Dynamic Spectrum Access for Cognitive Radio Networks

Priyangu Shaya Sarmah, J. Jayanthi

Abstract- **A radio in which the communication systems are conscious of their internal state and environment such as location and deployment of RF frequency spectrum at that location is known as cognitive radio.**

The usable radio spectrum is finite and is a precious resource, whereas with the increasing demand of wireless devices, the demand for access to it is becoming increasingly significant, and hence difficult to achieve. It has been known that the problems of spectrum underutilization and over utilization is not much because of the physical scarcity of frequencies, but mostly as a result of the spectrum management. Spectrum has been allocated in two different ways-First static, where the bands of the RF range are statically designated to the licensed users for a long period of time, second dynamic spectrum access, which deals with spectrum scarcity and helps in ensuring that the spectrum is efficiently utilized and no part of it is wasted. In this paper, the dynamic spectrum access for cognitive radio networks is performed to ensure efficient use of spectrum and hence helps in increasing system capacity. Matlab R2013a is used to perform the simulations and exhibit the dynamic spectrum access of a cognitive radio system.

Key words: Cognitive radio, Dynamic spectrum access, Spectrum management.

I. INTRODUCTION

Wireless communications technology has emerged to be an important aspect in the modern society.

Manuscript received June, 2015

Priyangu Shaya Sarmah, *Mtech, Digital electronics and communication systems, VTU, CPGS, Bangalore, Bangalore, India.*

Ms. J. Jayanthi, *Senior Principal Scientist, Joint Head, ALD division, CSIR, NAL, Bangalore.*

In 1895, a person named Guglielmo Marconi illustrated the wireless communications by taking use of electromagnetic waves. The wireless communications systems are designed based on the electromagnetic waves transmission which frequencies range between 3Hz and 300GHz. The electromagnetic spectrum, mainly its radio frequency portion (RF) portion is one of the world's most valued physical resources. The RF spectrum is so precious that its allocation is firmly regulated by world governments and even small portions of it can be sold for billions of dollars in spectrum auctions. This fact is strengthened by the multibillion prices for a 20MHZ frequency band at the European 3G spectrum auction Similarly in India's recent spectrum auctions 1MHZ of spectrum is sold for millions of rupees. As wireless devices are increasing, the demand for access to RF spectrum is also becoming increasingly crucial. The US Department of Defense claims that its spectral requirements are growing by 25% annually while at the same time the temporal and spatial use of the spectrum by its emitters is much less than 1% [2]. A survey by the Spectrum Policy Task Force (SPTF) of the Federal Communications Commission (FCC) has showed that in particular locations some frequency bands are heavily used by licensed systems whereas, at some times, there are many frequency bands which are largely unoccupied or partly occupied. The main factor responsible for inefficient use of the radio spectrum is the spectrum licensing scheme itself. Due to the current static spectrum licensing technique, the concept of spectrum holes arise, which are defined as the frequency bands which are although allocated to, but at sometimes and in some locations, are not utilized by the licensed users, and hence could be occupied by unlicensed users.

There are number of limitations in the spectrum access due to static licensing scheme, such as 1) fixed form of spectrum usage, 2) large amount of licensed users, 3)forbid spectrum access by unlicensed users,4) licensed for a bigger area. These limitations are being reduced by modifying the spectrum licensing scheme in order to improve the efficiency and utilization of the available spectrum.

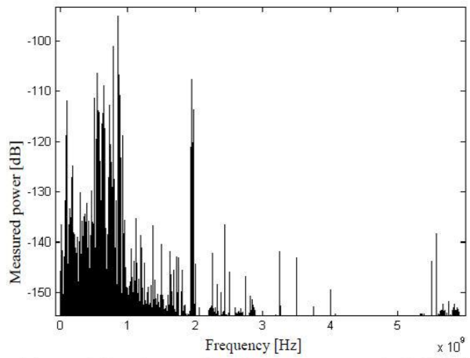

Fig 1: Spectrum utilization measurement at BWRC.

The basic idea in making the spectrum access more flexible is to allow the unlicensed users to access the radio spectrum under certain limitations. The underlying approach is known as dynamic spectrum access. A DSA network has two classes of users: primary and secondary. The primary users are those who are licensed to use a particular spectrum band and always have full access to that band whenever they need it. The secondary users are usually cognitive radios which can dynamically adjust their operating characteristics (such as waveform, power, etc.).Secondary users will sense the spectrum for available transmission opportunities, decide the presence of primary users, and try to use the spectrum in a way that little interferes with the activities of the primary users.

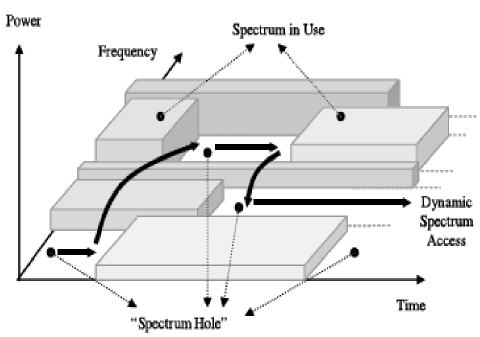

Fig 2: Spectrum holes.

II. COGNITIVE RADIO

The term cognitive radio was coined by Mitola in an article he wrote with Maguine in 1999[2]. Cognitive radio is based on the software defined radio, which is a reconfigurable wireless communication system in which the transmission parameters can be dynamically controlled. In easy terms, a cognitive radio can also be said as a very smart radio.

The term "Cognitive Radio" was defined in as follows:"Cognitive radio is a smart wireless communication system that is conscious of its ambient atmosphere. This cognitive radio will learn from the surroundings and adjust its inner states to statistical variations in the existing RF stimuli by adjusting the transmission parameters (e.g. frequency band, modulation mode, and transmit power) in real-time and [in an] on-line manner [1]."

A. Functions of cognitive radio

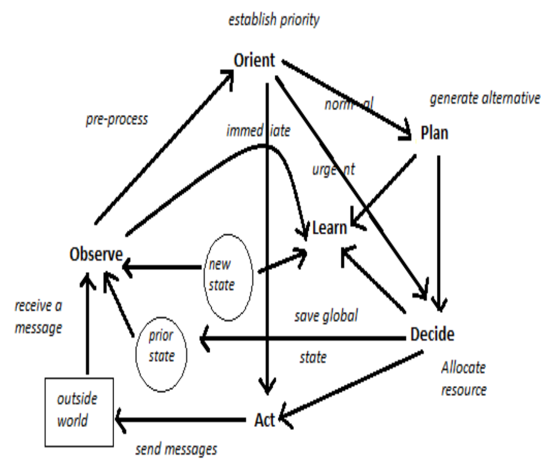

Fig 3: Cognitive cycle.

1. Spectrum sensing

The purpose of spectrum sensing is to discover the status of the spectrum and also the action of the licensed users by sensing the target frequency band periodically. Particularly, a cognitive radio transceiver will detect if there are spectrum holes and will find out the technique of accessing it without making interference with a licensed user's transmission. Spectrum sensing can be of two types: centralized or distributed.

2. Spectrum management

The information which is obtained from the spectrum sensing is used to plan and schedule the spectrum access by the users which do not have license to access the spectrum, i.e., the unlicensed users. Chief components of spectrum management are: spectrum access and spectrum analysis.

a) Spectrum analysis: In spectrum analysis, the data obtained from spectrum sensing is analyzed first to collect information about the spectrum holes and then a decision is made to access the spectrum, the decision is made by optimizing the system performance given the desired objectives and constraints.

b) Spectrum access: After making a decision on spectrum access which is based on spectrum analysis, the unlicensed users can access the spectrum holes. Spectrum access is mainly carried out on a cognitive access protocol (MAC) protocol, which is intended to avoid the collision arising between primary users and also with other secondary users.

3. Spectrum mobility

Spectrum mobility can be defined as a function which is associated to the altering of the operating frequency bands of cognitive radio users. If a licensed user starts to access a radio channel, currently being accessed by an unlicensed user, then the unlicensed user can switch to that spectrum band which lies idle. This phenomenon of changing in operating frequency band is known as spectrum handoff.

B. Cognitive radio architecture

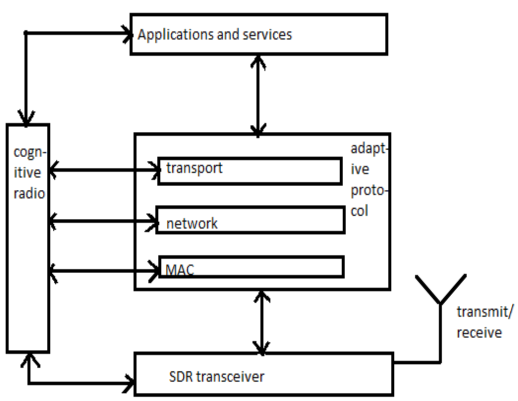

Fig 4: Cognitive radio protocol stack

In the above figure the protocol architecture of cognitive radio is depicted. The RF frontend is implemented in the physical layer based on software defined radio (SDR) transceiver. The adaptive protocols which lie in the application layers, transport, network, MAC should be conscious of the variations occurring in the cognitive radio environment. The adaptive protocols should also consider few important points such as the traffic activity of the primary users, the various transmission requirements of the secondary users etc. A cognitive radio control is used to link all modules which establish interfaces among the adaptive protocols, SDR receiver and wireless services and applications. This particular cognitive radio module make use of intelligent algorithms in order to process the calculated signal from the physical layer, gather data on various transmission requirements from the applications to organize the protocol parameters in various layers.

C. Objectives of cognitive radio

The two major objectives of the cognitive radio are as follows:

1) To attain extremely reliable and very proficient wireless communications.

2) To improve the utilization of the frequency spectrum [1].

D. Components of cognitive radio

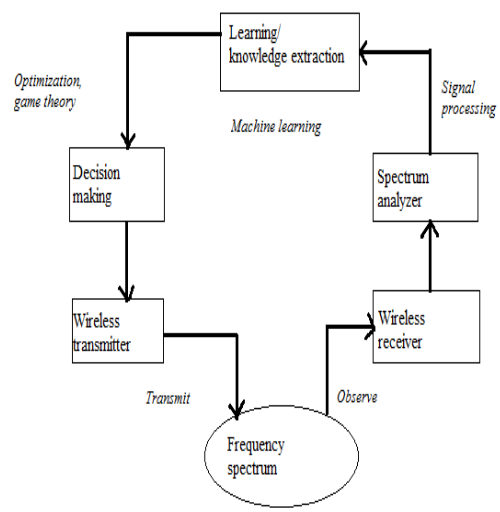

Fig 5: Components of cognitive radio.

The various components in a cognitive radio transceiver are depicted in the above figure. They are:

1. **Transmitter/receiver**: The major component is a SDR based wireless transceiver which performs data signal transmission and reception. Also, the wireless receiver also observes the activity on the spectrum sensing.

2. Spectrum analyzer: The spectrum analyzer analyzes the spectrum usage using measured signals. The spectrum analyzer should ensure that the unlicensed user while accessing the spectrum should not interfere with the transmission of a licensed user.

3. Learning/knowledge extraction: Learning and knowledge extraction make use of the information on spectrum usage to comprehend the behavior of licensed users.

4. Decision making: The decision on accessing the spectrum is made after the knowledge on the spectrum usage is available. The best possible decision depends on the ambient environment , i.e., it mainly depends on the cooperative behavior of the licensed users.

E. Dynamic spectrum access

Dynamic spectrum access mainly deals with the concept of spectrum sharing between licensed users and unlicensed users. The definition of dynamic spectrum access is [1]: It is a mechanism to adjust the spectrum resource practice in a near-real-time method to answer to the changing situations and goal (e.g. accessible channel and kind of applications), transformation of radio state (e.g. transmission mode, battery status, and location), and changes in environment and external constraints(e.g. radio propagation, operational policy). The term dynamic spectrum access simply means that no static assignments of frequencies are made [2].

F. Applications of cognitive radio

1. Cognitive radio is a key methodology for next generation wireless networks.

2. Cognitive radio also plays a crucial role in various eHealth services, to improve efficiency of the patient care and healthcare management.

3. Cognitive radios can also be used for military networks. With the help of cognitive radio, the parameters of wireless communication can be dynamically adapted based on the time, location and mission of the soldiers.

4. Cognitive radio concept is advantageous for public safety and emergency networks, which provide reliable and supple wireless communication.

5. Cognitive radio can be used for intelligent transportation systems, which will use various wireless access technologies to increase the efficiency and security of transportation by vehicles.

III. SPECTRUM DETECTION TECHNIQUES

Spectrum sensing deals with the detection of the presence of transmissions from licensed users. The various methods of spectrum sensing are:

A. Non-cooperative transmitter sensing

The non-cooperative method of spectrum sensing is used mainly by the unlicensed user to sense the transmitted signal from a licensed user with the help of local measurements and local observations.

The model for signal detection at time t can be described as [1],

$$x\ (t) = n\ (t),\ H_0 \quad (1)$$

$$x\ (t) = h*s\ (t) + n\ (t), H_1 \quad (2)$$

Here x(t) is signal received by an unlicensed user, s(t) is the signal transmitted by the licensed user, n(t) is the AWGN(additive white Gaussian noise),h is the gain of the channel. H_0 and $H_1$are the hypothesis of not having a signal from a licensed user and having a signal from a licensed user in the target frequency band respectively.

The three different methods in non-cooperative spectrum sensing discussed below:

1) Matched filter detection: Matched filter detection, also known as coherent detection, is attained by comparing a known signal with the unknown signal. Here the unknown signal is the signal which is received by the cognitive radio and the signal of the primary user is the known signal.. Since the matched filter has coherent nature, so detection can be faster. The advantage of matched filter detection is that since it is based on coherent detection, it can quickly reach to a decision whether a primary user is present or absent. Also this approach offers optimal performance and low cost.

2) Energy detection: Energy detector is the easiest way to analyze a received signal for the presence of primary users. Energy detection, known as non-coherent detection, is the finest technique for spectrum sensing if the information obtained from a licensed user is not available. In energy detection, the output signal obtained from a band pass filter is squared first and then integrated over the observation interval. A decision algorithm is used for comparison of the integrator output with a threshold [1] to decide if licensed user exists or not. Energy detector avoids the complex coherent receivers used by the matched filter and hence can be implemented using fast Fourier transform (FFT), which is used for translating a signal in time domain representation to frequency domain representation. The two drawbacks of energy detection technique are as follows: 1) it can be difficult to set the threshold level appropriately since the threshold depends mainly on the noise levels which vary considerably. One way to reduce the problem is to employ an adaptive threshold level but this can be again difficult. 2) It can only help in detecting the presence of the signal but it cannot distinguish the type of signal (e.g., signals from secondary users which share the same channel with the primary user), which can lead to high detection errors. Energy detection is advantageous since it offers low cost and no prior information is required. It remains attractive due to its simplicity, and so work is going on to design more robust energy detectors.

3) Cyclostationary feature detection: The modulated signals are generally cyclostationary in view of the fact that built in periodicity frequently takes place in training sequence, cyclic prefixes, etc. This periodicity is initiated in the transmitting signal of the primary users so that the receivers can utilize it for channel estimation, timing, etc. This periodicity can also be used for detecting the primary user. The underlying approach is based mainly on the autocorrelation function and also the power spectrum density. The advantage of cyclostationary feature detection is that it is the interference and stationary noise does not display spectral correlation because of which the cyclostationary detector performs well in a region of low-SNR.

B. Cooperative sensing

The case in which the unlicensed user's transmitter and receiver cannot detect the signal from a licensed user's transmitter as they are out of range is known as the hidden node problem. One way to solve the hidden node problem which occurs in non-cooperative transmitter sensing is to use cooperative spectrum sensing. In case of cooperative sensing, the spectrum sensing information obtained from numerous unlicensed users is exchanged with each other in order to detect the existence of licensed users. The architecture of cooperative spectrum sensing can be either distributed or centralized.

C. Interference based sensing

The FCC proposed the interference based sensing. Here, the sensing algorithm will first measure the noise or interference from all sources of signals at the licensed user's receiver. This information will be used by the unlicensed user for controlling the spectrum access without defying the interference temperature limit.

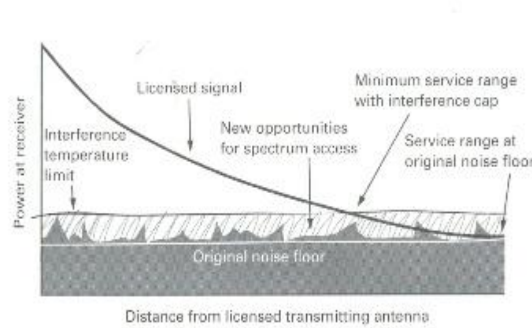

Fig 6: Interference temperature model [2].

IV. METHODOLOGY

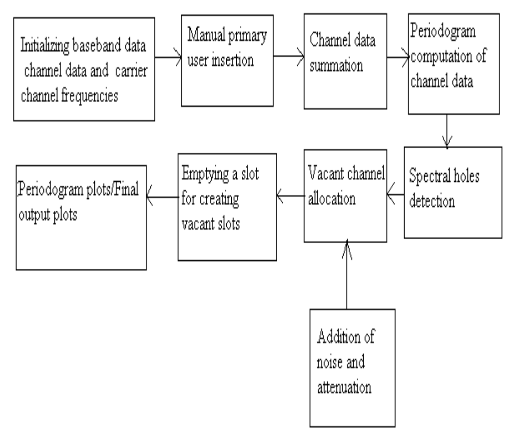

Fig 7: Methodology of performing dynamic spectrum access by manually inserting the primary users.

- **Initialization:** Initialization of 6 carrier frequency bands for users is done and also the sampling frequency (which should be greater than or equal to maximum of the carrier frequency) is initialized. In the starting, all the channels are assumed to be empty.
- **Manual primary user insertion**: Baseband signal is generated with t samples according to the equation x= cos (2*pi*f_m*t).After the baseband signal generation the user can manually insert the primary users. If the user wants to insert the primary user in the 1st frequency slot then the amplitude modulation of the baseband signal with

channel carrier frequency will be performed and this will repeat for the next five frequency slots.

- **Channel data summation**: After manual insertion of primary user is done, addition of all channel signals is performed for Periodogram computation.
- **Periodogram computation of channel data:** The Periodogram estimator is used to estimate the power spectral density of a signal.
- **Spectral holes detection:** Spectral holes are those frequency bands which are not utilized by primary users in some locations and hence can be used by the secondary users. The leftover unutilized frequency bands are detected and can be accessed by the secondary users.
- **Vacant slot allocation**: The spectral holes can be filled by the secondary users. The secondary user will first sense the spectrum and if some vacant slots are there, it will be filled by the secondary users but it will not interfere with the activities of the primary users. The estimated power spectral density is compared with the threshold power level and if the estimated PSD is greater than the threshold power level then primary user is present else primary user is absent.
- **Emptying a slot**: If all the slots are engaged then the users can be asked to vacate a particular slot based on requirements.
- **Addition of noise**: Additive white Gaussian noise (AWGN) noise can be added to make the simulation more realistic.
- **Attenuation**: Percentage of attenuation is incorporated to visualize the signal strength of the output plots.

V. RESULTS

The cognitive radio system will search for the spectrum hole where the primary user is absent and is find out by the energy detection method. The moment it finds the spectrum hole, immediately it assigns to the Secondary User (SU) and in case Primary User (PU) wants to use the slot, Secondary User immediately has to vacate it.

Initialization of six channels with carrier frequencies such as 1MHz, 2MHz, 3MHz, 4MHz, 5MHz and 6MHz respectively is done. And the sampling frequency is kept as 14MHz following Nyquist rule. By the use of energy detection method, Power Spectrum Density (PSD) of the signal is calculated first and compared with the predefined threshold value to find out whether primary user is present or not.

In this paper it is assumed that in the 6^{th}, 5^{th} and 1st frequency slots, primary users are present and 4^{th}, 3^{rd} and 2^{nd} are spectral holes.

The various simulation results obtained are as follows:

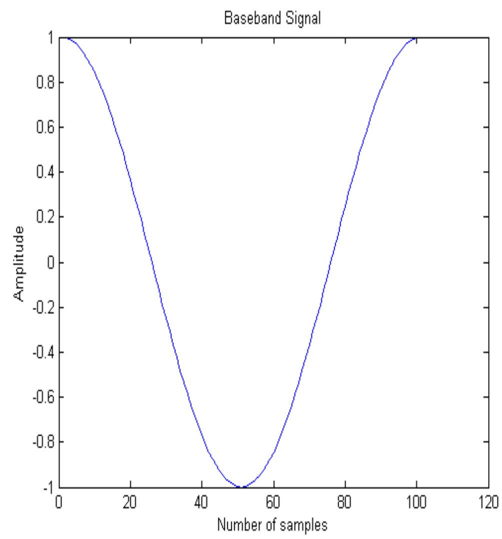

Fig 8(a): Baseband signal x (t).

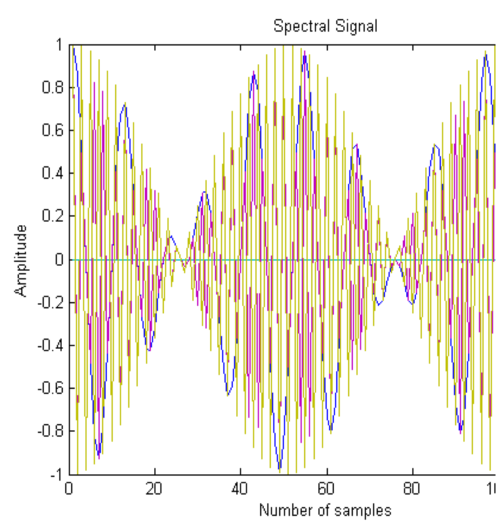

Fig 8(b): The spectral signal.

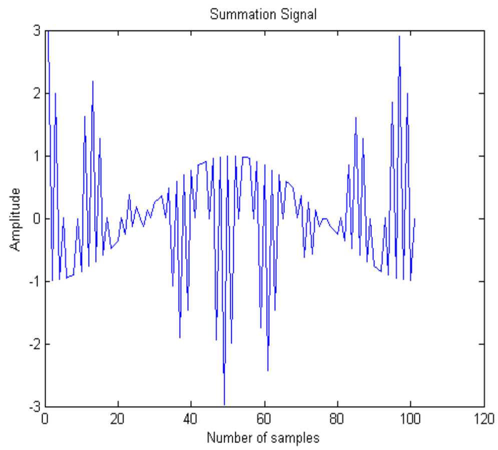

Fig 8(c): The summation signal.

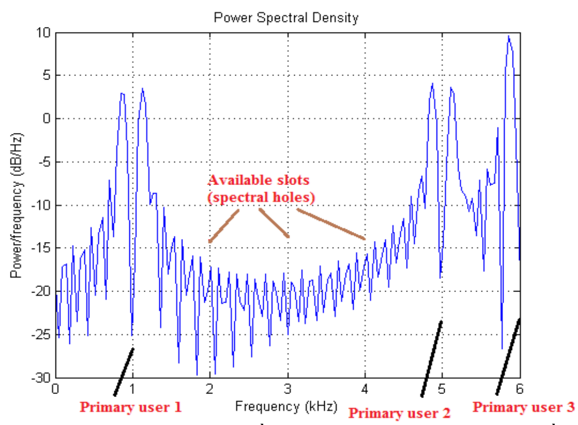

Fig 8(d): used bands (1st, 5th and 6th) and unused bands (2nd, 3rd, 4th).

The high peaks in Fig 8(d) are for the primary users 1st,5th,6th and low peaks indicates that there are no primary users in 2nd,3rd and 4th slots and hence can be used by the secondary users.

As shown in fig. 8(d), the unused bands are 2nd, 3rd, 4th.So the cognitive radio will search for the first spectral hole and will automatically allocate to the secondary user. In the figure 8(e), it is depicted that the first spectral hole is assigned to secondary user 1(SU1).

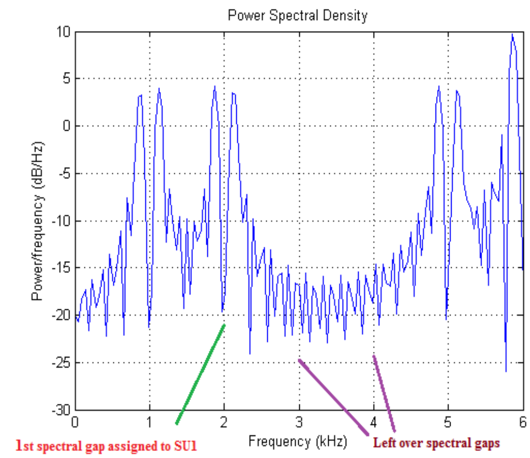

Fig 8(e): 1st spectral hole assigned to secondary user 1(SU1).

Next the cognitive radio will look for the next spectral hole and will again assign it to the next secondary user, i.e., secondary user 2(SU2).So in fig 8(f), after the allocation of 2nd frequency slot to secondary user 2(SU2) there is a rise in the peak of the 2nd frequency slot which shows that it is occupied.

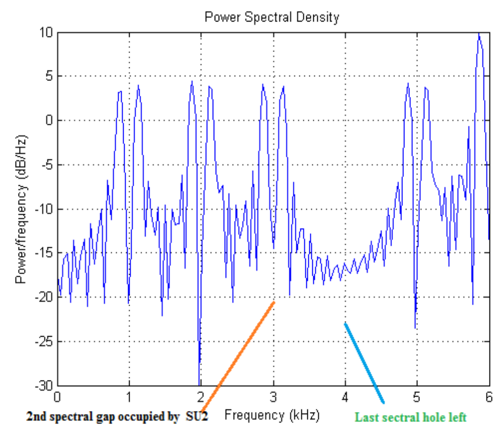

Fig 8(f):2nd spectral gap occupied by SU2.

Now only one available slot is left which will get occupied by the addition of another Secondary user as shown in Fig 8(g).The left over spectral hole is occupied by the secondary user 3.

Fig 8(g): Dynamic use of spectrum.

So finally, in fig 8(g), we obtain the dynamic spectrum access for cognitive radio networks. Here all the frequency bands are efficiently used and no part of the spectrum is wasted. System will not consider other users once all the frequency slots are allocated and can empty the spectral slots one by one as per requirements. If asked to vacate a slot, it will remove the data from the particular spectral gap and make it set for the next allocation.

We can add noise and attenuation parameter in order to examine the channel characteristics. Suppose the Signal to Noise Ratio (SNR) is taken as 10 dB then, the following graph is obtained in the Figure 8(h).

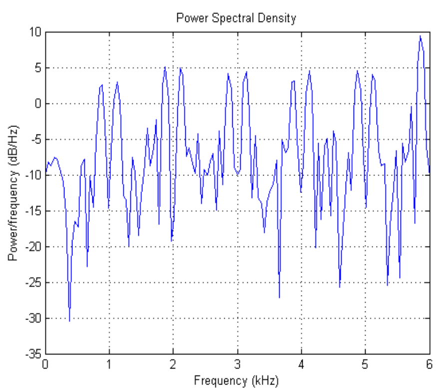

Fig 8(h): SNR=10dB.

Next to perform attenuation of the received signal, we consider attenuation percentage to be 25% and the graph obtained is shown in Fig.8 (i).

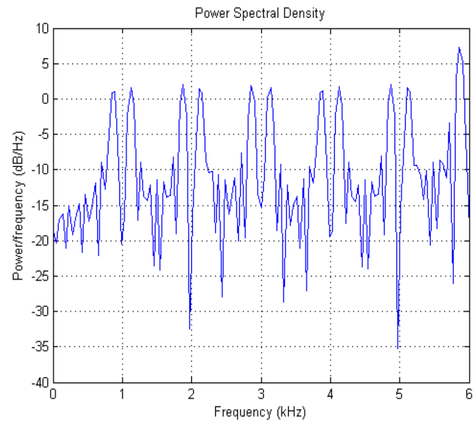

Fig 8(i): Attenuation=25%.

VI. CONCLUSION

Cognitive radio is the latest paradigm to design wireless communications systems which helps to utilize the radio frequency spectrum dynamically. Cognitive users, which are the secondary users, observe the spectrum and if there are spectral holes, can use it but it should not interfere with the primary users who are the licensed users of the spectrum. In this paper we have used the energy detection method to find the primary users and the spectral holes. The simulation results have depicted how the dynamic spectrum access of the spectrum is performed. We also used the Additive White Gaussian noise with the Signal to noise ratio (SNR) as 10 dB and Attenuation percentage to be 25.Thus the dynamic spectrum access in cognitive radio is carried out successfully without causing any interference with the other frequency bands occupied by the licensed users.

ACKNOWLEDGMENT

I, Priyangu Shaya Sarmah, would like to offer my sincere thanks to my mentor Ms .J. Jayanthi and also all the people of ALD and KTMD of CSIR, NAL who have helped me in my work and encouraged me and motivated in making it a success. I would also like to thank my parents and Almighty because of whom I have reached this stage in my life.

REFERENCES

[1] Zhu Han, Ekram Hossain and Dusit Niyato, "Dynamic Spectrum Access and Management in Cognitive Radio Networks', 2009.

[2] Linda E. Doyle," Essentials of Cognitive Radio", Trinity College, Dublin.

[3] S. Haykin," Cognitive Radio: Brain-empowered wireless communications", IEEE J. Select. Areas Commun.Vol.23,no.2,2005, pp.201-220.

[4] A. Bansal, Ms. R. Mahajan,' Building Cognitive Radio System Using Matlab', IJECSE, Vol.1, Number 3, 2012.

[5] S.Haykin," Cognitive Radios-Spectrum Sensing Issues", by Amit Kataria presented to the Faculty of the Graduate School at the University of Missouri-Columbia

[6] Konstantine Arkoudas and Ritu Chadha and Jason Chiang,'an application of formal methods to Cognitive Radios', Research paper.

[7] Mahmood A. Abdulsattar and Zahir A. Hussein,' Energy detection technique for spectrum sensing in cognitive radio: A survey', IJCNC, Vol 4, No.5, September 2012.

[8] Garima Nautiyal, Rakesh Kumar,'Spectrum Sensing in Cognitive Radio using Matlab', IJEAT, Vol 2,issue 5,2013.

[9] Proakis, John G. Digital Communications. McGraw-Hill College, 2000

[10] Qing Zhao and Brian M.Sadler,' A Survey of dynamic spectrum access ', IEEE signal processing magazine, May 2007.

AUTHORS

Priyangu Shaya Sarmah completed her bachelor degree in Electronics and Communication Engineering in 2012 from Bhemmana Khandre Institute of Technology, Visvesvaraya Technological University, Belgaum, Karnataka, India. She is currently pursuing the Master degree in Digital Electronics and Communication Systems from Visvesvaraya Technological University, Centre for Post Graduate Studies, Bangalore (VIAT Muddenahalli), India. Her project work is carried out at CSIR National Aerospace Laboratories under the supervision of Ms. J. Jayanthi, Senior Principal Scientist, Joint Head, ALD. Her project work is related to dynamic spectrum access for cognitive radio networks.

J. Jayanthi has a B.Tech Degree in Electronics from MIT and M.S from VTU with the research topic as 'Cognitive radio for civil aircraft communication'. She has been working in the field of real time embedded system for the past 25 years. She has led and executed the project for software design, development and certification of Stall Warning/Aircraft Interface Computer system for SARAS Aircraft as per DO178B Level A for the first time in the country successfully and now the system is flying as part of Avionics in the aircraft (Formal Flight trials are still due).She has designed and developed a microcontroller based Smart Fatigue Meter and enhanced Smart Fatigue Meter for Jaguar aircraft which will undergo flight trials shortly. She has led successfully Independent Verification and Validation for complex safety critical software such as Automatic Flight Control System and Engine Indication and Crew Alert System. She is currently working on application of formal methods to safety critical systems with a focus on civil aerospace applications and carrying out advanced research in software engineering and software health management, reliability and safety assessment.

