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Spectrum Analysing Module for Cognitive Radio Using Software Defined Radio

Keerthy K Murali[1] ,.Abhisha Devi[2]
[1](ECE Dept, SNGCE,India)
[2](ECE Dept, SNGCE,India)

Abstract: *Software Defined Radio (SDR) is one of possibilities to realize the structure of device with a high mobility, flexibility and reconfigurability. This technology can provide the seamless shifting between existed air-interface standards. Extending the flexibility further, a system capable to sense the spectrum space available for communication and adapt to it is cognitive radio. Obviously SDR in cognitive radio should be configured not only to independent standards, protocols and services but also to the extensively dynamic nature of bandwidth allocation. Moreover this need of dynamic allocation of Spectrum space is a must to cater to its increased demand. Cognitive radio is envisioned as the ultimate system that can sense, adapt and learn from the environment in which it operates. Sensing the available bandwidth a Software defined radio (SDR) in a cognitive system, tunes the circuits in the system for transferring data at optimum data rates, permissible by the space available. So it is a must for the SDR to accordingly add processing circuits to maintain the system performance at variable working frequencies. Here, we implement an SDR based spectrum lookup device which can be used by a CR. The SDR interfacing program detects unused frequency ranges. We employ energy detection method to perform spectrum sensing. In energy detection technique energy of the desired transmitted signal is detected and this detected energy is compared with a threshold value.*
Keywords- *SDR (Software defined radio), Cognitive Radio, RTL-SDR*

I. Introduction

Most part of current research works in the wireless communication technologies focuses on providing many varied services and maintaining high bit rate [1]. The possibility to be reachable in any place and at anytime has also become much demanded. That is why the greatest companies try to find possible solutions to satisfy these requirements. To this end, there is a need to devise the structure which will be able to support the possibility to retune mobile terminals according to the signal reception [2]. Existing approaches assume that a user should purchase a detached device for each standard, because most of them have their own specification of frequencies range, types of modulation, coding scheme, and access to the environment. Therefore, the mobile operator has to provide support for all wireless systems separately. To resolve this problem, the Software Defined Radio (SDR) technology comes in handy [3].

A need to extend the above adaption has aroused over a last couple of years wherein the spectrum demand has increased many folds. Spectrum allocation policy has faced spectrum scarcity in particular spectrum bands. In contrast, a large portion of the assigned spectrum is used sporadically, leading to underutilization of significant amount of spectrum space [4]. Spectral occupancy measurements consistently show that some bands are under-utilised in some areas at some times. The blue bands are low signal levels, indicating sparse utilization of the Spectrum Space, whereas the brown bands indicate high signal level that is heavy utilization of Spectrum Space. The inefficiency in Spectrum Utilization is obvious. Hence, dynamic spectrum access techniques were proposed to solve these spectrum inefficiency problems. The key enabling technology of dynamic spectrum access techniques is Cognitive radio. Joseph Mitola III and Gerald Q. Maguire who first officially presented the idea of Cognitive Radio [5], define it as “Cognitive radio is an intelligent wireless communication system that is aware of its Radio Frequency (RF) environment, and uses the methodology of understanding- by- building to learn from the environment and adapt its internal states to statistical variation in the environment by making changes to adjustable parameters, namely transmit power, carrier frequency and modulation strategy, all in real Time”[Mitola1999].

This paper introduces the SDR and Cognitive Radio Technology in Section 2 and 3 respectively. Section 4 explains implementation of spectrum analysing module for cognitive radio using software defined radio.

II. Software Defined Radio

A number of definitions can be found to describe Software Defined Radio, also known as Software Radio or SDR. The SDR Forum[6], working in collaboration with the Institute of Electrical and Electronic Engineers (IEEE) P1900.1 group, has worked to establish a definition of SDR that provides consistency and a clear overview of the technology and its associated benefits. Simply put Software Defined Radio is defined as: "Radio in which some or all of the physical layer functions are software defined" * A radio is any kind of device that wirelessly transmits or receives signals in the radio frequency (RF) part of the electromagnetic spectrum to facilitate the transfer of information.

In today's world, radios exist in a multitude of items such as cell phones, computers, car door openers, vehicles, and televisions. Traditional hardware based radio devices limit cross- functionality and can only be modified through physical intervention. This results in higher production costs and minimal flexibility in supporting multiple waveform standards. By contrast, software defined radio technology provides an efficient and comparatively inexpensive solution to this problem, allowing multi-mode, multi-band and/or multi-functional wireless devices that can be enhanced using software upgrades. SDR defines a collection of hardware and software (Fig. 2) technologies where some or all of the radio's operating functions (also referred to as physical layer processing) are implemented through modifiable software or firmware operating on programmable processing technologies. These devices include field programmable gate arrays (FPGA), digital signal processors (DSP), general purpose processors (GPP), programmable System on Chip (SoC) or other application specific programmable processors. The use of these technologies allows new wireless features and capabilities to be added to existing radio systems without requiring new hardware.

III. Cognitive Radio

Although cognitive radio was initially thought of as a software defined radios extension (Full Cognitive Radio), most of the research work is currently focusing on Spectrum Sensing Cognitive Radio, particularly in the TV bands. The essential problem of Spectrum Sensing Cognitive Radio is in designing high quality spectrum sensing devices and algorithms for exchanging spectrum sensing data between nodes. Standards groups and regulatory bodies around the world are increasingly seeking new ways of using, allowing access to, or allocating spectrum. This was made clear during the SDR Forum's Global Regulatory Summit on SDR and Cognitive Radio Technologies (June 2005), when standards, regulatory, and other key stakeholder representatives from around the world discussed their spectrum management challenges and goals, and the role of new technologies.

This interest in developing new spectrum utilization technologies—combined with both the introduction of SDR and the realization that machine learning can be applied to radios—is creating intriguing possibilities for new and promising technologies such as cognitive radio. Although the term cognitive radio—coined by Joe Mitola III in 1999—has evolved over time and now has several specific meanings in a variety of contexts, it is most commonly perceived as "the next step up" for software defined radios emerging today. Within the wireless industry, consensus is growing that many of the key attributes of cognitive radio—its promise to deliver a radio that is aware of its radio frequency (RF) environment, can adapt to this environment, and consequently can adjust its operating parameters—are best (if not only) enabled through SDR technology. The SDR Forum, which has several initiatives under way to support the continued development of cognitive radio, is in the process of drafting a definition that summarizes a cognitive radio as shown in the inset above.
Other perspectives within the industry describe a cognitive radio as a device that can:

- autonomously exploit locally unused spectrum to provide new paths to spectrum access
- roam across borders and self-adjust to stay in compliance with local regulations
- negotiate with several service providers to connect a user at the lowest cost
- adapt themselves and their emissions without user intervention; and/or
- understand and follow the actions and choices taken by their users and over time learn to become more responsive and to anticipate the users' needs.

The three basic areas of radio operation where cognitive radio can make an immediate impact are human-machine interface (HMI), radio-centric operations, and network-centric operations.

1. In the area of HMI, cognitive radio technology can provide a level of automation that can simplify the user interface to a complex device.
2. For radio-centric operations, the adaptive RF signal-in-space formation and adaptive modulation provide adaptation capabilities under cognitive control that could improve system performance based on observed

conditions.

3. More network-centric applications of cognitive radio could include the autonomous selection of network membership (e.g., 3G/Wi-Fi hotspot/WiMax) or cognitive/predictive handoff

Where the cognitive device anticipates the need to hand off based on prior experience rather than simply by following predefined algorithms based solely on signal level. That is, the device recognizes that it regularly traverses the same path (i.e., daily commute) and over time, learns when it is going to enter "bad spot" and reasons to hand off to a different system before the outage occurs. Spectrum Utilization efficiency is not the only benefit of cognitive radio technology; however, it is one of the more high-profile possibilities, in part due to the economics of being able to sublease spectrum as needed. The supply of available radio frequency spectrum is often described as being in a state of shortage. Whereas demand for spectrum in the most useful frequencies exceeds supply, some statically allocated spectrum bands experience low utilization. A cognitive radio that is capable of exploiting unused or lightly used spectrum will have great value in improving efficiency of spectrum utilization. Based on the technology advancements of SDR, a cognitive radio could:

- easily operate on multiple frequencies with a variety of power levels and modulation bandwidths;
- incorporate sophisticated control algorithms to prevent or reduce interference so more spectrum can be exploited;
- provide the capacity to move the regulators from a band-by-band set of rules to more mega-policies, enabling both new technologies and new entrants; and
- assist the regulator to serve the public interest by providing spectrum when and where it is needed by using technology to satisfy the ever-increasing spectrum demand and streamline the licensing process. Most of the current spectrum assignment rules in place around the world challenge the dynamic

spectrum access[9] aspect of cognitive radio due to the rigid table of allocations derived from historical allocation and assignment methods. Attitudes have begun to change, and there is growing interest by regulators to study the possibilities of allowing dynamic spectrum access. A snapshot of the current regulatory and licensing landscape for cognitive radio is from an international perspective, pre-regulatory activity has begun in all three ITU areas (Americas, Europe/Africa, and Asia), most notably in Australia, Korea, Sweden, the United Kingdom, and the United States, The U.S. Federal Communications Commission (FCC) has been one of the more proactive regulator bodies in its support of cognitive radio via its spectrum policy task force and cognitive radio Notice of Proposed Rulemaking (NPRM[10]). Rulemaking for the 3650-3700 MHz refers to contention-based operation that can be interpreted as benefiting from cognitive technologies, the partitioning and disaggregation clauses in recent commercial spectrum license rulemaking proceedings also indicate the FCC's desire for more flexible spectrum access, and the SDR/CR rules apply to device certification. Many of the bands have secondary use regulations that could be exploited by cognitive radio solutions with little to no additional rulemaking. Going forward, regulations that could speed cognitive radio development and deployment include dynamic spectrum access and interference metrics, and authorization for experimental licenses to prove-out the technology before adopting new rules.

In addition to the regulator community's interest in cognitive radio, the commercial, civil, and defence sectors also have specific interests in this type of highly functioning radio. Commercial market drivers include spectrum access for increased capacity and new wireless internet services as well as international harmonization. Work under NSF (DIMSUM) is addressing spectrum brokering between base stations and providers. In addition, cognitive radio can increase carriers' revenues by facilitating new spectrum-based and location-based services. This is achieved by improving system performance, reducing frequency planning complexity, facilitating secondary market agreements (i.e., spectrum brokering), and increasing capacity through access to more spectrum. For a new carrier, this is critical because it provides initial market entry. Equipment manufacturers will also benefit due to the increased demand for wireless devices. Civil market drivers include public safety and domestic security requirements for multi-network interoperability and spectrum-on-demand for emergencies. Defence industry drivers include rapid set-up time through reduced planning requirements and simplifying human-machine interface for user- friendly use of complex devices, international spectrum access, and multi-networking.

Initial applications for cognitive radio could include dynamic spectrum access such as Dynamic Frequency Selection (DFS) in the Unlicensed National Information Infrastructure (U-NII) bands, DARPA's Next Generation Radio (XG) and connectionless in defence applications, machine-learning for improved wireless performance, and autonomous network association/membership. In the future, cognitive radio could be used to develop the broadband mobile wireless Internet infrastructure to support all wired Internet user applications (e.g., music and video downloads, e-mail connectivity, and mobile TV) over the wireless Internet with its inherent benefit of mobility.

A variety of technical advances have been made in both the "cognitive" and "radio" sides of cognitive radio. On the radio side, the continued development of software defined radios that exploit the processing flexibility of DSPs running on programmable chip technologies is creating new opportunities for high-performance, extremely flexible radios. On the cognitive side, cognitive processing and computing opportunities are being developed by a wide range of commercial, defence, and research organizations, such as the DARPA Information Processing Technology Office (IPTO). Many of the capabilities of a cognitive radio are achievable with today's technology.

In fact, numerous organizations around the world are currently developing what can best be described as rudimentary cognitive radios. Technical challenges still need to be addressed, however, for the development of an ideal cognitive radio. These challenges include the need to develop:

- efficient, agile, RF front ends and verification, validation, and authentication (VV&A)[12] of operational characteristics;
- wideband linear, adaptive filtering and amplification and
- advanced cognitive processing for applied learning, reasoning, and knowledge representation algorithms for specific wireless domain solutions

Cognitive radio represents a logical extension for the SDR Forum. By its very definition, software defined radio is the ability to reconfigure a radio's operating parameters—and that is exactly why it is so attractive for cognitive radio technology. In this effort, the SDR Forum has the appropriate resources, talent pool, and commitment in place to provide tightly focused technical analysis and broad cross-disciplinary research on this issue. The SDR Forum has several cognitive radio initiatives under way. Most recently, the Forum has created a Cognitive Applications Special Interest Group and a Cognitive Radio Working Group to leverage the role of SDR in the continued development of cognitive radio technology. The Cognitive Applications Special Interest Group is studying the business case, market drivers, regulatory, and other cross-disciplinary implications of SDR within a Cognitive Radio framework, and the Cognitive Radio Working Group[14] is working to produce technical guidance and standardization to design, develop, and implement cognitive concepts and features based on SDR technology and architecture.

In addition, the Forum's Regulatory Committee has taken an active role in cognitive radio-related regulatory proceedings around the world and has endorsed cognitive radio in its response to the FCC's "Notice of Proposed Rule Making" on this issue. Through these and other initiatives, the SDR Forum will continue to work to provide a broad view of the business, regulatory, and technical implications of cognitive radio by providing key leadership to insure factual representation of the state of the art in technology and applications, and by providing overall technical leadership within the industry. Types of Cognitive Radio System: Depending on the set of parameters taken into account in deciding on transmission and reception changes, and for historical reasons, we can distinguish certain types of cognitive radio. The main two are:

- Full Cognitive Radio ("Mitola radio"): In which every possible parameter observable by a wireless node or network is taken into account.
- Spectrum Sensing Cognitive Radio: In which only the radio frequency spectrum is considered. Work presented here is for Configuring the SDR for Spectrum Sensing Cognitive Radio.

IV. Implementation Of SDR Based Spectrum Look-Up Device For Cognitive Radio

To configure the SDR for Spectrum sensing Cognitive Radio we should consider all the situations that the Radio System is likely to face in cognition:

1. Reduction in available Bandwidth for transmission, due to the adoption to a smaller spectrum hole
2. Availability of Higher Bandwidth

The first situation needs lossless data compression algorithms to be adopted. Whereas the higher bandwidth available in the second situation may be capitalized in the following two ways:

- To transmit small packets of data with high accuracy (at low the bit error rate), required in Emergency Services (time bound emergency information should take care of data reduction to minimum possible size so as to utilize low data rates where BER is low). [8], [9].
- To transmit bulk data at higher data rate e.g. real time applications like Mobile Services [10].

In this experimental study, we develop a system that consists of a host computer employing a cognitive radio module and an RTL-SDR. Till date USRP (Universal Software Radio Peripheral) is a popular hardware device for doing real-time communication experiments in SDR. But now, a 20 dollars revolution from OSMO SDR has introduced a hardware called RTL-SDR Realtek RTL2832U which is the cheapest one .The DVB- T (Digital Video Broadcast Terrestrial) dongle proved to be efficient for SDR purposes as the chip is able to transmit raw I/Q samples to the host. The operating frequency range of RTL-SDR is from 64 to 1700 MHz, with sample rate of 3.2 MS/s.

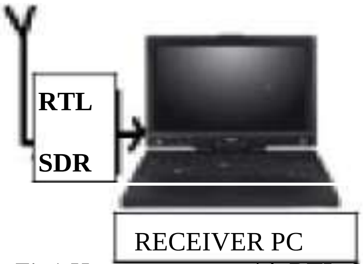

Fig1.Host computer with RTL-SDR receiver

First we set the center frequency for SDR input port which determines the peak frequency in Fourier transform of the wavelet. The wavelet function is in effect a band pass filter.Inorder to cover the entire spectrum infinite levels would be required. Signal source that receives data from an RTL-SDR radio and outputs a column vector signal of fixed length specified by the samples per frame parameter. Here the center frequency also specifies the center frequency of the input signal for the RTL-SDR radio. The lost samples output to instruct RTL-SDR receiver blocks to output the number of lost samples during the host hardware data transfer. Where zero indicates the no data loss, positive number indicates over run occur. The default value is not selected which means that the port is not enabled and no information about dropped packet is not displayed. Latency output port. Select this parameter to instruct the RTL-SDR Receiver block to indicate latency during host-hardware data transfers in number of frames.

Output data type specify the complex output data type as double, single, or int16. When you select double or single for the output data type, the complex values are scaled to the range of [-1,1]. When you select int16, the complex values are the raw 16–bit I and Q samples from the board. The default is int16.This block supports the following complex output data types:

- Double-precision floating point
- Single-precision floating point
- 16-bit signed integers

Samples per frame specify the number of samples in a frame for the block to output. This value must be a positive, scalar integer that is an integer multiple of 256. The default value is 1024.The find peak frequency block uses an FFT to find the frequency with the maximum power in the received signal which is equal to the frequency offset.Fig.3 shows spectrum analyzer output.The periodogram block returns the PSD estimate of the received signal. Probe block finds the index of the maximum amplitude across the frequency band and converts the index to the frequency value according to

Foffset = Index of Max Amplitude*FrameSize/(FFT length*frame sample time) (1)

The MATLAB function findpeakfreq.m performs this conversion. The frequency and magnitude of the detected signal is compared with a threshold value according to energy detection spectrum analyzing technique. If the detected frequency is less than a threshold value and also the magnitude is greater than another threshold value set by using trial and error method, we can assume that the spectrum is free which is available for secondary user. The occupied block has value 0.Otherwise we can assume that the spectrum is not free which is used by primary user. Then the occupied block will be 1.fig.4 shows the spectrum analyzer output.

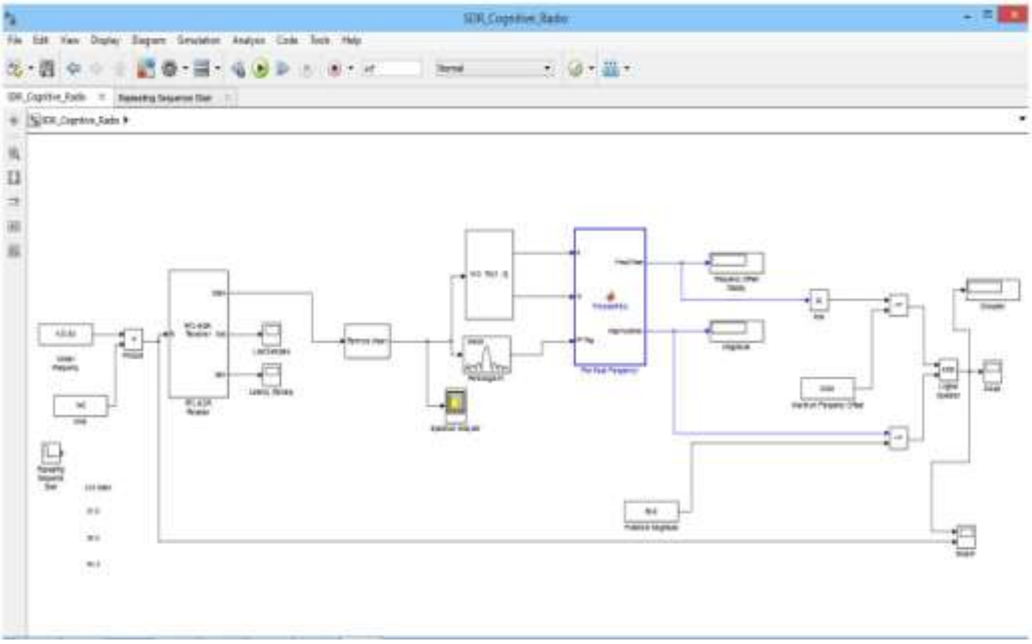

Fig 2.Simulink platform for spectrum analyzing module for cognitive radio

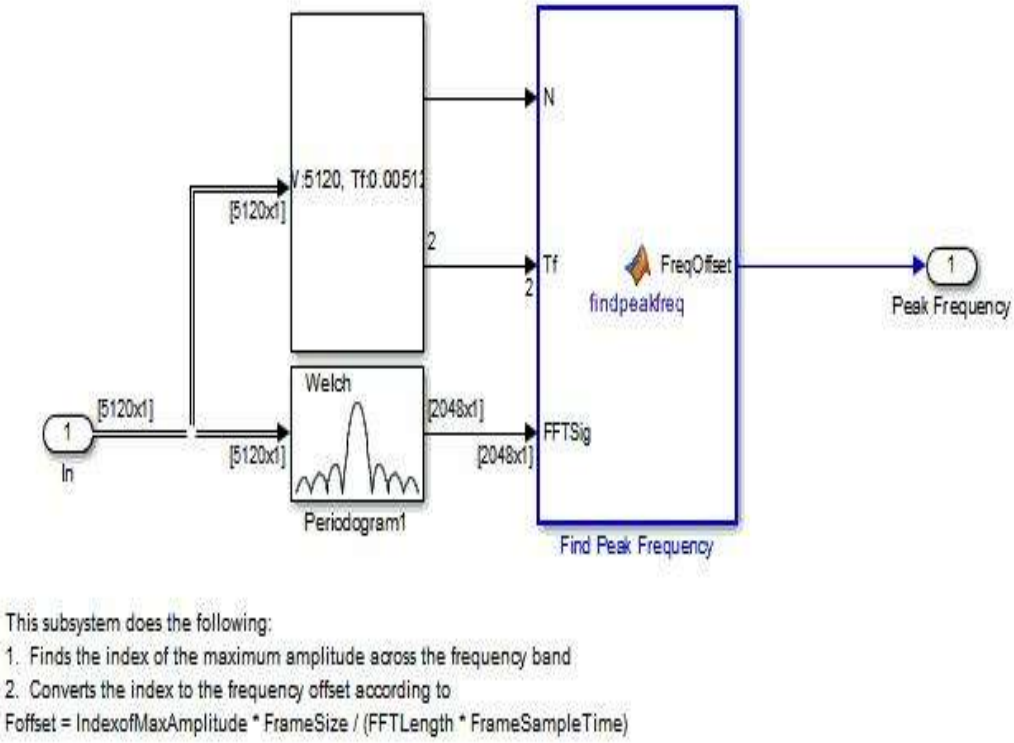

Fig 3.simulink platform to find frequency offset

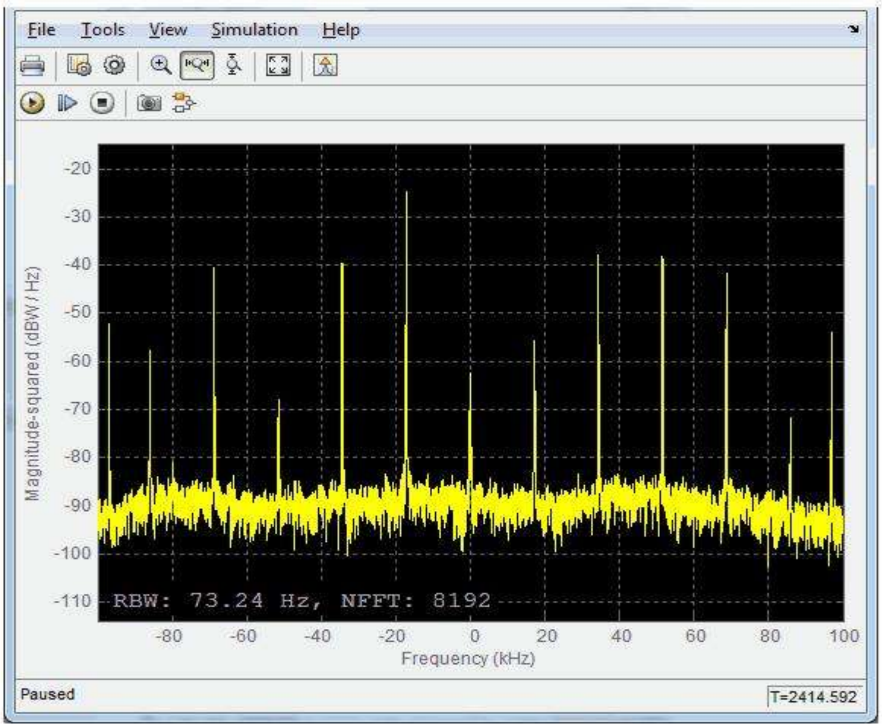

Fig.4 spectrum analyzer output

V. Conclusion

Cognitive radio is an innovative technology proposed to increase spectrum usage by allowing dynamic allocation of the unused spectrum in changing environments. Cognitive users monitor the spectrum and are allowed to use it as long as it does not interfere with primary users to whom it has been licensed. SDR will have a key role to play, in the Cognitive Systems. Here, we implemented an SDR based spectrum lookup device which can be used by a CR. The SDR interfacing program detects unused frequency ranges. We employed energy detection method to perform spectrum sensing. In energy detection technique energy of the desired transmitted signal is detected and this detected energy is compared with a threshold value. According to this value analysed the spectrum is free or used by primary user.

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