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Applications of Cognitive Radio Networks: A Review

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Abstract

Cognitive radio network is one of the future technology of wireless communication. Recently, wireless communications are facing the problem of spectrum scarcity due to the huge demand for various applications. There are many applications such as health services, personal entertainment, military and public safety, smart home appliances, smart farming, traffic monitoring, controlling etc., using wireless communication, and most of them are delay sensitive and real time applications. The wireless communication can improve their performance with the capabilities of cognitive radio. In this study, many cognitive radio enabled wireless applications are discussed. It shows that it can be easily deployed with cognitive radio enabled devices without any cost. With this, unused licensed spectrum is utilized efficiently and moreover, it solves the problem of spectrum scarcity.

Keywords: Cognitive radio, health service, machine learning, wireless body area network

1. Introduction

Wireless communication is the fastest growing communication technology due to the anytime, anywhere access. It can easily be set up anywhere (indoor/outdoor) without too much cost. Therefore, it has become the most popular communication technology. It covers from short to long distance depending on the types of wireless communication technology. It includes Satellite communication that covers long distance and Bluetooth technology that covers short distance. Various wireless communication technologies are available for different user's communication requirements. These communication technologies are Satellite communication, Infrared communication, Television and Radio Broadcasting, RADAR, Wi-Fi (Wireless LAN), Mobile communication system, Bluetooth technology, GPS, ZigBee, Paging, Cordless phones, RFID, etc.

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Most wireless communication technology uses ISM (Industry-Scientific-Medical) frequency band for the communication. Bluetooth devices, cordless phones, NFC (Near Field Communication), RFID and ZigBee devices operate in 2.4 GHz, 900 MHz and 868 MHz unlicensed spectrum. ISM frequency band transmits data over short range. Wi-Fi also uses the ISM band for communication that covers up to 100m distance. It is also available with the capacity of 5GHz. RFID and NFC systems use 13.56 MHz in the range of 13.553 MHz to 13.567 MHz ISM frequency band. RFID and NFC wireless technology is incorporated with the credit cards, identity cards, payment system, and secure access system. Licensed-free ISM frequency band is overcrowded due to the huge use of it. Therefore, sometimes it is insufficient to use it and that affects the wireless communications. To address this problem, cognitive empowered wireless communication will be the solution.

Cognitive Radio (CR) technology is built on the software defined radio and it is used to empower wireless communication. CR wireless communication can effectively work in the situation of insufficient frequency spectrums. It can easily detect the licensed unused spectrum and switch their communication over the unused spectrum. Spectrum scarcity problems can be resolved with efficient spectrum utilization. Also, it can easily coordinate the communication among CR users with the ability of sensing, learning and making intelligent decisions [1-2]. However, characteristics of cognitive radio is discussed as follows:

- **Cognitive capability:** Spectrum sensing techniques are used to achieve the tasks. CR has the ability to sense the unused licensed spectrum at specific location and time. The main challenges are the spectrum sensing accuracy, sensing duration, and uncertainty in background noise power.

- **Reconfigurable capability:** CR has the reconfigurable capability to adjust the transmission parameters dynamically. It achieves the maximum spectrum and throughput utilization, minimum interference, reducing energy, and power consumption. Reconfigurable parameters include time slot allocation, power control, frame size, data rate control, frequency band allocation, routing, etc. The reconfigurable capability is based on optimization algorithms which make optimal decisions. The main challenge is to converge the techniques within a short period.

- **Learning capability:** CR has the learning ability for making cognitive decisions. CR makes decisions based on the past experience or knowledge. But, unfortunately available

past knowledge is limited and it is not enough to train the model. Due to this constraint, it is challenging to develop the learning techniques without much knowledge. Therefore considering this challenge, selection of appropriate learning technique is also very important.

The Federal Communication Commission (FCC) regulates the frequency band allocation to the deployment of different wireless communication technologies [3]. This static spectrum allocation technique is not efficient, and most of the time allocated spectrums are underutilized, and it can be utilized by the CR wireless users using dynamic spectrum allocation schemes [4]. There are many applications of wireless communication technology. It includes:

- Home entertainment
- Disaster relief
- Health care
- Intelligent transportation
- Vehicular networks
- Traffic monitoring
- Vehicle tracking
- Military and public safety application
- Home appliances and indoor applications
- Bluetooth audio streaming

The wireless communication technology is incorporated with the current edge technology such as IoT (Internet of Things), Robotics etc. Nowadays many home appliances and other equipment are manufactured along with IoT sensors to sense the different kinds of information such as temperature, pressure, light, weight, etc. for the intelligent decisions. Camera devices are used to capture the real time images or video, and that can be processed for further action. For example, at a toll booth, cameras capture the image of the number plate of a vehicle, extract the information such as vehicle number and send it to the server for further action. It can also act as video surveillance at the airport to detect the criminals or suspicious activity. Such real time video streaming can be monitored on mobile devices using wireless technology. Due to the vast applications of wireless technology and its popularity, wireless devices such as wireless printer, wireless headphone, Bluetooth speakers, wireless keyboard and mouse, and many more are increasing in demand, and hence frequency used by these devices for the data transfer is congested. Therefore, it is needed to address such issues

using CR technology. Wireless networks with CR technology are also called Cognitive Radio Networks (CRN).

The IEEE 802.22 standard is developed for the Wireless Regional Area Networks (WRAN) using CR technology. It operates on the VHF/UHF TV bands with 33km to 100km coverage area. It allows the access of the unused TV bands to the unlicensed users [5]. This paper is organized as follows. Section 2 discusses the existing works of cognitive radio networks applications. Proposed applications are presented in section 3, and finally the paper is concluded in section 4.

2. Related Works

In this paper, various emerging cognitive radio applications such as public safety, smart grid, cellular networks, and wireless medical applications are explored. Wireless communication is mostly used for the emergency services such as police, fire brigade, and medical emergencies including ambulance service in case of road accidents or any health emergency. For such applications, data delivery on time that is without any delay and error free is very important. ISM frequency band or allotted spectrum by FCC sometimes is overcrowded and sufficient spectrum is not available to provide reliable service. Therefore, in order to provide reliable communication, these applications can use CR enabled devices that have the ability of spectrum sensing and selection. In the CR enabled wireless communication, CR users can utilize the free channels of primary users for the data communication and also can switch their communication on another free channel if primary users need the current channel [6]. Applications of cognitive radio in wireless sensor networks such as military and public security, health care, home appliances, real time surveillance systems, and intelligent transportations are explored along with challenges and issues [7].

2.1 Natural Disasters

Flood disasters are a common problem in the world due to the global warming effects. There is a huge change in the climates and weather that causes irregularities in the rain and temperature. There is a huge loss of nature, humans and its properties due to the heavy flood disasters. Many times, Search and Rescue operations are needed when people and animals are lost, and to trace them, the traditional system is not efficient due to the loss of communication infrastructure. CR enabled IoT based systems can effectively work in the Search and Rescue

operation. It does not require any costly infrastructure to establish a network for the communication. Paper [8] proposed a framework for flood management based on CR enabled IoT that supports Search and Rescue operation in association with wireless sensor networks.

2.2 Cognitive Radio Vehicular Ad hoc Networks (CR- VANET)

VANET is one of the emerging areas for vehicle to vehicle communication. Due to the short distance between vehicles and higher mobility with high speed of vehicles, IEEE 1609 is developing standards for wireless access in vehicular environment. It is dedicated and supports short range communications only based on the IEEE 802.11p. For this communication, the US Federal Communications Commission has allocated 75 MHz spectrum. The European Telecommunications Standards Institute has allocated 30 MHz spectrum with 5.9 GHz frequency band for the deployment of Intelligent Transportation System services. The increasing number of vehicles in the city as well as in rural and urban areas, results in the overcrowding of the spectrum band. Therefore, it reduces the performance of vehicular communications. Following are the applications and services of VANET:

- To provide safety related information including road accidents and road conditions to the vehicle driver.
- To provide information about traffic congestion routes.
- In car-entertainment with audio and video streaming.
- To provide information about roadside restaurants, petrol pumps, vehicle garages, etc.

By considering various applications and its usage by vehicles, available spectrum provided by IEEE 802.11p is not sufficient. Furthermore, it becomes congested and needs to switch the communication over the other available channels. Cognitive Radio allows spectrum sensing and spectrum decision for the communication in which it senses the free channels and selects the best channel to perform the communications. This system can be incorporated with the VANET called CR-VANET to improve the performance of vehicular communications [9-11].

2.3 Smart Grid

Smart grid is another application of cognitive radio networks. It is a CR enabled power grid. In this, electric power generation and distribution is incorporated with wireless communication technology.

Smart grids provide many services to the society such as,

- It reduces the cost of power generation and distribution.
- It can manage power consumption.
- It can provide the smart bill of power consumption to the customers.
- It can control power grid failure situations by immediate decision upon receiving the power consumption data.
- It can save energy by following a demand-supply strategy.
- It can integrate different energy resources such as renewable and distributed.

Smart grid considers different sources of power generation including solar power, coal power, wind power and water power. This power is then distributed to the customers as per their need. It may include commercial purpose, residential or industrial purpose. The billing system is different for different types of customers. Smart grid forms one intelligent network by taking into account all these possibilities and uses the network for dual purpose, that is transmission of data and electricity. In smart homes, many devices are equipped with IoT sensors that communicate through ZigBee protocol of IEEE 802.15.4 standards. Some devices such as smart light/fan, air conditioner, etc are remote controlled and voice enabled that uses infrared and Wi-Fi for the communication. Some devices such as speakers, mobiles, laptops and TV are wirelessly connected through Bluetooth or Wi-Fi service. Therefore, all require power and sufficient spectrum band for the communication. CR enabled smart meters in smart grid networks play a vital role. It can monitor and control the real time load and manage demand-supply ratio. Smart meter operates on the 2.4GHz ISM spectrum band. However, such a spectrum band is mostly utilized by the smart home appliances with various radio technologies such as Bluetooth, ZigBee and Wi-Fi and becomes overcrowded. Therefore, in this situation, smart meters can use available licensed spectrum which is unused by primary users for reliable communication [12].

2.4 Smart Farming

Farmers are adopting the smart techniques for the smart farming. Smart techniques such as IoT, Artificial Intelligence and Machine Learning (AIML) and Big data analytics are widely explored in the agriculture field for the monitoring of the soil condition, water or moisture level, prediction of crops, demand-supply chain management, weather prediction etc. Measurement of all these parameters in precision helps to increase the quantity and quality of the crops. Therefore, there is a huge demand for IoT enabled smart devices for

smart farming. All these devices operate in either 2.4 GHz or 900 MHz and 868 MHz unlicensed spectrum. Such a licensed free spectrum band is not sufficient when all the devices are working on the same operating frequency. Due to shortage of the frequency, it causes delay in data delivery and thereby, smart devices are unable to take real time decisions. Therefore, it is needed to empower wireless communication using cognitive radio technology. CR enabled smart devices can sense the idle channels of primary users and select one of the best from the available channels in the situation of shortage of frequency. This helps to avoid the delay in data delivery and be able to take real time decisions.

Paper [13] proposed a model for Precision Agriculture. This model was used to control the parameters in the greenhouse. Smart greenhouse was built based on many sensors to sense the different parameters such as soil moisture, water level, temperature etc. Based on this information, CR enabled smart sensor nodes take the decision and control the parameters for the available crop in the greenhouse using wireless sensor network.

In [14], the author proposed a model for smart irrigation using a CR enabled IoT system. Water is a natural resource and is required to grow the crop. Different amounts of water are required based on the type of land and crop. For growing crops, different quantities of water are required at different stages of crop. Therefore, this smart irrigation system optimizes the use of water for the crop. CR enabled IoT systems overcame the limitation of frequency for the smart irrigation.

2.5 CR enabled hospital management in Rural/Urban areas

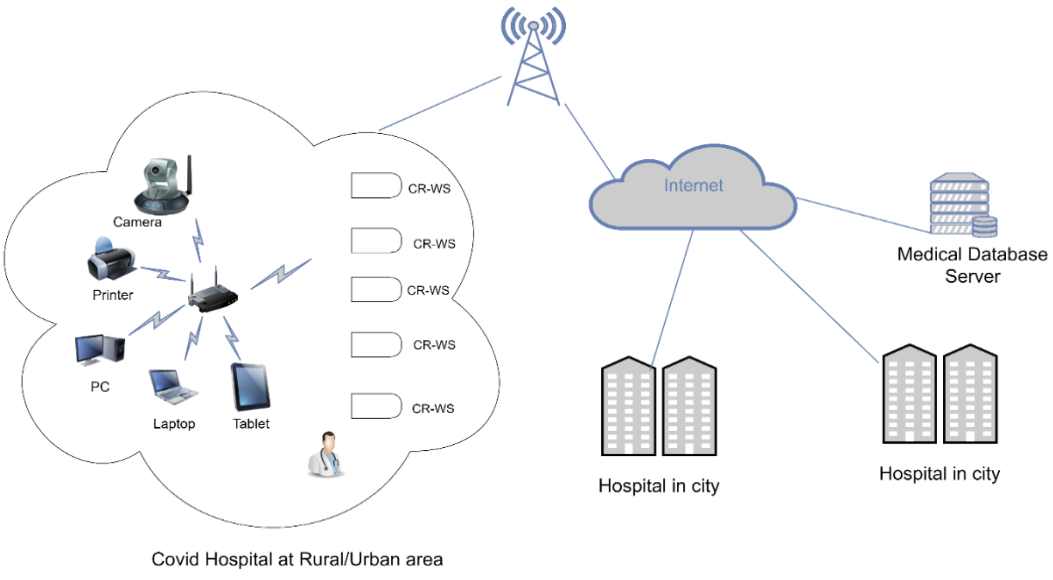

Figure 1. CR enabled hospital management in rural/urban areas

Fig. 1 shows the CR enabled hospital management model in rural/urban areas. The IEEE 802.15.6 standard was developed for the Wireless Body Area Network (WBAN). It operates on the ISM 2.4 GHz frequency band and other frequency bands which are approved by the national medical or frequency regular authorities. FCC has approved 40 MHz spectrum allocation to the medical WBAN. In WBAN, different wearable sensors on the human body operate at low power and support short range reliable wireless communication. It supports data rates up to 10 Mbps for various medical applications. There is a wide range of smart wearable body sensors. It includes accelerometers, gyroscopes, power supplies, smart fabrics, etc.

Body wearable sensors can be placed on different parts of the body such as chest, legs, finger, waist, arm, etc. Some sensors can be placed on the clothes itself such as a vest or T-shirt. The purpose of these sensors is to collect the information about the distance walked by the person, total steps counted during walk, count heart rate, total calories burned, blood pressure, temperature, and monitor the oxygen level in blood. These sensors can easily be worn like rings, pins, necklace, gloves, shoes, and belt. Therefore, WBAN is useful for the real time health monitoring system.

WBAN suffers from the shortage of allotted frequency. Many wireless devices such as Laptop, Mobile, Printer and Camera operate on the ISM 2.4 GHz frequency band. Body area network sensors also operate on the same bands. Therefore, there may be a shortage of such frequency and causes communication interruption. However, medical data is critical and delay sensitive. It should be transmitted on time and without any loss. It would be challenging by facing channel shortage for the communication.

Therefore, CR enabled WBAN can handle spectrum shortage and provide reliable communications. In this, Cognitive Radio Wearable Body Wireless Sensor (CR-WS) can collect the patient information and transmit it to the doctor (specialist) for the observations. Medical database server is used to store and maintain all this information for the future purpose. During treatment of Covid-19 patients, all previous history of that patient such as diabetes, sugar, blood pressure etc., Covid-19 symptoms, patient's personal information such as gender, age, weight etc. will be stored into the database server. This information is further analyzed using machine learning techniques. It will be useful to perform the test and treatment of new patients. Machine learning based model for the Covid-19 test is shown in the figure 2.

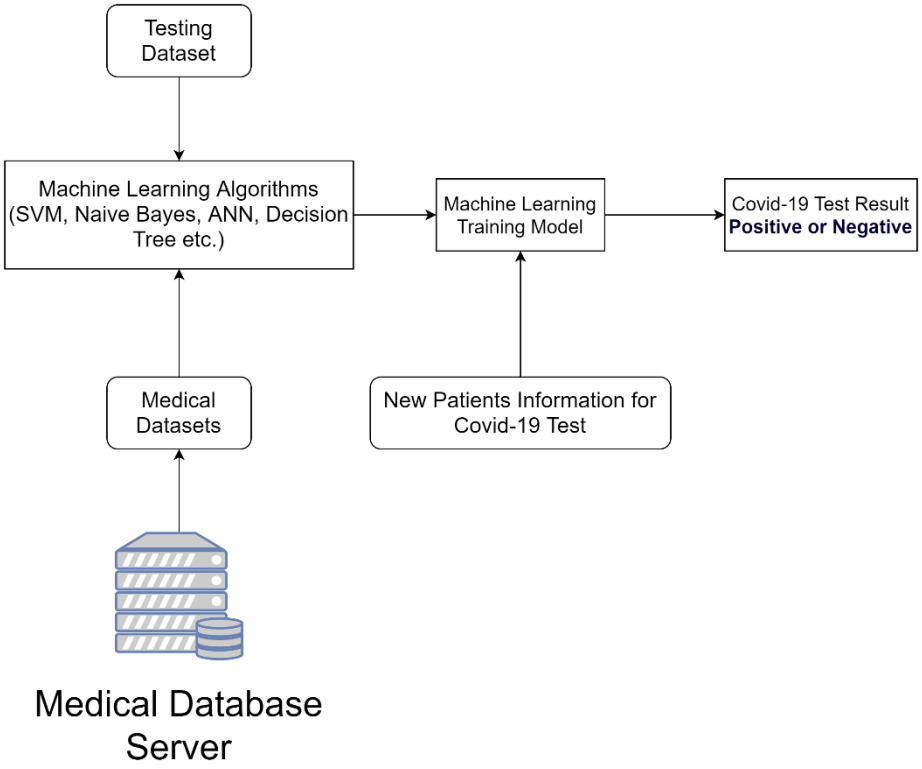

Figure 2. Machine learning based model for Covid-19 test

In this, supervised machine learning models can be trained using medical datasets and testing datasets. Then, patient's information will be given to this model to test whether the patient is Covid-19 positive or not. All CR-WSs transmit the patient's information to the medical database server. While transmitting such information, if there is any channel shortage of unlicensed frequency, then CR-WS can switch their communication over the licensed channel. In the covid-19 situation, all existing hospitals are filling up soon and it is needed to set up the temporary covid-19 hospital for the medical emergency situation. Specially, it is more challenging to provide health service in rural areas where doctors (experts) are limited. Doctors from the city hospitals can monitor the health system of covid-19 patients and can take the necessary action on it. This model is also helpful to monitor the stock of oxygen, medicines, injections, and vaccines in rural areas.

3. Research Challenges

There are many parameters that make an impact on routing performance in cognitive radio networks. These parameters include primary user activity, accuracy in channel sensing and selection, mobility of users, selection of appropriate routing metrics and energy efficient devices. To increase the routing performance, it is needed to study, design, and predict the

accurate parameters. Research challenges and issues are discussed with respect to these parameters in cognitive radio networks.

- Behavior of Primary Users: Secondary Users (SU) would consider the behavior of Primary Users (PU) to increase the performance of routing by selecting appropriate channel. In order to utilize these spectrums, channel usage pattern or behavior of PUs about channel usage need to be observed and based on this, efficient techniques must be developed.
- Accuracy in channel sensing: Many researchers have contributed their work in channel sensing in cognitive radio networks. Accurate channel sensing definitely improve the performance of accurate channel selection. Therefore, there is still a scope to improve the performance of spectrum sensing in cognitive radio networks.
- Accuracy in channel selection: After accurate channel sensing, the accuracy in channel selection is improved. Most of work on channel selection is already found in the literature. Various machine-earning techniques such as clustering, supervised, and reinforcement learnings are used to perform best channel selection in cognitive radio networks. However, still there is a scope to improve the channel selection using advanced artificial intelligence algorithms.
- Detection of security vulnerabilities: Detection of security vulnerabilities in the communication network improves the routing performance. CR takes decisions based on the information shared by other users. In this, PUs share the location information with SUs and based on it, SUs make decisions about the channel selection. If an attacker intercepts the communication and compromises such information before receiving the SUs, then improper channel selection will be initiated by the SUs based on this false information. Similarly, SUs set up a path based on the information such as available channels, number of neighboring nodes, location information, etc. shared by other users. Therefore, it is important to detect the malicious nodes before sharing the information or making any decision based on the information shared by malicious nodes.
- Selection of routing metrics: It is observed that routing metrics make the difference in the routing performance. Routing metrics such as delay and hop count are not much efficient in the cognitive radio networks. Therefore, many novel routing metrics such as delay and energy aware (combined metric), spectrum and energy aware, interference minimization, spectrum stability, route stability and so on are designed

and the routing performance is analyzed in terms of throughput, packet delivery ratio, delay, packet dropped, etc. Yet there is a scope to design novel routing metrics to enhance the routing performance.

4. Conclusion

In this study, many CR enabled wireless applications are discussed and proposed. Most of the applications are socially relevant and it is a need of the society. To get timely services to the people, it is significant to deploy the applications using a cognitive radio network. There are endless applications that use wireless networks. Cognitive radio improves the performance of such applications and also efficiently uses the spectrum to solve the spectrum scarcity problem. As a future scope, the performance of cognitive radio networks will improve by working on different research challenges such as accurate channel sensing and selection. Blockchain can also play a vital role in the cognitive radio networks while sharing channel information and location information among primary users and secondary users. Malicious node can easily be detected with the aid of blockchain technique.

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