Survey on Spectrum Sharing Techniques in Cognitive Radio Networks

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Abstract- **Cognitive radio is becoming one of the trendyresearch area due to increased demand for radio spectrum for wireless communication. Two stages of work with which we can overview the whole process of cognitive radio technology is spectrum sensing and resource allocation. To perform these the person should be aware of how to share the spectrum between licensed and unlicensed user. So in this paper our main goal is to review all the spectrum sharing methods with which licensed user (primary user) and unlicensed user (secondary user) are going to share the spectrum.**

***Index Terms* – primary user, secondary user, underlay, outerlay, licensed user and unlicensed user.**

I. INTRODUCTION

Communication is the process of transmitting information from transmitter to receiver. It can be broadly classified into wired and wireless communication. In wired communication normally copper wires, twisted pair cables, coaxial cables and optical fiber cables are used. In wireless communication air is the media to transfer the data among them. Wireless communication is most advantageous and there are many reasons to switch to wireless communication. Cisco has listed many important notable points to switch from wired towireless communication [1].

Wireless communication mainly needs transmitter, receiver and channel (air). And the most important need for wireless communication is wireless spectrum, wireless spectrum is the collection of electromagnetic radiation and frequency bands. Each country has their own wireless spectra that ranges from 3 to 300 GHz. International communication union divides theworld into 3 different regions as shown in Figure 1 for convenience of spectrum allocation [2]. This radio spectrum is used for TV broadcasting, mobile stations, amateur radio, marine communication, air traffic control and navigation system etc,. as shown in Figure 2 [3]. Allocation of spectrum in India is done by department of telecommunication under ministry of communication [4] and ITU will allocate all over the world.

According to cisco VNI GLOBAL survey, global data trafficwill increase upto 11.2 EB/month in 2017 [1]. And accordingto European parliament prediction, the global mobile data traffic will increase to more than 10 times between 2014 to 2019 [5]. Thus need for spectrum is continuously increasing but our spectrum is finite physical resource, the graph of spectrum need vs.demand according to research statistics released by rysavy research is as shown in the Figure 3 [6] forthis continuouslyincreasing demand spectrum allocation and spectrum management has to be done more effectively.Radio spectrum management is a complex activity because it involves the process of taking decision in continuously changing environment. In order to meet this growing demand concept of spectrum sharing started. This spectrum band can be shared in many ways, one way is that this spectrum willhave some range of frequencies named as unlicensed band and that band can be used by any device. Another way is using the "whitespace"(unused frequency between two used frequency iscalled white space or spectrum hole) in between the used frequencies as shown in Figure 4 [7]. To dynamically sense this white space or spectrum hole"cognitive radio" is used.

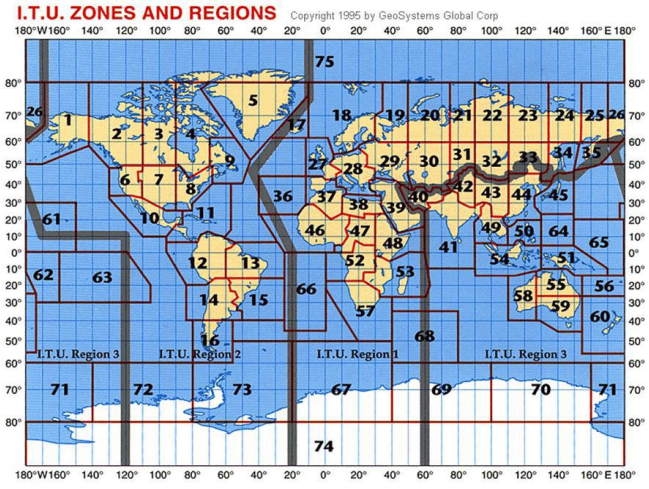

Figure 1. I.T.U. Zones and Regions

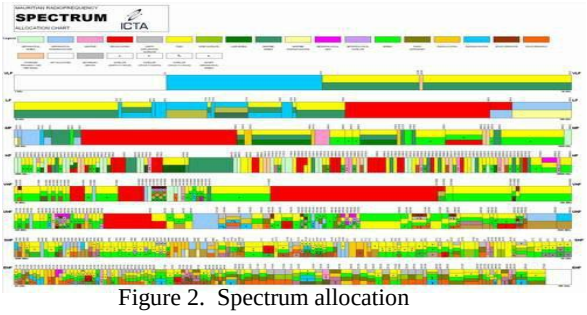

Figure 2. Spectrum allocation

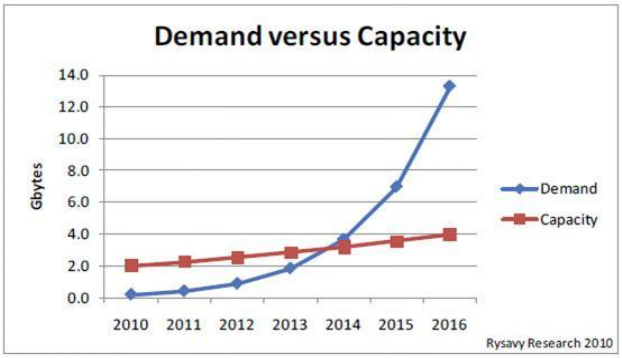

Figure 3. Spectrum demand and capacity

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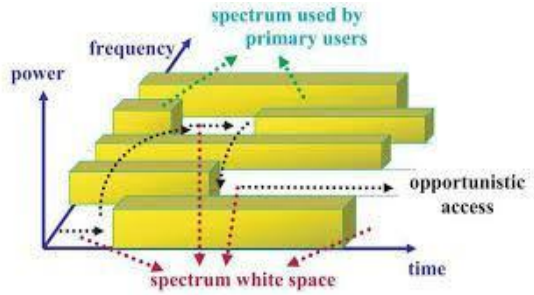


Figure 4. Spectrum holes and opportunistic access.

A) What is cognitive radio?:

"Cognitive radio is the device which is configured to continuously sense the unused frequency around it's deployed environment". Cognitive radio concept encashes the "white space" frequencies,which means that it senses the unused bands and allocates it to unlicensed users for certain duration of time and it will be dynamically changing according to spectrum usage around it's environment. So cognitive radio deals with allocation of unused frequency between licensed and unlicensed user.

Licensed user (primary user) means user/device who has higher priority and legal rights to use specific band of spectrum. Whereas unlicensed user (secondary user) is the user/device who has lower priority to use the same band of spectrum which is used by primary user, by causing tolerable range of interference. ITU, FCC, CEPT are those standard organizations which govern these allocation and license of using the spectrum.

B) Conceptual division of cognitive radio functionality:

The overall concept of cognitive radio can be divided into 3 stages, they are spectrum sensing, resource allocation and quality of service (QOS).

1) Spectrum Sensing:

It is the process of finding the unused frequency around its environment where cognitive radio is deployed. The quality of spectrum sensing is measured by probability of detection (pd) or probability of false alarm (pf).

2) Resource Allocation:

Resource allocation is a plan for using the unused frequency in an efficient way. It is a process of assigning and managing available frequency in the spectrum.

3) Quality of Service:

It is the overall performance of network service, especially it is the performance seen by the users of that network. In assessing the quality of service of a network bit rate, throughput, availability, jitter etc. are the points to be considered.

C) Regulating radio spectrum:

For efficient utilization of the entire radio spectrum (3 KHz – 300 GHz), it needs to be regulated by some central authority so that there are no harmful clashes between radios for particular spectrum range, thus maintaining harmony between the radio systems. This also leads to the removal of under-utilization of the spectrum. Thus this gives technical, economical and social advantages and hence regulation is very important.

Regulation mainly includes of dividing the spectrum into bands based on technical reasons and demand profiles, and distributing rights of access to the particular bands to some specific users called licensed users and/or also to unlicensed users. And also defines access limits to the granted spectrum bands .This regulation is carried out by government regulatory bodies.

Four ways are adopted for the purpose of radio spectrum regulation.

- Licensed spectrum for exclusive usage (Exclusive use model)

  The licensee has the exclusive usage rights to his allocated spectrum bands with no other contending users, and is allocated and monitored by the regulator body.

  Ex. UMTS (Universal Mobile Telecommunication Systems)
- Shared usageof licensed spectrum(command and control model)

  Here particular band is shared by radios of specific technology and this is not same as the secondary usage of licensed spectrum by a cognitive radio.

  Ex. DECT (Digital Enhanced Cordless Telecommunication)
- Unlicensed spectrum (commons model or open access)

  Any radio system can utilize this spectrum, but should confirm w.r.t technical standards established by the regulatory body.Ex.UnlicensedNational Information Infrastructure (U-NII) bands
- Open spectrum

  Any spectrum band can be used by anybody, under a minimum set of rules from technicalstandards or etiquettes that are required for sharing spectrum.

"Regulators" are the institutions, national and international, that licenses particular spectrum for exclusive usage or for share access, or declaring a part of spectrum as unlicensed or as open access. On global scale, all the frequency allocations among all parts of the world is harmonized by ITU-R, a radio

communication wing of International Telecommunication Union. And in Europe, frequency allocation is organized by Electronic communicationsCommittee (ECC) of the European Conference of Post and Telecommunications Administrations (CEPT), in United Kingdom its the Office of Communications (Ofcom), in Japan its Ministry of Internal Affairs and Communications (MIC), by Ministry ofInformation Industry (MII) in china and by FCC &National Telecommunications and Information Administration (NTIA) in USA.

The spectrum regulation should achieve following key objectives

- All radio should get sufficient Quality-of-Service (QoS)
- Spectrum access should not be blocked for ant radio, and also not be blocked from transmitting for long durations.
- These should not be an hindrance for new innovations in the markets(wireless comm.) that are economically successful and are quickly changing
- The spectrum shouldn't be underutilized, and should bw used to its fullest extent, including spatial reuse of spectrum.
- Spectrum should be used in a dynamically adaptive way, takingthe local communication environment including spectrum usage policies into account
- Due to the standards established by the regulatory bodies, the commercial radio services' costs shouldn't increase substantially.

II. SPECTRUM SHARING METHODS

Spectrum sharing is the technique of accessing the same frequency by number of users. If we consider sharing of spectrum in frequency domain point of view, FDMA and OFDMA methods are noteworthy and with respect to time domain point of view TDMA is major method and CDMA is the combination of both. But this paper concentrate on the spectrum sharing methods in "accessibility rights" point of view. On the basis of rights of accessibility radio spectrum has been divided as shown below:

- Sharing of unlicensed spectrum(horizontal sharing)
- Sharing of licensed spectrum.
  - Multiple access sharing
  - Coordination(horizontal sharing)
  - Secondary spectrum sharing access(vertical sharing)
    - Real time access: Negotiated(spectrum hole and underlay access)
    - Opportunistic(spectrum hole and underlay access)
    - Non real time access(based on agreements)

A)Horizontal sharing and Vertical sharing:

Cognitive radios will have to share spectrum either (i) with unlicensed radio systems, or(ii) with licensed radio systems that are typically designed for exclusive use of otherwiseunused spectrum. These two sharing techniques are the basic way of sharing, which can be applicable for both licensed and unlicensed spectrum. If all users have equal rights to use the certain band of frequency such a scenario needs the use of horizontal sharing methods (sharing among the radios of equal regulatory status). If sharing between primary user and secondary user is based on priority in such a scenario vertical sharing method used(sharing of spectrum with primary user).

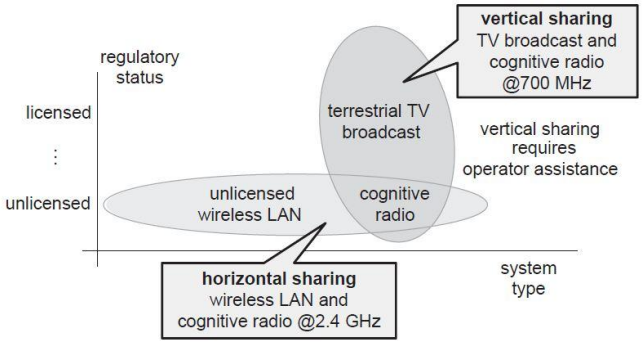


Figure 5. Regulatory status define horizontal and vertical sharing

B) Sharing of unlicensed spectrum:

Unlicensed frequency bands are the part of huge spectrum bands, these are used by the users who are ready to operate by accepting the rules applied by the regulatory bodies regarding interference to the licensed user by unlicensed user. 2.4 GHz is most commonly used unlicensed band, many devices with in the range of Bluetooth (IEEE 802.11) are using this unlicensed band. And another bands are 5ghz called UNNI band, this band is used by 802.11a(European hyperlan). As these Bluetooth and hyperlan are not licensed bands, some different devices like microwave ovens are also operating in this band that causes the interference.

C) Advantages of unlicensed bands:

- It makes a way to develop innovative technologies like Bluetooth to operate in unlicensed band.
- Cost for users who are using that band will be consider-ably reduced as the network cost reduced.
- Advance radio frequency deployment planning is needed.

These Bluetooth and Wi-Fi are considered as low power transmission applications so rules regarding their interference with licensed bands are discussed in part15 of FCC rules. According to FCC rules, operator or devices using this low power transmission range need not to have license to use since the transmitter comes under part 15 of FCCrules. It's because that transmitter itself has FCC authorization before it comes to market [8].

D) Sharing of licensed spectrum:

In this technique if we want to share the spectrum among the number of equal priority devices, the spectrum server will allocate the bandwidth to each device. This spectrum is allocated based on the request of each device and it is also based on the traffic load predictions. Traffic load predictions are predicted based on previous history of traffic period and duration of allocated spectrum utilizations. This accurate traffic prediction is achieved by various estimation methods like autoregressive (AR), moving average (MA) or autoregressive moving range (ARMA) [9].

If traffic load of specific device represented by m(k) where 'k' is the sampling time of traffic load, then k2-k1 represents the resource allocation period for all k1, k2 belongs to k. That duration of period k2-k1 is called resource allocation and is represented as 'τ'. The traffic prediction is done by auto regressive, movingaverage, and autoregressive moving average methods.

In autoregressive estimation technique yule walker equations [10] are used to derive mathematical equation for traffic

prediction. For autoregressive technique,

$$y(t) + p_1 y(t-1) + \ldots + p_n\, y(t-N) = b_0\, i(t) \qquad (1)$$

where y(t) = output of the multiple phase system, i(t) = white noise process input, b_0 = coefficients calculated by yulewalker equations.

Autoregressive moving average model is the combination of both auto regressive and moving average model discussed in paper. The effective utilization of spectrum is possible when all the participating devices in network are highly uncorrelated.

E) Secondary spectrum access:

Secondary spectrum access is the major approach for the best utilization of underutilized spectrum. There are two categories of secondary spectrum access they are real time secondary spectrum access and non-real time secondary spectrum access. Almost all the vertical sharing is used in SSA (secondary spectrum access).

1) Non-real time spectrum sharing access:

Sometimes the licensed user of certain spectrum band may be willing to allow secondary user to access that band for specific duration of time. Spectrum sharing in such a scenario is called non-real time SSA.

Example: if a spectrum is purchased by any educational institutions generally they can use only during day time (9am to 5pm). If the organization lets other users to use that spectrum after 5pm for rent such a scenario becomes non real time SSA. non real-time SSA is person to person agreement(which means an agreement between licensed purchaser and unlicensed user) therefore that approach is based on proper agreements between licensed and unlicensed users.

2) Real time spectrum sharing access:

In real time spectrum sharing access technology a cognitive radio device is continuously searching the spectrum hole to allow secondary user this with tolerable interference. Based on co existence of primary user and secondary user two major approaches of spectrum accessing are formulated, they are overlay approach and underlay approach.

In overlay approach secondary user is allowed to access the band when primary is not using that band. But in underlay approach secondary user is allowed to use the licensed band of primary user upto certain threshold interference. In real time SSA negotiated access and opportunistic access are the two approaches through which spectrum can be shared.

3) Negotiated access:

This negotiated access concept has been started when interaction between primary user and secondary user exists. Universal signaling channel for cognitive purpose is used to access the licensed channel – this is the CPC (cognitive pilot channel). The major task of CPC is to achieve overlay SSA by identifying the availability of spectrum opportunities in licensed band. To get the information about spectrum opportunities primary system has to broadcast information such as transmission power and usage time interval about idle resource on CPC, which helps secondary user to seize the chance to transmit on availability of resource. In some different scenarios the primary user system will broadcast information about busy channel so as to prevent interference of secondary user to primary user for specific time and location. Identification of idle band through CPC may not give complete protection to primary users from interference of secondary user.

In overlay approach primary user will send the information about transmission power level, user time interval etc.. On the basis of that secondary user will get idle band to transmit the data so this overlay approach is transmitter centric. But in underlay approach interference effects on primary user has to be considered. So here, instead of identifying an idle channel for secondary user, the CR will determine which transmission power can be used in specific channel to mitigate interference to primary user.

4) Opportunistic access:

This opportunistic access concept will exist when there is no interaction between primary user and secondary user (ex: TV broad casting). In opportunistic access two forms of access are possible first one is identifying “spectrum hole” or “white spaces”, this approach is called overlay approach/overlay access.

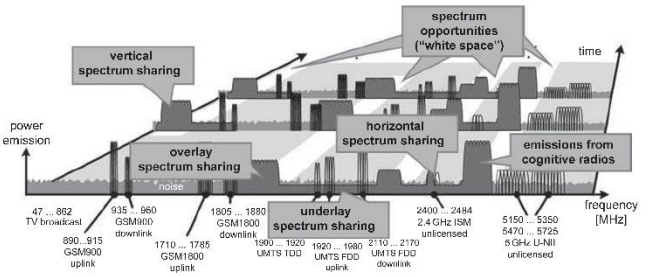
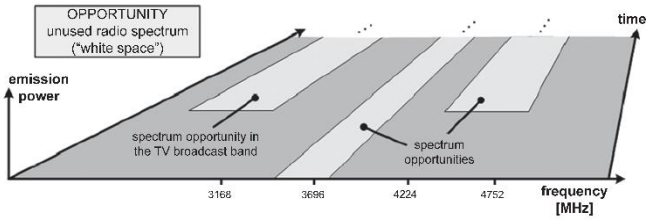
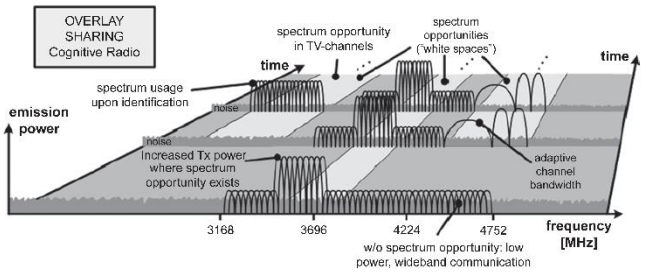


Figure 6.Opportunistic (secondary) spectrum usage



(a) Spectrum holes in radio spectrum



(b) Overlay access by cognitive radio

Figure 7.Spectrum opportunities used in overlay spectrum sharing

And another approach is “underlay approach access”. It is also called “gray spaces”. In this concept secondary user will confirm that its transmission its transmission will not cross the threshold limits of interference for primary user.

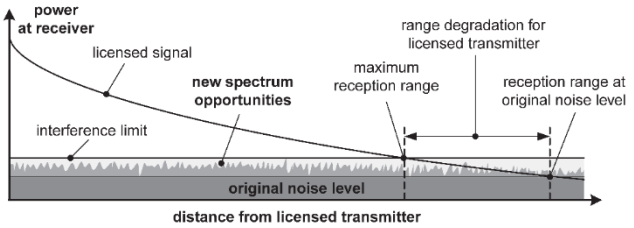


Figure 8.Underlay spectrum sharing based on the interference temperature

III. CHALLENGES OF SPECTRUM SHARING:

A) Lack of maturity:

As the overall cognitive radio is still under research many sharing concepts are still unproved. For the type of system which are considered for the experiments of spectrum sharing, the research activities on these experiments are still at the level of simulation. These simulations are to be followed by testing and then they are successfully deployed. The practical problems that may exist during deployment are not easily predictable. Presently both government and industry are introducing new architecture that can be used for best balance of spectrum sensing and databases, finally one architecture will be finalized for supervising all the activities of cognitive radio network sensing and sharing. Until this sharing technique matures, industry and government will be hesitant to invest abundant money in these unproven approaches.

B) Multiplicity of government system:

To share the spectrum among various fields, government need to analyze many factors related to interference and propagation of radio signals. Recently in 2013 four different working group with in CSMAC has been started for the initial evaluation of 1775 1780 MHz band to analyze law management, explosive disposal, satellite control [11]).

C) Propagation modeling complexities:

Propagation models are very important to determine the factor of frequency reused and interference point. Industries are using many different models for this purpose. They have not yet agreed for one type of model which is appropriate for each spectrum sharing scenarios.
Ex: Difference exist between Longley-Rice model and Hata models. In Longley rice model parameters like frequency effective related power, antenna Height, polarization, surface refractivity are considered. This model involves two parts, one for prediction of user or entity and another for point to point link forecasting [12]. In Hata model link distance, antenna effective height path loss are considered. Particular models have not yet developed for small cell that operate at low power. This uncertainty and unparticularity about which model could be used as standard is becoming one of the problem in modelling the complete process of the cognitive radio network.

D) Frequency management:

The FCC is planning to freely allocate all the channels inside the whole band. To per-form this all radios must be tuned to the whole band but as there is no front end filter to remove the interferences between cross user there is no interferences protection. Small signal blocking effect from adjacent channel may limit the performance. Low power levels and lack of synchronization will create burden on the SAS manager.

E) Unclear role of spectrum sensing:

Cognitive sensing means continuously monitoring the unused frequency around the environment where that device is deployed, that approach is called dynamic spectrum access. Pure sensing approaches are not reliable to protect deployed spectrum therefore sensing combined with database can provide more efficient system with more spectrum reuse. This sensing with database is the closed loop approach, it is more complex and require more planning and more hardware but sensing without the database is an open loop approach and they are simple but less efficient. So type of spectrum sensing play an important role in overall cognitive process therefore type of spectrum sensing method to be used should be very clear.

F) Database security:

Database management and maintaining privacy for primary user becoming major challenge due to malicious database corruption, and taking information related to primary user illegally from the database. Modification of database, the problem of impersonation of the database and maintaining the confidentiality for the primary user data are the major challenges in cognitive radio technology.

G) Sharing security:

Malicious attacks can create the problem in spectrum sensing and databases. Some of the government radio bands related to defense are strictly restricted from public use or interference from any other spectrum range related to commercial band. When spectrum sensing starts it may give information about all the nodes thus we get the data present in all the nodes which are involving in this process. This process occur continuously therefore if any unauthorized (rouge) device is present in that network it may leads to spectrum hijack.

IV. CONCLUSION

The cognitive radio technology is one of the major solution for the problem of continuously increasing demand for finite spectrum resource. We have described the basic idea of cognitive radio and need for it, and we discussed many sharing techniques based on the rights of accessibility point of view. We have classified the spectrum sharing techniques into licensed and unlicensed. Licensed spectrum can be shared with horizontal sharing concept. Traffic load estimation is the key parameter to decide the allocation of spectrum, this traffic load concept is described in this paper. Based on the coordination between primary user and secondary user, negotiated and opportunistic sharing techniques also exists and overview of those techniques are covered in this paper. Overlay and underlay approaches are also described which explains about the difference between idle band use and using licensed band with permissible interference. This paper describes all the overview of cognitive radio technology and description of all sharing techniques and their necessity. In this paper we have conceptually divided the overall functionality of cognitive radio technology into 3 parts. Finally we describe the present challenges of spectrum sharing in cognitive radio technology. In the whole paper our goal is to survey the all types of spectrum sharing methods in the rights of accessibility point of view so the whole paper focuses on sharing techniques.

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