated and explained. The paperpresent main functions of spectrum management and transmit power control for implementation in cognitive radio environment.

## COGNITIVE RADIO

In today's radio systems are not aware of their radio spectrum environment as they are designed to operate in a predefined frequency band using a specific spectrum access system. As discussed in the introduction, most of the time the spectrum is not efficiently utilized. The spectrum utilization can be improved significantly by allowing secondary users (unlicensed) to dynamically access spectrum holes which is temporally unoccupied by the primary user as shown in Figure A.

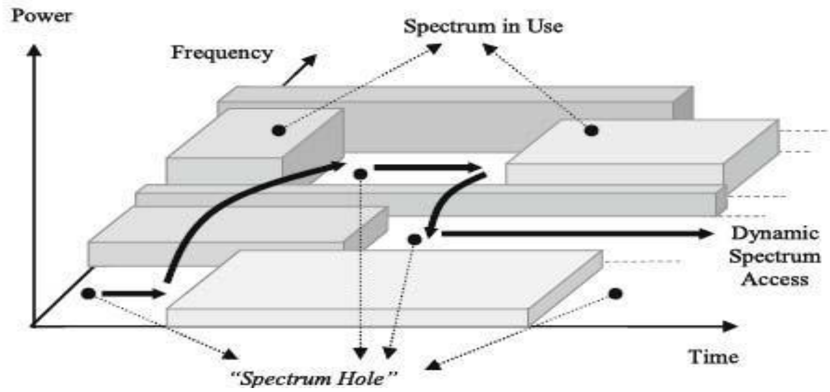


Figure A. Spectrum hole [5]

A white space (spectrum hole) is a band of frequencies assigned to a Primary User (PU), but at a particular time and specific geographic location, the band is not being utilized by that user [6]. White space idea can be further generalized as transmission opportunity in radio spectrum space. The spectrum space is occupied by radio signals which have angle of arrival, dimensions of location, frequency, time, energy and possibly others [7]. A radio built on cognitive radio concept have the ability to sense and understand its local radio spectrum environment, to identify white spaces in radio spectrum space, to make independent decisions about how it accesses spectrum and to adjust its transmissions consequently. This type of cognitive radio using dynamic spectrum access has the potential to appreciably improve spectrum efficiency utilization resulting in easier and flexible spectrum access for current and future wireless communication services.

A cognitive radio is assumed to be a fully re-configurable radio device that can "cognitively" adjust itself to the communications requirements of its user, to the radio frequency environment in which it is operating and to the different network and regulatory policies which apply to it [10]. Cognitive radio is an intelligent wireless communication system that is responsive of its surrounding and uses the methodology of understanding by building to learn from the environment and adjust its internal status to arithmetical variations in the incoming radio frequency motivation by making corresponding changes in certain operating parameters in real time, with two primary objectives i-e highly reliable communications whenever and whatever needed and efficient utilization of radio spectrum [6]. Completely capable cognitive radio is improbable to be achieved in the next two decades but some cognitive radio features will be slowly implemented in radio equipment in the future years.

To achieve these objectives, cognitive radio is required to modify its characteristics and to access radio spectrum without causing undue interference to the primary licensed users. Cycle of cognitive radio operation as secondary radio system is shown in Figure B. Major Steps of the cognitive cycle are spectrum sensing, spectrum decision, spectrum sharing and spectrum mobility [11].

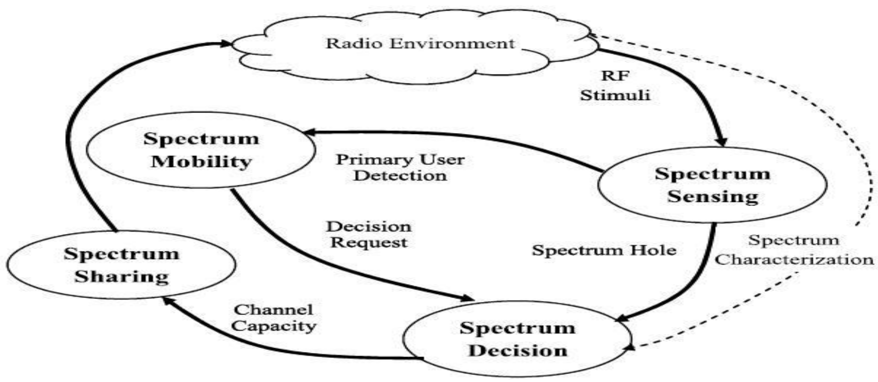


Figure B. Cycle of Cognitive Radio [11]

Spectrum sensing: It is active process in which cognitive monitors its radio environment and geographical surroundings to detect usage figures of Primary Users (PU) and Secondary Users (SU) tofind out possible white spaces. Sensing can be done by one cognitive radio and by multiple cognitive radio terminals exchanging information in a cooperative way which improves overall accuracy of the system.

Spectrum decision: Founded on spectrum sensing information cognitive radio selects when to start its proper working, operation, operating frequency and its matching technical constraints.

Spectrum sharing: Spectrum sharing cognitive radio networks allowed cognitive radio users to share the spectrum bands of the licensed-band users. However, the cognitive radio users have to restrict their transmit power so that the interference caused to the licensed-band users is kept below a certain threshold.

Spectrum mobility: Process by which a cognitive-radio user changes its frequency of operation. Cognitive-radio networks aim to use the spectrum in a dynamic manner by allowing radio terminals to operate in the best available frequency band, maintaining seamless communication requirements during transitions to better spectrum.

Cognitive radio is developing radio concept based on software defined radio, digital signal processing and artificial intelligence [12]. The primary objective of cognitive radio is to use natural resources efficiently including space, frequency, time, and transmitted energy by sensing the environment and adaptive transmission without causing excessive interference to the primary licensed users. The performance requirements for cognitive radio system are reliable white spaces, Primary User (PU) detection, accurate link assessment between nodes, fast and accurate frequency control and power control method that assures reliable communication between cognitive radio terminals and non-interference to Primary Users (PU).

## SPECTRUM AWARENESS

The most important features of the cognitive radio is its ability to acquire, measure, sense, learn and aware of the radio's operating environment in order to recognize spectrum space opportunities and efficiently use them for adaptive transmission. This assignment is very demanding since cognitive radios are in a way blind and they cannot see other radios. Their awareness of the outside world is based on information obtained from others or their own "hearing". Imagine that a blind man arrives at a crossing and tries to conclude weather the road is free or not to go based only on his hearing [14]. This functionality of cognitive radio is exercised through spectrum awareness. Spectrum awareness can be classified as passive and active awareness (or also called spectrum sensing) [5]. Figure C shows basic classification of spectrum awareness methodologies for cognitive radio. In the passive awareness radio spectrum information is received from outside world like from primary communications system, from server, from centralized database, or predefined policy set [14]. Considering this approach relevance of data in space and time is critical and additional communication channel is needed for acquiring information. While leading to simplified secondary transceivers, these methods require modifications to the primary system, additional data acquisition, data storage resources, data management system and additional network capacity. Usually, passive results in rather static secondary usage without optimally exploiting spectrum space opportunities. On the other hand active awareness is based on spectrum sensing which isperforming in cooperative and non-cooperative manner. Cooperative spectrum sensing significantly improves errors even with small number of non-correlated sensing units [17].

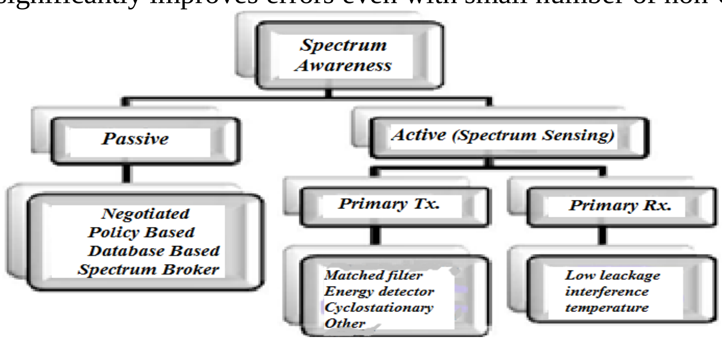


Figure C. Spectrum awareness classification

In active awareness secondary users actively sense the radio environment and adjust their transmissions based of the measurements. In cooperative situation local measurements will be combined and signaled to all secondary users before decisions about spectrum use are made. In non-cooperative model secondary users build their decisions independently based on the observations about the spectrum environment. The active awareness is more complex and hardware demanding but generally it results in improved Secondary Users (SU) spectrum usage statistics compared to spectrum usage based on passive awareness [14]. Cognitive radio systems may employ either in one or both forms of awareness.

Systems based on negotiated spectrum usesthe primary system announces Secondary Users (SU) about the allocated frequencies and the available spectrum opportunities using spectrum signals [16]. Negotiation is usually centralized and includes determination of geographical, temporal, technical, financial, service quality and interference constraints and conditions. In this approach the national regulatory agency identifies a licensed band of the radio spectrum where low or deterministic pattern of band is used [16]. The regulatory authorityallocates a set of policies that provide rules and constraints concerning how to use this radio spectrum for Secondary User (SU). Secondary devices repeatedly seek for updates of policies that are relevant for their regulatory domain and update their information bases. When the system is updated, Secondary Users (SU) adjusts their transmission parameters like frequency and power to meet predefined policies.

The regulatory authority or the primary operator maintains a database of frequency resources which includes location information and an estimate of the interference range of the Secondary User (SU). In licensed system frequencies used can be seen and checked from the table. Whenever a Secondary User (SU) needs to transmit it checks the table chooses an available band and reserves it to its use. Other Secondary Users (SU) can then see that this particular band is occupied by a Secondary User (SU) and can choose other resources for their own use. When a Primary User (PU) or Secondary User (SU) stops transmitting the associated band is released from the table and would be available to other users.

The spectrum broker approach server is used to enable coexistence of primary and secondary radios in a shared environment in a centralized fashion [14]. The centralized spectrum server attains information about surrounding and interference through local measurements from different terminals and then offer suggestions to the efficient spectrum use. Service providers and users of the networks do not a priori own any spectrum instead they obtain time bound rights from a regional spectrum broker to a part of the spectrum and configure it to offer the network service.

Commonly design constraint of cognitive radio is limiting cumulative interference to licensed primary users below a prescribed level determined by regulatory policy or primary spectrum user. As interference actually takes place at the receiver location active spectrum awareness should be focused on detecting the receiving activities of primary users. So do not assume cooperation between primary and secondary system primary receivers are much harder to detect than primary transmitters using active awareness techniques.

The authors in [19] proposed methods where primary receivers are detected by measuring local oscillator leakage power by the RF front end. Previously,this method in some countries was used for detection of TV viewers not paying for TV subscription. Major difficulty of this method is in short detection range and long detection time to achieve accuracy which involves building large network of passive sensors assisting Secondary Users (SU) in spectrum decision.

In the receiver centric method of active spectrum awareness is based on calculating interference power in the Secondary User (SU) surroundings and changing it to interfering temperature [6]. Interference temperature constraint is considered as sum of receiver noise floor level at the primary system service range plus interference cap determined as total positive variation of noise level as depicted inFigure D. Both of the temperatures determines interference temperature gap which can be additionally filled by cognitive radio system. It sets up accurate measure of allowed cumulative interference level that primary receiver could bear without reduction in service area. The interference gap can be used for short range secondary transmissions.

Another proposed method of active spectrum awareness is to change the problem of detecting primary receivers to detecting primary transmitters. In this approach matched filter detection, energy detection, cyclostationary feature detection and others (e.g. waveform based sensing, radio identification, multitaper spectral estimation) are popular methods [18].

Comparing to other detection methods matched filter detection [15] is optimum method for Primary User (PU) detection in stationary Gaussian noise channel since it maximizes received signal-to-noise ratio [5].

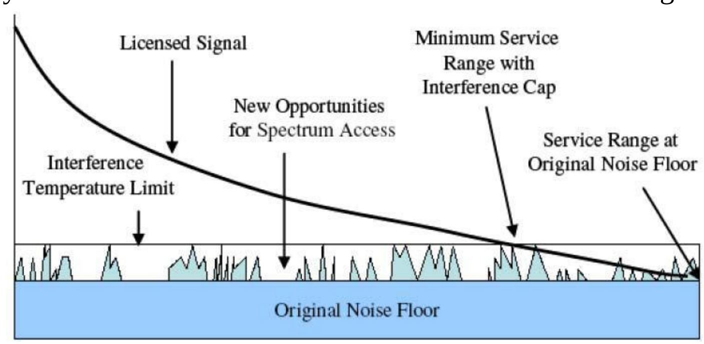


Figure D. Interference temperature constraint [5]

The advantage of this method is that it requires short time and low number of samples to achieve required level of false alarm or missed detection. Matched filter detection have high processing gain but sensing device have to achieve high coherence and demodulate Primary User (PU) signal. Thus the Secondary User (SU) needs knowledge of primary user signal at both PHSYICAL and MAC layers. This is possible since most of wireless networks have pilot, preambles, synchronization word or spreading codes that can be used for coherent detection. On the other hand matched filter detection requires dedicated receiver for every Primary User (PU) signal class and have large power consumption which makes it unworkable for larger implementation in spectrum awareness for cognitive radio.

Another important proposed method is energy detection method [5]. Energy detection method is the most common way of Primary User (PU) transmitter detection because of its low computational and implementation complexities. This method is widely used in radiometry, detecting receiver performs Non-coherent detection and do not need any knowledge of the Primary User (PU) signal or its statistics. The received signal energy is obtained by integrating received signal over observation time interval and receiver bandwidth. Processing gain of energy detector is proportional to FFT size and observation time. The signal is detected by comparing energy of the received signal to the threshold level. Threshold level depends on the noise floor and required level of false alarm and is highly susceptible to uncertainty in noise power or in-band interference. Energy detector cannot differentiate between primary signals, noise or interference and has poor performance under low signal-to-noise ratio. Energy detection method is not appropriate for detecting spread spectrum signals for which more sophisticated signal processing algorithms need to be used.

Cyclostationary detection method [15] is based on the inherent redundancy in the Primary User (PU) transmitted signals. Modulated signals of the modern communication systems are associated with sine wave carriers, pulse trains, repeated digital spreading and frequency hopping sequences. Signal could be modeled as a cyclostationary random process, due to built-in periodicity in the signal and its statistics. Characteristic features of cyclostationary signals are that they exhibit correlation between widely separated spectral components. Spectral cyclic correlation function is used for detecting Primary Users (PU) since modulated signal have nonzero correlation components. Advantage of this detector is that it can differentiate wanted signal from the noise because modulated signals are cyclostationary with spectral correlation and noise is in wide-sense stationary process with no correlation. Primary User (PU) transmissions can be detected using cyclostationary detection even with negative signal-to-noise ratio. The disadvantage of this method is that it is computationally complex and requires significantly long observation time.

Active and passive spectrum awareness techniques are used for obtaining information about radio spectrum uses. Several methods of spectrum awareness can be combined in order to improve spectrum decision accuracy. Radio spectrum statistics based on historical sensing could also provide useful insight for spectrum awareness. Normally, energy detection methodology is regularly used because of its low complexity but it has major disadvantages. Match filtering methodology is much more accurate, but it is most complex since detailed information about primary transmission is necessary. Information about past and current spectrum use offers foundation for opportunistic spectrum space access in cognitive radio. The functions of spectrum management in cognitive radio system are to access, assign and use radio spectrum efficiently without causing unnecessary interference to Primary Users (PU).

## SPECTRUM MANAGEMENT AND TRANSMITTER POWER CONTROL

The active coexistence of Primary User (PU) and Secondary Users (SU) in space, time domain and frequency domain forcedistinctivedispute to the spectrum management in cognitive radio systems. Spectrum decision, spectrum sharing and spectrum mobility are the basic spectrum management functions [11]. Spectrum access models can be classified as exclusive use and shared use models [20] as shown in Figure E.

In conventional radio systems command and control model and long-term exclusive use are traditional spectrum access models are used [21]. Dynamic exclusive model is that radio spectrum which is used completely by one system in determines white spaces. To improve spectrum efficiency, some level of elasticity is introduced. Under some defined rules, the cognitive users access the radio spectrum at different points in time. Flexibility helps licenses to put spectrum to its most valuable use with the most effective technology, without waiting for a regulator's permission. Two types of approaches have been proposed under this model spectrum property rights and exclusive dynamic spectrum allocation [22].
Primary Users (PU) having spectrum property rights can have various levels of flexibility. They can use assigned radio spectrum however they wish, or they could be restricted to specific radio service

andtechnology. License is assigned for temporary basis with long duration and for permanent usage. Using spectrum property right licensee of spectrum can trade, lease and borrow parts of spectrum on secondary spectrum markets to cognitive radio user. Economy and market forces will therefore play an important role in driving toward the most profitable and efficient use of this limited resources.

The other approach, exclusive dynamic spectrum allocation aims to improve spectrum efficiency exploiting the spatial and temporal traffic statistics of different services. Based on observed traffic statistics, spectrum is shared between different services. In a given region and at the given time, spectrum is assigned to services on exclusive use, but this allocation varies at a much faster scale than the static policy. Dynamic spectrum allocation can take advantage of daily user's migration from residential to business areas, or day and night variations of usage statistics. Moreover, governmental and emergency applications have exclusive access to large portions of radio spectrum which are rarely used. Under dynamic spectrum allocation model the radio spectrum can also be for some commercial application.

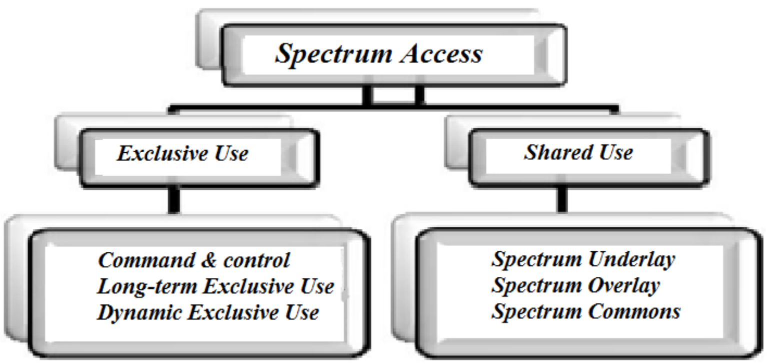


Figure E. Spectrum access models

If interference constraint is satisfying inshared use spectrum access model [21],the radio spectrum can be simultaneously used by a Primary User (PU) and a Secondary User (SU). Unlicensed users can opportunistically access the radio spectrum if it is not occupied or fully used by Primary Users (PU). The licensed spectrum is consequently opened to Secondary Users (SU), while limiting the interference observed by Primary Users (PU). Interference constraints for Secondary Users (SU) have to be defined carefully in order to allow Primary Users (PU) to operate without noticeable reduction of service quality.

In underlay or interference avoidance model [20] allows concurrent transmission of primary and Secondary Users (SU) in ultra wideband fashion. The transmit power of the Secondary User (SU) is limited so that the generated interference is below the noise floor for the Primary User (PU). Due to power constraints systems using underlay model can be used only for short-range communication. By spreading transmitted power over a wide frequency band, Secondary Users (SU) can achieve high data rates on short distances. The Primary User (PU) receives an exclusive right to spectrum access in spectrum overlay model.

If the spectrum is not utilized at a particular time or frequency, it can be opportunistically accessed by Secondary User (SU). Cognitive radio opportunistically communicates in non-intrusive manner over the white spaces. Spectrum commons mode employs open sharing among peer users as the basis for managing radio spectrum. Spectrum commons model [20,21] requires radio spectrum sharing without priority allocation to service or class of users. In a shared radio spectrum band devices might cooperate or merely co-exist. When devices cooperatively share radio spectrum band, they have to use common inter-networking protocol and communicate with each other. Cooperative approach is more technologically demanding but most of the possible time and spectrum collisions can be avoided.

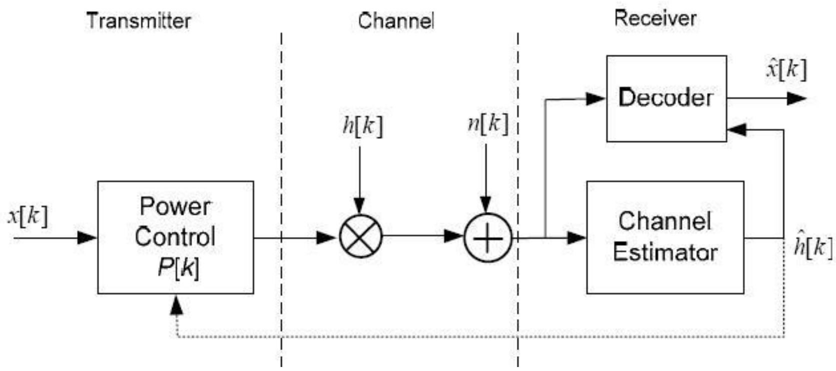


Figure F. System model for transmitter power control [14]

While satisfying quality and capacity goals transmitter power control in cognitive radio network assures interference free operation. In figure F,system model for transmitter power control is shown. Objective function of the transmit power control can be focused on maximum capacity of the link, maximum overall network capacity and transmission at the minimum power level to maintain link. Transmitter power level along with the attenuation of channel determines the quality of the received signal, the range of the transmission and the interference level it creates to the other receivers in the network. In recent years, studies on Transmit Power Control (TPC) are progressing in order to investigate different transmit power control strategies for opportunistic radio spectrum access systems [22]. Presented transmit power control strategies differ depending on settings of primary goals for power control, presumptions about available input data and on methodology used for transmit power control parameter determination. In [22], opportunistic transmit power control is presented which enables cognitive user to maximize its transmission rate i.e. power, while guaranteeing Primary User (PU) outage probability. The authors in [23] proposed fuzzy logic transmit power control scheme which dynamically adjust transmit power relating to Secondary User (SU) interference observed at Primary User (PU), distance between primary and secondary user and received power difference at the secondary user base station shown in figure G. To avoid interference at primary user, exchange of sensing information between users is required. In [24], authors propose distributed cognitive network access scheme with the aim of providing best quality of service with respect of combination of radio link and core network performance. Fuzzy logic decision has been used to choose the most suitable access opportunity even in multi-technology scenarios. A power control approach based on spectrum sensing side information in order to mitigate interference to the primary user is presented in [25]. Cognitive radio transmit power is calculated in three step procedure using missing probability of energy detection dependence on distance between primary and secondary user. In [26], the authors investigate the optimal power control with and without interference temperature constraints based on observed Shannon capacity. The optimal power control in cognitive radio network is modeled as a concave minimization problem.

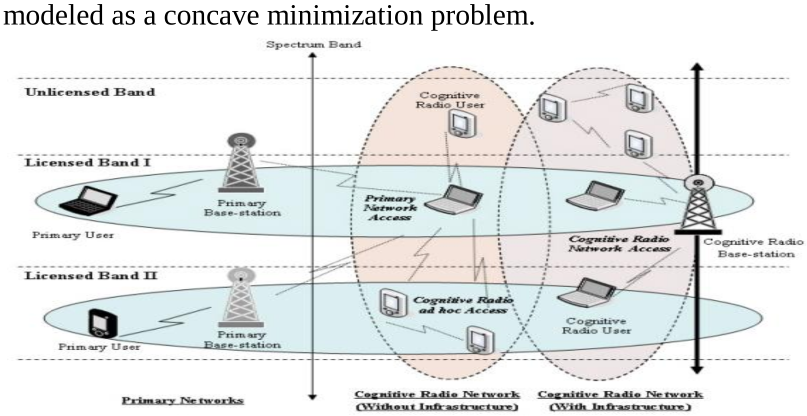


Figure G. Secondary Base Station

Basic spectrum management functions aiming at implementing efficient use of radio spectrum are spectrum access and transmit power control. Different methods of exclusive and dynamic spectrum access are investigated in the paper. The attention is given to spectrum overlay model of shared use dynamic spectrum access since it is no need to make changes to primary legacy systems and therefore most appropriate for cognitive radio systems. Transmit power control function is also essential for further improvements in cognitive radio. Research have been focused on transmit power control techniques which focuses on obtaining self goal of cognitive radio like maximum secondary link data while satisfying constraints of non-interference.

**RESEARCH CHALLENGES**

The developments of cognitive radio system normally face to many research challenges like:

- Detecting interference at primary receiver; Goal of cognitive radio is to protect primary system from interference, till the time it is not feasible method of detecting influence of cognitive radio at primary receiver because of its passive nature.
- Reliable & Speedy detection;Complete cognitive cycle of cognitive radio is happening in real time, therefore, it is essential to develop reliable and fast methods of spectrum awareness.
- Spread spectrum detection; Primary use of using spread spectrum is difficult to detect as the power of the primary use is distributed over a wide frequency range, possibly hidden in the noise.
- Hidden node problem; a threat to detect the hidden node problem while working in primary is always there due to possible shadowing effect or multipath fading in propagation between primary transmitter and sensing receiver.
- Learned and intelligent; appropriate models of artificial intelligence, bio inspired intelligence and machine learning methods have to be embedded in cognitive radio in order to fulfill its demanding tasks.
- Dual multi environment; most of cognitive radio will have to autonomously work in multi-service, multi-technology and multi user environment, it remains to show how cognitive radio can work and adjust in this challenging environment without causing chaos, disorder and anarchy.
- Vertical and horizontal sharing of radio spectrum; cognitive radio has to protect the operation of primary licensed radio services (vertical sharing) and also to overcome the problem of co-existence with other secondary use devices (cognitive devices and others).
- Spectrum space opportunities; cognitive radio is primarily focusing on efficient frequency, but to achieve efficient usage of natural resources, all dimensions of radio spectrum space as a theoretical hyperspace have to be used efficiently.
- Spectrum mobility; cognitive radio have to vacate spectrum when primary user begins to transmit, therefore cognitive radio have to switch its operating frequency from one spectrum hole to another while preferably uninteresting data transmission.
- Transmission power control; to find right balance between cognitive radio self-goal of achieving maximum data rate and altruistic network or community goal leaving enough opportunities for other secondary devices.
- Hardware requirements; cognitive radio must be capable of spectrum sensing and operating over wide radio spectrum range, follow many radio technologies and different modulation schemes, which causes various hardware challenges.

**6. SUMMERY &CONCLSION**

Radio system based on cognitive radio technology is a challenging and promising concept, leading to new directions in developments of wireless communications and leap progress in radio spectrum usage efficiency. 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. To look in to 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.

However, cognitive radio is still in its infancy. Development of cognitive radio systems are cross related and dependent to developments in many different technical and non-technical areas like: software defined radio, digital signal processing, artificial intelligence and machine learning, but also bio-inspired intelligence, social group behavior, economical studies, etc. Emergence of full cognitive radio capable radio system is still years, even decades far away from practical realization. In the present scenario, the implementation of cognitive radio is a good gesture. Even if only thirty percent of predicted cognitive radio system functionalities will be realized in radio devices in the forthcoming years, this would bring significant advances to future wireless communications systems.

In this paper, we have presented motivation for developments on opportunistic spectrum access, an overview of cognitive radio systems and major technical and research issues in cognitive radio.We have also presented different proposed methods and research challenges in this article. We hope that this paper will provide a glance of the technical challenges and exciting research activities in the cognitive radio systems.

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