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Research Article

Cognitive Radio Networks: Implementation, Analysis and Challenges

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Abstract

With advancing wireless communication technologies, hundreds of new applications are entering public utilization, and therefore the demand for radio frequency bands is on the rise. Since the radio frequency spectrum is an exhaustible resource requiring efficient utilization, cognitive radio technology presents a solution to the issue of spectrum efficiency, which hitherto could not be met through conventional approaches. This manuscript offers an overview of cognitive radio systems, which places special emphasis on their characteristics and operational mechanisms. The implementation and evaluation of simulation outcomes are covered while substantial challenges encountered in their design and deployment are addressed. Both basic and advanced tests have been carried out, and analytical assessment is provided along with simulation graphs and a data set generated by the cognitive radio system. Simulation results indicated that, based on the requirement and criterion of the SU users, the best free available channels are allocated.

Keywords: Cognitive Radio, Frequency spectrum, Spectrum sensing, Spectrum sharing

INTRODUCTION

Since wireless radio frequency spectrum is a limited resource and allocated through licensing process to users. Two issues are concerned here, first one is band of allocated frequency spectrum is being not available due to more traffic and second one is allocated frequency spectrum is relatively unused. As per the measurements taken over 24 hours in USA, the usage of the radio spectrum from 30 MHz to 3 GHz varies widely from place to place and time to time, ranging from 15% to 85%. This shows that most of the spectrum is used inefficiently, with some parts being underused and others overcrowded, as shown in Figure 1 (Ghosh G et al., 2014s).

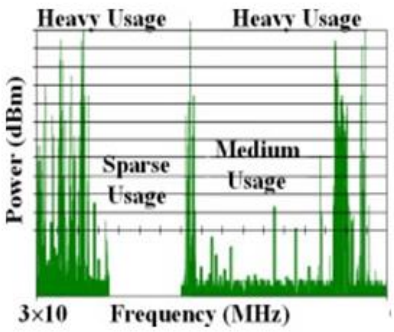

Figure 1. Radio spectrum utilisation.

This spectrum efficiency will limit the data transfer as it cannot accommodate more number of users due to that QOS will be dropped. To solve the spectrum scarcity problem and to improve the spectrum efficiency, need an intelligent system and cognitive radio system is introduced by Joseph Mitola in 1989 and lots of research is being done on this topic solutions are proposed by many researchers and available in literature. Cognitive radio found a very good solution for advanced and efficient 5G, WSN and IoT. This paper is organized as follows. Next section will describe cognitive radio system, its applications and operation. Section 3 talk about detailed function of individual modules in cognitive radio. Section 4 shows cognitive radio architecture. System model is presented in section 5 followed with simulations and analytical evaluations are discussed in section 6. Key challenges are discussed in section 7 and paper is concluded with section 8 and the same is illustrated in the following block diagram Figure 2 (Zareei M, et al., 2017).

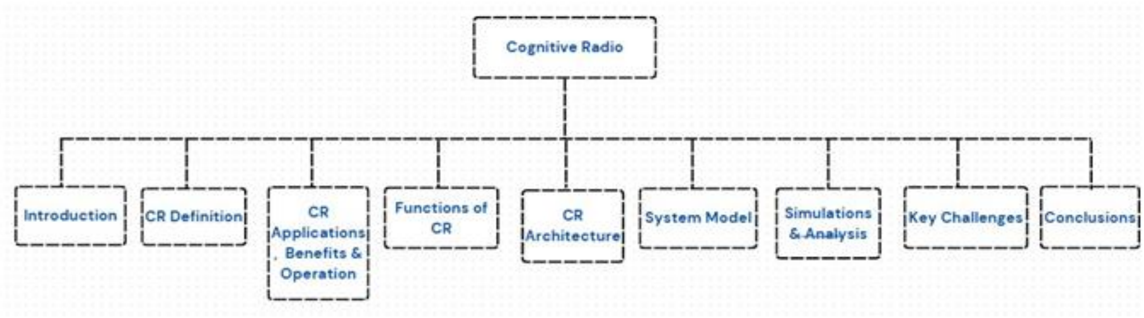

Figure 2. Paper organisation.

MATERIALS AND METHODS

Cognitive radio system definition

Cognitive radio system is a form of a smart wireless communications, in which a trans receiver intelligently detects which communication channels are available and which are not and immediately moves to vacant channels and avoid occupied ones. Since cognitive radio dynamically adapting to the radio environment (changing of transmission and reception parameters), which can significantly improve the spectrum utilization, reduce interference and supports to wider range of applications used in 5G networks and beyond (Shaat M et al., 2010).

Applications and benefits: Applying cognitive radio in wireless communication, will increase the spectrum utilization and avoid wastage of spectrum, Wi-Fi network allows user to use available channels and congestion is being avoided. Ensures reliable and efficient wireless communication due to dynamically availability of channels. It supports different types of devices by optimizing spectrum use (Zheng R et al., 2023).

Cognitive radio operation: Cognitive radio system/network is split into two networks, primary network and a secondary network. Primary network is licensed band network consists of primary base station and primary users and secondary network is unlicensed network, shares the unused spectrum with primary network and it consists of secondary base station and secondary users. Cognitive radio system continuously monitors the network and when it finds vacant channel, also called spectrum hole, it allocates to secondary user. As soon as PU arrives, SU will leave the network, without interfering PU. SUs also referred as cognitive users. Spectrum hole also known as white space is demonstrated in Figure 3 followed with cognitive cycle and cognitive network shown in Figures 4 and 5 (Wang B et al., 2010).

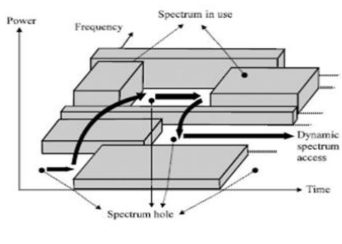

Figure 3. Spectrum hole.

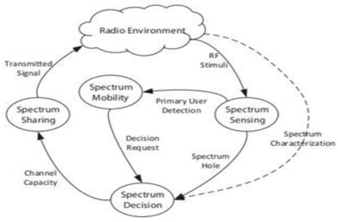

Figure 4. Cognitive cycle.

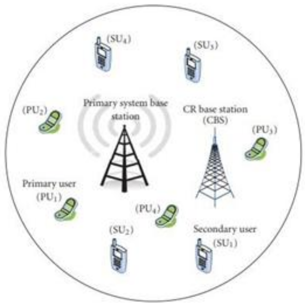

Figure 5. Cognitive radio network.

Functions of cognitive radio

Cognitive radio device has to be able to collect surrounding information in network on spectrum usage to know available channels to be used for communication in opportunistic way. Functions or features of cognitive radio are spectrum sensing, Spectrum analysis, Spectrum decision, spectrum mobility and spectrum sharing and will be discussed here. Functional diagram for cognitive radio is presented in Figure 6 (Nasser A et al., 2021).

Figure 6. Functional diagram of cognitive radio.

Spectrum sensing: Cognitive radio monitors the radio spectrum and detects which frequency bands are in use and which are not. Available frequency bands are called spectrum holes or white spaces. Cognitive user can only access idle frequency band and when the signal form PU is detected, cognitive user must vacate the allocated spectrum to avoid the harmful interference to PU.

Spectrum analysis: In this phase, cognitive radio analyses the detected spectrum holes or white spaces, to assess the suitability for communication based on factors like signal strength, noise level, inference and regulatory constraints.

Decision making: Based upon analysis, cognitive radio decides the best channel and transmission parameters like frequency, modulation and power level to use for communication and hop among multiple bands to maintain QOS requirements.

Spectrum mobility: If frequency band becomes occupied or suboptimal, then SU has to switch to another available band based on factors such as noise level, interference, path loss, channel error rate and holding time to ensure continuous communication (Yu H et al., 2020).

Spectrum sharing: In this phase, coordination among multiple cognitive users for the spectrum usage to ensure fairness and to avoid interference is done. Channels are efficiently managed and interference is avoided.

Learning: Cognitive radio learns from past experiences to improve the future spectrum sensing, spectrum analysis and decision making processes.

Cognitive radio concept architecture-ring key hardware modules

Cognitive radio architecture is presented in Figure 7. There are two sub systems in cognitive radio. A cognitive unit, takes decisions based on different inputs. A SDR unit has software that allows it to work in many different ways. Separate spectrum sub system is there to check signal environment and to see if other services or users are present. Cognitive unit is further divided into two parts, cognitive engine and policy engine. The cognitive engine, used to find the solution based on inputs and the policy engine, make sure that the solution provide by cognitive engine follows the regulatory rules and external policies (Tian J et al., 2019).

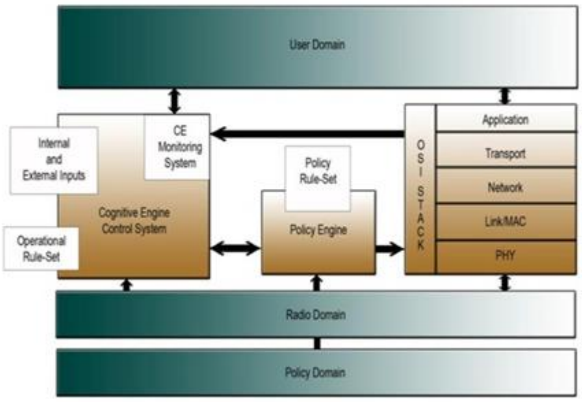

Figure 7. Cognitive radio concept architecture.

System model

Functional block diagram for system model is shown in Figure 8. Radio environment has two types of users. Primary users also called licensed users, and secondary users also called unsilenced or cognitive users. Spectrum sensing block is used to efficiently sense the free channels or holes or white spaces in network and spectrum analysis block will study the detected free channels in terms of signal quality, interference and suitability to fulfil the requirement. Based on analysis, decision block will decide the best channel to be used. Spectrum mobility block, will manage to shift the user from one channel to another and to keep communication continuous. Spectrum sharing block is used to share the channel among cognitive users to avoid interference with primary users and cognitive users. Policy engine ensures the regulatory and policy constraints. Cognitive engine is an intelligent core component of cognitive radio system coordinates with all the modules and will take intelligently takes good decisions based on input and policies. User interface is interface for users to interact with cognitive radio system (Abdel Hakeem SA et al., 2022).

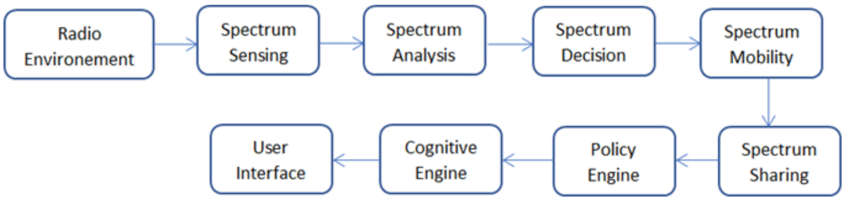

Figure 8. Functional model.

Channels and time slots:

Channels $C=[C_1, C_2, C_3, \ldots\ldots, C_n]$ (1)

Time slots $T=[T_1, T_2, T_3, \ldots\ldots\ldots T_n]$ (2)

Number of channels occupied by PUs:

Channels occupied by PUs=$r \in [0, n]$ (3)

where 'r' represents number of channels occupied by PUs

$PUs=[PU_1, PU_2, PU_3, \ldots\ldots., PU_r]$ (4)

Number of free channels available:

$C_{free}=n-r$ (5)

$C_{free}=[C_{free1}, C_{free2}, C_{free3}, \ldots.. C_{freen-r}]$ (6)

Number of SUs:

$Sun=[SU_1, SU_2, \ldots.. SU_n]$ (7)

Channel assignment to SUs following requirement criteria:

Assignment ensures that no two channels are assigned to same SUs

$SUi \rightarrow C_j, C_j \in C_{free}$ where r=1, 2, 3, n-r (8)

Channel assignment function:

$A(SU_i)=C_j, C_j \in C_{free}$ $1<i<n-r$ (9)

Probability of occupancy:

$P(O) = X, X \sim U(0, 1)$ (10)

Bandwidth requirements for SUs:

$B_n = [B_1, B_2, B_3, \quad B_n]$ (11)

Channel properties assignment:

Signal Quality=$X_{SQ} \sim U(0, N)$ N=1, 2, ……N (integer) (12)

Bandwidth=$X_{BW} \sim U(1, M)$ M=1, 2, …..M (Mbps) (13)

Latency=$X_L \sim U(1, S)$ N=1, 2, ……M (m s (14)

Stability=$X_S \sim U(0, N)$ N=1, 2, …… N (integer) (15)

RESULTS AND DISCUSSION

Simulation results and analysis

Experiments have been carried out with different parameters and different properties of environment.

Experiment 1: Simplicity purpose, in our first experiment, network is fixed with five channels and five time slots. At every time slot, PUs are Randomly generated from 0 to 5. In first step, SU will scan all the channels and detects unused spectrum (white spaces or holes) and identifies occupied channels in spectrum scanning phase and second step spectrum analysis phase, will analyse all the channels min terms of quality and suitability. Based upon analysis, third step spectrum decision will decide which channel is most suitable for SU user and allocated. In this experiment, only one SU user is used in every time slot and it is assigned available channel. Simulation results in Figure 9 demonstrates that, only one PU is generated for time slots 1 to 3 and no PU is generated for time slot 4 and two PUs are generated for time slot 5. For each time slot SU is assigned the vacant channel. In first time slot channel 3 is occupied by PU and channels 1, 2, 4, 5 are vacant channels, from which channel 5 is chosen and assigned to SU. Similarly, same procedure is followed for other time slots. Same experiment is repeated for ten channels, ten time slots and one SU is used to get channel assigned and simulation results are presented in Figure 10. The aim of this experiment is to study the basic channel assignment to one SU in cognitive radio.

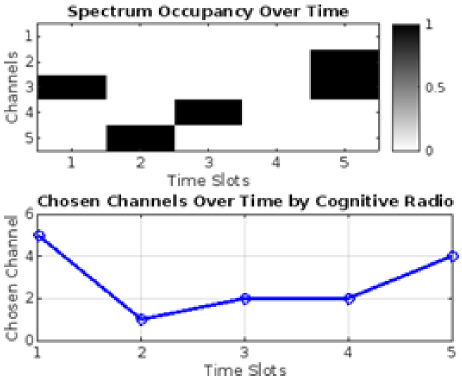

Figure 9. CR results for 5 channels.

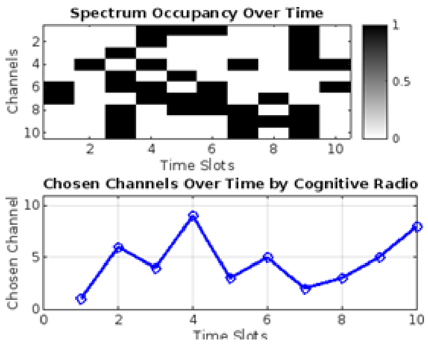

Figure 10. CR results for 10 channels.

Experiment 2: In second experiment, in order to gain comprehensive understanding of cognitive radio wider range of parameters is adjusted as shown in following Table 1 to explore different aspects of cognitive network.

Table 1. Parameters.

Total channels=20
Occupied probability=0.3
Total time-slots=50
Total number of SU mobiles=5

In this second experiment, at each time slot, PUs are randomly generated from 0 to 20. Spectrum scanning process identified the vacant channels, occupied channels and listed them. Five SU mobile nodes are assigned unique channels in each time slot. Figure 11 demonstrates total channels, PUs occupancy and empty/available channels for each time slot. Figure 12 shows, at each time slot individual mobile users are assigned unique channels. Channel occupancy is remains most of the time 30%. Table 2 demonstrates sample data of spectrum assignment which includes, spectrum occupancy where #1s to show PUs presence and #0s to show PUs absence, SU mobile number, available/vacant channels and channel chosen by SU. Summary of different channels utilized by individual SU in fifty time slots is presented in Table 3. Aim of this experiment is to study and investigate the unique channel assignment to each SU user at each time slot.

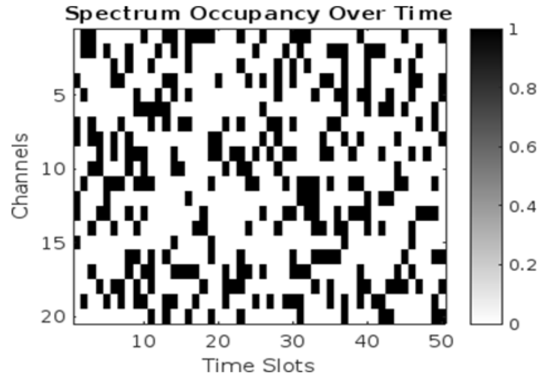

Figure 11. Spectrum occupancy.

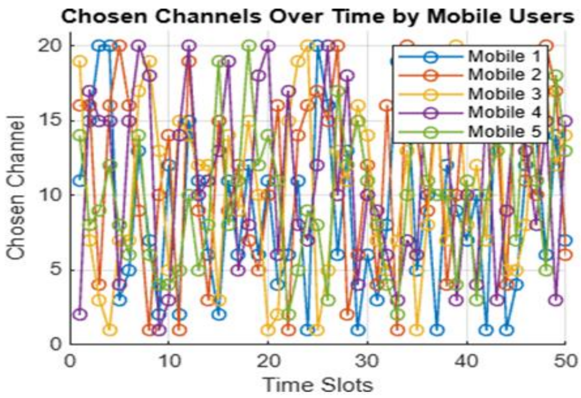

Figure 12. Channels chosen by mobile users over time.

Sample data of spectrum assignment to mobile devices in each time slot

Table 2. Sample data of spectrum assignment.

Time slot 1:
Spectrum occupancy: 0 0 0 1 0 0 1 1 0 0 0 1 1 0 1 0 0 0 0 0
Mobile user 1:
Free channels: 1 2 3 5 6 9 10 11 14 16 17 18 19 20
Chosen channel: 11
Mobile user 2:
Free channels: 1 2 3 5 6 9 10 14 16 17 18 19 20
Chosen channel: 16
Mobile user 3:
Free channels: 1 2 3 5 6 9 10 14 17 18 19 20
Chosen channel: 19
Mobile user 4:
Free channels: 1 2 3 5 6 9 10 14 17 18 20
Chosen channel: 2
Mobile user 5:
Free channels: 1 3 5 6 9 10 14 17 18 20
Chosen channel: 14

Time slot 2:
Spectrum occupancy: 1 1 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0
Mobile user 1:
Free channels: 3 4 6 7 8 9 10 12 13 14 15 16 17 18 20
Chosen channel: 15
Mobile user 2:
Free channels: 3 4 6 7 8 9 10 12 13 14 16 17 18 20
Chosen channel: 16 And so on…….

Table 3. Summary of simulation results.

Summary results:
Mobile user 1:
Chosen channels: 11 15 20 20 3 5 13 7 2 12 2 15 11 6 2 11 6 12 6 11 4 6 11 1 20 16 6 13 1 6 3 8 19 17 5 10 1 12 9 7 10 1 17 1 4 12 14 6 14 7
Mobile user 2:
Chosen channels: 16 16 4 16 20 16 9 1 10 14 1 19 9 3 15 9 12 7 5 10 16 1 14 16 17 15 20 2 6 12 4 16 1 20 14 9 17 4 10 19 17 15 15 4 19 11 10 20 17 6
Mobile user 3:
Chosen channels: 19 7 3 1 7 7 17 19 13 5 15 14 12 12 3 14 9 15 10 1 2 15 19 20 1 5 13 11 16 14 7 5 7 13

Experiment 3: In this experiment parameters and properties have been configures as follows:

Parameters are selected as shown in the following Table 4:

Table 4. Parameters.

Total channels=10;
Occupied probability=0.5;
Total time slots=5;
Number of SU mobile users=3;
Bandwidth requirements=[2, 3, 4];

Properties generated for each channel are shown according to the following Table 5:

Table 5. Properties to channels.

Assigned properties to channels
Signal quality=0 to 10
Bandwidth=1 to 5 Mbps
Latency=1 to 10 ms
Stability=0 to 10

Occupied probability is fixed to 0.5, so random number is generated between 0 and 1 for each channel and compared with occupied probability, if it is less than or equal to occupied probability, then that channel is considered as occupied, else it is considered as free channel, shown in spectrum occupancy Figure 13. Parameters are fixed and assigned properties to channels are shown in above tables. Properties of channels are graphically presented in Figure 14. Cognitive radio phases Spectrum scanning, spectrum analysis, spectrum decision, spectrum mobility and spectrum sharing are implemented and results are presented below in Figure 15 and Table 6. It is found that, in decision phase, cognitive radio preferred stability of channel or bandwidth fulfilment or signal quality or latency to occupy for communication and interference of cognitive radio with PUs and other SUs are completely avoided. Purpose of this experiment is to choose the unique channel for each secondary mobile user at each time slot based on its requirements.

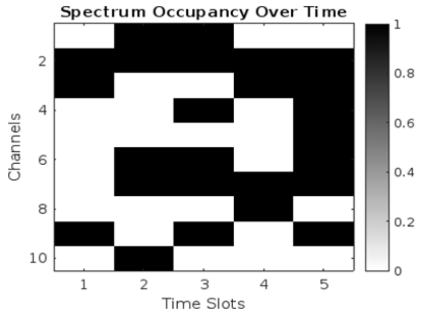

Figure 13. Spectrum occupancy.

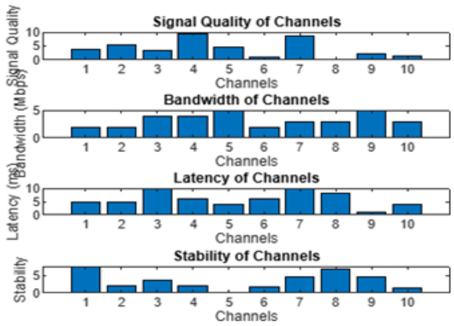

Figure 14. Properties of channels.

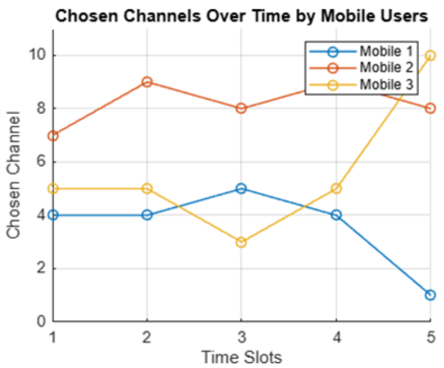

Figure 15. Chosen channels over time by mobile users.

Table 6. Spectrum occupancy and channel chosen.

Time Slot 1:
Spectrum Occupancy: 0 1 1 0 0 0 0 0 1 0
Mobile User 1:
Free Channels and their Properties:
Channel 1 - Signal Quality: 3.61, Bandwidth: 2, Latency: 5, Stability: 7.70
Channel 4 - Signal Quality: 9.41, Bandwidth: 4, Latency: 6, Stability: 2.18
Channel 5 - Signal Quality: 4.45, Bandwidth: 5, Latency: 4, Stability: 0.03
Channel 6 - Signal Quality: 1.11, Bandwidth: 2, Latency: 6, Stability: 1.92
Channel 7 - Signal Quality: 8.65, Bandwidth: 3, Latency: 10, Stability: 4.50
Channel 8 - Signal Quality: 0.36, Bandwidth: 3, Latency: 8, Stability: 6.82
Channel 10 - Signal Quality: 1.38, Bandwidth: 3, Latency: 4, Stability: 1.28
Chosen Channel: 4
Mobile User 2:
Free Channels and their Properties:

Channel 1 - Signal Quality: 3.61, Bandwidth: 2, Latency: 5, Stability: 7.70
Channel 4 - Signal Quality: 9.41, Bandwidth: 4, Latency: 6, Stability: 2.18
Channel 5 - Signal Quality: 4.45, Bandwidth: 5, Latency: 4, Stability: 0.03
Channel 6 - Signal Quality: 1.11, Bandwidth: 2, Latency: 6, Stability: 1.92
Channel 7 - Signal Quality: 8.65, Bandwidth: 3, Latency: 10, Stability: 4.50
Channel 8 - Signal Quality: 0.36, Bandwidth: 3, Latency: 8, Stability: 6.82
Channel 10 - Signal Quality: 1.38, Bandwidth: 3, Latency: 4, Stability: 1.28
Chosen Channel: 7
Mobile User 3:
Free Channels and their Properties:
Channel 1 - Signal Quality: 3.61, Bandwidth: 2, Latency: 5, Stability: 7.70
Channel 4 - Signal Quality: 9.41, Bandwidth: 4, Latency: 6, Stability: 2.18
Channel 5 - Signal Quality: 4.45, Bandwidth: 5, Latency: 4, Stability: 0.03
Channel 6 - Signal Quality: 1.11, Bandwidth: 2, Latency: 6, Stability: 1.92
Channel 7 - Signal Quality: 8.65, Bandwidth: 3, Latency: 10, Stability: 4.50
Channel 8 - Signal Quality: 0.36, Bandwidth: 3, Latency: 8, Stability: 6.82
Channel 10 - Signal Quality: 1.38, Bandwidth: 3, Latency: 4, Stability: 1.28
Chosen Channel: 5
Time Slot 2: Spectrum Occupancy: 1 1 0 0 0 1 1 0 0 1
Mobile User 1:
Free Channels and their Properties:
Channel 3 - Signal Quality: 3.58, Bandwidth: 4, Latency: 10, Stability: 3.53
Channel 4 - Signal Quality: 9.41, Bandwidth: 4, Latency: 6, Stability: 2.18
Channel 5 - Signal Quality: 4.45, Bandwidth: 5, Latency: 4, Stability: 0.03
Channel 8 - Signal Quality: 0.36, Bandwidth: 3, Latency: 8, Stability: 6.82
Channel 9 - Signal Quality: 2.23, Bandwidth: 5, Latency: 1, Stability: 4.68
Chosen Channel: 4
Mobile User 2:
Free Channels and their Properties:
Channel 3 - Signal Quality: 3.58, Bandwidth: 4, Latency: 10, Stability: 3.53
Channel 4 - Signal Quality: 9.41, Bandwidth: 4, Latency: 6, Stability: 2.18
Channel 5 - Signal Quality: 4.45, Bandwidth: 5, Latency: 4, Stability: 0.03
Channel 8 - Signal Quality: 0.36, Bandwidth: 3, Latency: 8, Stability: 6.82
Channel 9 - Signal Quality: 2.23, Bandwidth: 5, Latency: 1, Stability: 4.68
Chosen Channel: 9
Mobile User 3:
Free Channels and their Properties:
Channel 3 - Signal Quality: 3.58, Bandwidth: 4, Latency: 10, Stability: 3.53
Channel 4 - Signal Quality: 9.41, Bandwidth: 4, Latency: 6, Stability: 2.18
Channel 5 - Signal Quality: 4.45, Bandwidth: 5, Latency: 4, Stability: 0.03
Channel 8 - Signal Quality: 0.36, Bandwidth: 3, Latency: 8, Stability: 6.82
Channel 9 - Signal Quality: 2.23, Bandwidth: 5, Latency: 1, Stability: 4.68
Chosen Channel: 5
Time Slot 3:
Spectrum Occupancy: 1 1 0 1 0 1 1 0 1 0

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Mobile User 1:
Free Channels and their Properties:
Channel 3 - Signal Quality: 3.58, Bandwidth: 4, Latency: 10, Stability: 3.53
Channel 5 - Signal Quality: 4.45, Bandwidth: 5, Latency: 4, Stability: 0.03
Channel 8 - Signal Quality: 0.36, Bandwidth: 3, Latency: 8, Stability: 6.82
Channel 10 - Signal Quality: 1.38, Bandwidth: 3, Latency: 4, Stability: 1.28
Chosen Channel: 5
Mobile User 2:
Free Channels and their Properties:
Channel 3 - Signal Quality: 3.58, Bandwidth: 4, Latency: 10, Stability: 3.53
Channel 5 - Signal Quality: 4.45, Bandwidth: 5, Latency: 4, Stability: 0.03
Channel 8 - Signal Quality: 0.36, Bandwidth: 3, Latency: 8, Stability: 6.82
Channel 10 - Signal Quality: 1.38, Bandwidth: 3, Latency: 4, Stability: 1.28
Chosen Channel: 8
Mobile User 3:
Free Channels and their Properties:
Channel 3 - Signal Quality: 3.58, Bandwidth: 4, Latency: 10, Stability: 3.53
Channel 5 - Signal Quality: 4.45, Bandwidth: 5, Latency: 4, Stability: 0.03
Channel 8 - Signal Quality: 0.36, Bandwidth: 3, Latency: 8, Stability: 6.82
Channel 10 - Signal Quality: 1.38, Bandwidth: 3, Latency: 4, Stability: 1.28
Chosen Channel: 3
Time Slot 4:
Spectrum Occupancy: 0 1 1 0 0 0 1 1 0 0
Mobile User 1:
Free Channels and their Properties:
Channel 1 - Signal Quality: 3.61, Bandwidth: 2, Latency: 5, Stability: 7.70
Channel 4 - Signal Quality: 9.41, Bandwidth: 4, Latency: 6, Stability: 2.18
Channel 5 - Signal Quality: 4.45, Bandwidth: 5, Latency: 4, Stability: 0.03
Channel 6 - Signal Quality: 1.11, Bandwidth: 2, Latency: 6, Stability: 1.92
Channel 9 - Signal Quality: 2.23, Bandwidth: 5, Latency: 1, Stability: 4.68
Channel 10 - Signal Quality: 1.38, Bandwidth: 3, Latency: 4, Stability: 1.28
Chosen Channel: 4
Mobile User 2:
Free Channels and their Properties:
Channel 1 - Signal Quality: 3.61, Bandwidth: 2, Latency: 5, Stability: 7.70
Channel 4 - Signal Quality: 9.41, Bandwidth: 4, Latency: 6, Stability: 2.18
Channel 5 - Signal Quality: 4.45, Bandwidth: 5, Latency: 4, Stability: 0.03
Channel 6 - Signal Quality: 1.11, Bandwidth: 2, Latency: 6, Stability: 1.92
Channel 9 - Signal Quality: 2.23, Bandwidth: 5, Latency: 1, Stability: 4.68
Channel 10 - Signal Quality: 1.38, Bandwidth: 3, Latency: 4, Stability: 1.28
Chosen Channel: 9
Mobile User 3:
Free Channels and their Properties:
Channel 1 - Signal Quality: 3.61, Bandwidth: 2, Latency: 5, Stability: 7.70
Channel 4 - Signal Quality: 9.41, Bandwidth: 4, Latency: 6, Stability: 2.18
Channel 5 - Signal Quality: 4.45, Bandwidth: 5, Latency: 4, Stability: 0.03

Channel 6 - Signal Quality: 1.11, Bandwidth: 2, Latency: 6, Stability: 1.92
Channel 9 - Signal Quality: 2.23, Bandwidth: 5, Latency: 1, Stability: 4.68
Channel 10 - Signal Quality: 1.38, Bandwidth: 3, Latency: 4, Stability: 1.28
Chosen Channel: 5
Time Slot 5:
Spectrum Occupancy: 0 1 1 1 1 1 1 0 1 0
Mobile User 1:
Free Channels and their Properties:
Channel 1 - Signal Quality: 3.61, Bandwidth: 2, Latency: 5, Stability: 7.70
Channel 8 - Signal Quality: 0.36, Bandwidth: 3, Latency: 8, Stability: 6.82
Channel 10 - Signal Quality: 1.38, Bandwidth: 3, Latency: 4, Stability: 1.28
Chosen Channel: 1
Mobile User 2:
Free Channels and their Properties:
Channel 1 - Signal Quality: 3.61, Bandwidth: 2, Latency: 5, Stability: 7.70
Channel 8 - Signal Quality: 0.36, Bandwidth: 3, Latency: 8, Stability: 6.82
Channel 10 - Signal Quality: 1.38, Bandwidth: 3, Latency: 4, Stability: 1.28
Chosen Channel: 8
Mobile User 3:
Free Channels and their Properties:
Channel 1 - Signal Quality: 3.61, Bandwidth: 2, Latency: 5, Stability: 7.70
Channel 8 - Signal Quality: 0.36, Bandwidth: 3, Latency: 8, Stability: 6.82
Channel 10 - Signal Quality: 1.38, Bandwidth: 3, Latency: 4, Stability: 1.28
Chosen Channel: 10
Summary Results:
Mobile User 1:
Chosen Channels: 4 4 5 4 1
Mobile User 2:
Chosen Channels: 7 9 8 9 8
Mobile User 3:
Chosen Channels: 5 5 3 5 10

Key challenges

Below are the key challenges faced in the design and implementation of cognitive radio:

Spectrum sensing:

Detection accuracy: Cognitive radios must be able to determine the presence of spectrum holes (unoccupied frequencies) to ‘learn’ from the primary user and not interfere with his/her use of the specific frequency. But identifying weak signatures in noisy environments or under fading situations is not easy and results to false alarms or missed detections.

Sensing time and delay: Spectrum sensing also has to be done in real time with little delay so as to be able to respond quickly to any new changes. One of the key problems is the decrease of the sensing time while ensuring high detection accuracy.

Hidden node problem: It can be also hidden by physical obstacles or fade effects so primary users can be not revealed. This hidden node problem may cause cognitive radios to falsely assume the spectrum is clear thus causing interference.

Energy efficiency: Cooperative spectrum sensing is known to be energy consuming especially if it is to be done on hand held devices. One of the main design constraints is where to find a right measure between energy consumption and accurate sensing.

Spectrum management:

Dynamic spectrum allocation: Controlled allocation of the available spectrum amongst a number of cognitive radio users (secondary users) is not an easy task as it ensures fair access to the authorized spectrum, and also reduces as much as possible interference with the primary users. This calls for efficient algorithms for schedule that would allow for real time spectrum management.

Quality of Service (QOS) assurance: This is due to the instability of the spectrum and so when it comes to the issue of Quality of Service required such as; latency, throughput and reliability of varying applications, it becomes a challenge.

Interference management: Cognitive radios has to use only that spectrum space that is available with licensed users, as well as other cognitive radios, without any injurious effect. The main strategy that needs to be applied in the realization of CR operation is to ensure that proper interference management is incorporated into the protocols and algorithms that are applied in the environment.

Designing a cognitive radio network:

Network coordination and control: Many cognitive radios may have to work in a distributed fashion; hence, efficient methods for reporting sensed spectrum and addressing interference as well as controlling efficient use of the spectrum must exist.

Mobility management: Users can be mobile thus making changes in the available frequency band frequently. Some of the big issues, and there are many, involve transitioning from one cell to another and hand-off, and guaranteeing a consistent QoS during this process.

Scalability: The more users are learning, adopting and using the cognitive radio, the harder becomes the challenges involved in the spectrum management, coordination and interferences. Algorithm and architecture scalability is a very critical measure in large scale implementations.

Machine learning integration:

Data collection and processing: Cognitive radios use means data models in making their decision making process. Nevertheless, gathering sufficient, high quality data in real-time for collecting, analyzing and utilizing data relevant to current conditions of the network is quite difficult.

Model training and adaptation: Deep machine learning models consist of algorithmic models, which need to be trained using big data which is a scarce commodity at times. In addition, these models have to be dynamic in accommodating environment change, user behavior, and spectrum availability, which can be challenging in dynamic networks.

Computational complexity: When it comes to machine learning algorithm, deep learning or reinforcement learning one might find the computations to be highly complex and might put a strain on real time processing in devices with limited processing power.

Security and privacy:

Spectrum sensing data falsification attacks: It explained that cognitive radios are prone to adversarial operations in which one party feeds the other with wrong spectrum sensing information with intention of changing the frequency utilization of a spectrum or interrupting a specific network.

Unauthorized spectrum access: Cognitive radios have to be able to identify any unauthorized intrusions into the licensed frequency bands so that any regulatory infringement or interference is nipped in the bud.

Privacy concerns: Like all cognitive radios, these systems tend to exchange spectrum sensing data and network information and, therefore, privacy infringement. The two major concerns are firstly, how the exchange of data can occur securely and secondly, how the privacy of the user can be protected.

Regulatory and standardization:

Regulatory compliance: Cognitive radios have to conform to some set of regulations that may be geographic or country specific. The major constraint is how to comply with DSA rules and regulation and at the same time not to cause any interference with the licensed users.

Lack of standardization: Lack of standardization for the cognitive radio technology at the international level is a limitation since it may not be easily adopted across the world. Standardization of these solutions is one of its major prerequisites there must be common protocols and frameworks.

Hardware and implementation:

Reconfigurable hardware design: Cognitive radios need to have dynamic hardware structures in which the hardware is also programmable and they often use SDRs. It is difficult to develop a reconfigurable hardware which is low cost, low power dissipation and possesses high performance.

Computational resources: As it was depicted, employing higher degrees of cognition as spectrum sensing, decision making and machine learning on the system demands huge computational power. The management of resources is the other aspect that needs to be tuned and fine-tuned to fit the performance dictated by the hardware's architecture.

Real-time processing: Cognitive radios have to work in real-time to sense the environment, make decision and adapt rapidly to the change. Maintainability of low latency and response time is difficult in even relatively simple scenarios and with slight variations.

Cross-layer design:

Integration across protocol layers: CR capabilities that include sensing, decision making, and spectrum allocation cut across physical, MAC and the network layers. The most difficult task is to achieve the best interaction between layers and its integration to improve operational efficiency and flexibility.

Trade-offs between layers: There is always a conflict of interest between various layers (for example, energy consumption at the physical layer and throughput at the network layer), and therefore the solutions need to be well thought through and complex.

Economic and market:

Incentive mechanisms: Prescribing the right motivation to prompt primary users to release their spectrum and to make the secondary users conform to spectrum-sharing policies is not easy. It is critical that spectrum resale is kept realistic whilst remaining fair.

Market adoption: The actual use of cognitive radio technology means that stakeholders such as the regulators, the service providers and the end-users have to approve it.

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The technological advancement, the costs required to invest in the technology, and perceived benefits also affect the level of diffusion.

User experience:

User adaptation and acceptance: Since users cannot tolerate interruptions, delays, and poor quality of the communication in cognitive radios, issues related to QoE are critical to ensure end-users' acceptance.

Interface design: Thus, design of user interfaces for controlling and configuring such cognitive radios especially for a layman becomes difficult.

CONCLUSION

In this paper overall view of cognitive radio is presented, functionality, features and architecture are shown. Cognitive radio is studied, implemented and results are analysed. Three experiments have been conducted. In first experiment, simple implementation is applied just to see, how cognitive radio really works and we found all stages of cognitive radio worked perfectly well. In second experiment, to study the cognitive radio network operation in detail, more number of channels is chosen in network and performance in evaluated. In third experiment, properties are assigned to each channel along with parameters and found that cognitive radio preferred stability of channel or bandwidth fulfilment or signal quality or latency to occupy for communication. Interference of cognitive radio with PUs and other SUs are completely avoided. Here assuming that every SU has its own channel requirement and channel is assigned accordingly. Work is under process to test cognitive radio in heavy traffic and congestion condition environment and will be published soon.

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