

Evaluation of Spectrum Sharing in Cognitive Radio Networks Using Fuzzy Logic

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Abstract- Cognitive radio (CR) network is the footstep and essential need of the new wireless emerging technologies like the Wireless Sensor Network (WSN), Internet of Things (IoT), Bluetooth, and Vehicular Ad Hoc Network (VANET). Due to tremendous progress in the number of wireless devices and their traffic, large scale use of these technologies may soon cause a shortage of spectrum as all these technologies use unlicensed bands. So, CR is a vital choice for their survival. The proliferation of mobile devices and the heterogeneous environment of wireless communications has increased the need for additional spectrum for data transmission. It is not possible to altogether allocate a new band to all networks, which is why fully efficient use of the already available spectrum is the demand of the day. Cognitive radio (CR) technology is a promising solution for efficient spectrum utilization, where CR devices, or secondary users (SUs), can opportunistically exploit white spaces available in the licensed channels. SUs have to immediately vacate the licensed channel and switch to another available channel when they detect the arrival of the incumbent primary user. However, performance for the SU severely degrades if successive channel switching happens. Moreover, taking the channel-switching decisions based on crisp logic is not a suitable approach in the brain-empowered CR networks (CRNs) where sensing information is not only imprecise and inaccurate but also involves a major uncertainty factor. In this paper, I propose a fuzzy logic-based decision support system (FLB-DSS) that jointly deals with channel selection and channel switching to enhance the overall throughput of CRNs. The proposed scheme reduces the SU channel switching rate and makes channel selection more adaptable. The performance of the proposed scheme is evaluated using a fuzzy logic, and a comprehensive comparison study with a baseline scheme is presented. The simulation results are promising in terms of the throughput and the number of hand-offs and making our proposed FLB-DSS a good candidate mechanism for SUs while making judicious decisions in the CR environment.

Keywords- a fuzzy logic-based decision , CR environment etc.

I. INTRODUCTION

The available electromagnetic radio spectrum is a limited natural resource and getting crowded day by day due to increase in wireless devices and applications. It has been also found that the allocated spectrum is under utilized because of the static allocation of the spectrum. Also, the conventional approach to spectrum management is very inflexible in the sense that each wireless operator is assigned an exclusive license to operate in a certain frequency band.

And, with most of the useful radio spectrum already allocated, it is difficult to find vacant bands to either deploy new services or to enhance existing ones. In order to overcome this situation, there is needed to come up with a means for improved utilization of the spectrum creating opportunities for dynamic spectrum access. Because of the developing interest of the remote correspondences exceptionally in the situation when I have restricted or

under used assets, increasingly more spectrum assets are required which gives us the inspiration of Cognitive Radio. Cognitive radio is a versatile, intelligent radio and system innovation that recognizes the accessible diverts in a remote spectrum. Intellectual Radio Systems includes Primary Users (PU) and Secondary Users (SU).

In the event that the sign is unfit to recognize the nearness of PU it alludes to the SU, with the goal that it doesn't make any association the PU. Out of all the biggest reason that tends to inefficiency in usage of the radio spectrum is the licensing scheme in the spectrum allocation.

The traditional command-and-control model which is followed while distribution of spectrum holds a drawback that the radio spectrum allocated to the licensed user is not used by the unlicensed user for its further application and stays ideal when the licensed user is not using the spectrum. And the reason being the static and the inflexible allocation, we need to confine to a dedicated

spectrum band operation, which returns to a wastage in the efficient resource for use. Hence the adaptability of the transmission band with respect to different environment is compromised. So the focus of our tends to lie on the issue that the scarcity of the resources be met with availability.

1. Cognitive Radio Networks:

Cognitive radio is another worldview of structuring remote correspondence frameworks which expects to improve the use of the Radio Frequency (RF) spectrum. The inspiration behind CR is the shortage of the accessible frequency spectrum, expanding request, brought about by the rising remote applications for remote users [1] [13].

The majority of the accessible radio spectrum has just been allotted to existing remote users, and just some frequency spectrum of it tends to be authorized to new remote applications. Regardless, an examination by the Spectrum Policy Task Force (SPTF) of the Federal Communications Commission (FCC) has demonstrated some results that some frequency groups are intensely utilized by licensed user at specifically areas and at specific timings, however that there are additionally numerous frequency groups which are just mostly involved or to a great extent vacant, remain unused. For instance we have a case that of spectrum band distributed to cell organizes in the USA which achieve the most elevated usage amid working hours, however remain to a great extent empty from midnight until early morning.

Out of all the biggest reason that tends to inefficiency in usage of the radio spectrum is the licensing scheme in the spectrum allocation. The traditional command - and - control model which is followed while distribution of spectrum holds a drawback that the radio spectrum allocated to the licensed user is not used by the unlicensed user for its further application and stays ideal when the licensed user is not using the spectrum .And the reason being the static and the inflexible allocation, we need to confined to a dedicated spectrum band operation, which returns to a wastage in the efficient resource for use. Hence the adaptability of the transmission band with respect to different environment is compromised [2].

For instance, in the event that one spectrum band is vigorously utilized, the remote user can't change to work on another on the more utilized band. The privilege to get to the spectrum is commonly characterized by transmit power, frequency, spectrum owner, space, sort of utilization, and the term of permit [14].

Regularly, a permit is allocated to one licensee, and the utilization of Spectrum by this licensee must fit in with the detail in the permit (for example most extreme transmit control, area of base station). In the current spectrum permitting plan, the license can't change the kind of utilization or exchange the privilege to other licensee. This constrains the utilization of the recurrence spectrum and

results in low use of the frequency spectrum. Basically, because of the present static spectrum licensing scheme, spectrum holes or spectrum holes arises. Spectrum holes are therefore characterized as frequency bands which are designated to, however in certain areas and at times not used by, licensed users, and in this way, could be used by unlicensed user.

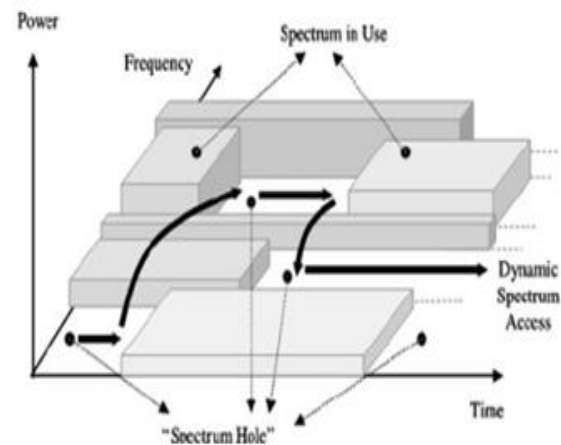


Fig 1. Spectrum Holes.

The constraints in spectrum access because of the static spectrum authorizing plan can be outlined as pursues:

- 1.1 Fixed sort of spectrum utilization:** In the present spectrum authorizing plan, the kind of spectrum use can't be changed. For instance, a TV band which is apportioned to National Television System Committee (NTSC) - based simple TV can't be utilized by advanced TV communicate or broadband remote access innovations. Notwithstanding, this TV band could remain to a great extent unused in numerous areas because of satellite TV frameworks.
- 1.2 Licensed for a huge district:** When a spectrum is licensed, it is generally allotted to a specific client or remote specialist co-op in a huge locale (for example a whole city or state). In any case, the remote specialist co-op may utilize the spectrum just in territories with a decent number of supporters, to pick up the most noteworthy rate of profitability. Thus, the dispensed recurrence spectrum stays unused in different regions, and different clients or specialist organizations are disallowed from getting to this spectrum.
- 1.3 Large lump of licensed spectrum:** A remote specialist organization is commonly licensed with a vast piece of radio spectrum (for example 50 MHz). For a specialist organization, it may not be conceivable to get permit for a little spectrum band to use in a specific territory for a brief time frame to meet a transitory pinnacle traffic load. For instance, a cdma2000 cell specialist organization may require a spectrum with transmission capacity of 1.25MHz or 3.75MHz to give transitory remote access administration in a hotspot territory.

2. Functions of Cognitive Radio:

The main functions of cognitive radio to support intelligent and efficient dynamic spectrum access are as follows:

2.1 Spectrum scrutiny: The data acquired from spectrum sensing is utilized then to calendar and plan spectrum access by the unlicensed clients. For this situation, the correspondence necessities of unlicensed clients are additionally used to enhance the transmission parameters [4]. Real parts of spectrum management that is the spectrum access Optimization, spectrum analysis. In spectrum examination, data from spectrum sensing is broke down to pick up information about the spectrum.

2.2 Spectrum sharing: Spectrum sharing is a promising technique to enhance spectrum utilization in cognitive radio environments. Cognitive sharing the spectra of licensed users provides unlicensed users with the opportunity to access rigid spectrum resources without degrading the performance of the licensed users [5]. The result of this simultaneous sharing of limited spectrum resources by licensed and unlicensed users is more efficient spectrum utilization. Spectrum sharing with licensed users is achieved by allowing unlicensed users to transmit when the interference power constraint at the licensed users is being satisfied [6]. The interference power constraint protects the performance of the licensed users while at the same time determining the performance of the unlicensed users sharing the licensed spectrum. Therefore, the interference power constraint plays an important role in the spectrum sharing environment.

2.3 Spectrum Sensing: The objective of spectrum sensing is to decide the status of the spectrum and the action of the licensed users by occasionally sensing the objective frequency band. Spectrum sensing can be either concentrated or dispersed. In brought together spectrum sensing, a sensing controller (for example passageway or base station) detects the objective recurrence band, and the data in this manner acquired is imparted to different hubs in the framework Specifically, a cognitive radio handset recognizes an unused spectrum or spectrum openings (for example band, area, and time) and furthermore decides the strategy for getting to it (for example transmit power and access span) without interfering with the transmission of a licensed user [6]. Spectrum sensing can decrease the complex nature of client terminals, since all the sensing capacities are performed at the sensing controller. Be that as it may, unified spectrum sensing experiences area decent variety. For instance, the sensing controller will most likely be unable to distinguish an unlicensed client at the edge of the cell. In appropriated spectrum sharing, unlicensed clients perform spectrum sensing autonomously, and the spectrum sensing results can be either utilized by individual intellectual radios (for

example non-helpful sensing) or imparted to different clients (for example agreeable sensing). But in all ways sensing acquires a correspondence and handling overhead, the exactness of spectrum sensing is higher than that of non-helpful sensing.

3. Cognitive Radio Cycle:

Simon Haykin proposed a basic cognitive cycle in 2005. He considered CR as a feedback system and the functionalities that are required to carry out by a cognitive radio to access a white space spectrum in DSA forms a CR cycle. The cognitive cycle starts with the passive sensing of RF stimuli and executes a series of tasks sequentially. The tasks performed by a CR include spectrum sensing, spectrum management, and spectrum sharing and spectrum mobility. Spectrum sensing enables CR users to detect the primary user's signal in licensed bands [8].

CR users periodically monitor spectrum bands to find spectrum holes. CR users must avoid conflict with primary users by determining their transmission activity in a band. In spectrum decision/ management process the best available channel is selected which meets the user communication requirements [9]. CRs analyses the channel characteristics of the sensed idle channel in order to determine if it satisfies the desired quality of service (QoS). Also, they must be aware of the activity of licensed users to get a calculation on how long SUs can use that channel without interrupting PU activity.

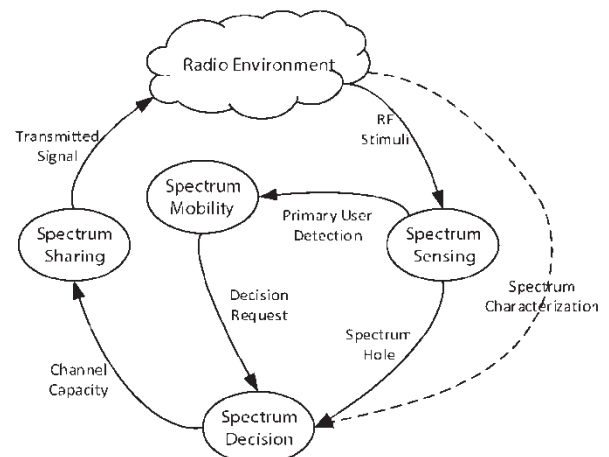


Fig 2. Cognitive Radio Cycle.

Spectrum sharing is the core of dynamic spectrum access since it determines how fairly the white space is being shared different SUs. The objective is to assign spectrum bands to cognitive users in order to avoid interfering with licensed users and maximize their performance. Spectrum mobility refers to CR users' ability to quickly adapt and leave a channel in a changing environment [6]. Even after initiating transmission in the best suited channel, CRs must continue to monitor the same channel since PU may appear at any time. When the presence of PU is detected, CR must ceases its transmission in that channel and make

it available for the PU. In the meantime it should find another white space to continue its transmission.

4. CRN Applications:

4.1 Leased Networks: The primary user can provide a leased network by allowing opportunistic access to its licensed spectrum with an agreement. A primary network (PN) allows unlicensed or secondary networks (SNs) to temporarily use part of its spectrum in exchange for monetary payments and/or some type of service provided by the SNs to the spectrum owner, assuring the absence of harmful interference at the primary users (PUs). The PN improves its revenue, its performance, or both, while the SNs gain access to spectrum resources, achieving a win-win situation. Besides that, SU should reduce their interference level within a specified limit so that PU doesn't have to sacrifice the required QoS. Leased network is more preferable for the PU since its utility is increasing. Eg:- A Primary network can provide its spectrum access rights to a regional community for the purpose of broadband access.

4.2 SMART grid networks: When intelligence is added to the conventional power grid, it becomes a smart grid. A smart grid transforms the way power is generated, delivered, consumed and billed. One of the high level layers of smart grid called as Advanced Metering infrastructure (AMI) or field area network (FAN) that carry information between premises via smart meters often require a bandwidth in a range of 10-100Kb/s per device. Therefore legacy cellular network cannot be assisted for AMI/FAN as cellular data traffic grows dramatically year by year. Also, it has coverage issues in rural areas. Cognitive-radio-based AMI/FANs may offer many advantages such as bandwidth, distance and cost, as compared with other wireline/wireless technologies in certain markets.

4.3 Public safety networks: Public safety and emergency networks are another area in which CRN can be implemented. In the case of natural disasters, which may temporarily disable or destroy existing communication infrastructure, emergency personnel working in the disaster areas need to establish emergency networks. CRN can enable the usage of the existing spectrum without the need for an infrastructure and by maintaining communication priority and response time.

4.4 Cellular networks: Rural areas with low population density are known to have poor cellular coverage. It is because of the fact that the installation cost for infrastructure cannot be recovered back due to insufficient number of subscribers. If white space spectrum such as TVWS is being made available for unlicensed use, cellular operators can use them for backhaul, to connect their cell towers to their backbone networks. Thus reducing labor intensive backhaul cables installation and thereby providing coverage to more customers in underserved areas.

Another access network application is in femtocell networks. Usually, femtocell consumers buy a mini-cell tower from their cellular operator and install them in their homes since they are getting bad coverage in certain parts of the home. Major issue with these femtocells is, since these operate in same frequency of cellular network, QoS is sacrificed due to interference. In addition, coverage of these cells is limited. When TVWS is used for femtocells, above mentioned issues can be avoided to a greater extent since there is no interference between femtocell and main cell.

II. LITERATURE SURVEY

In the present era, how important is the communication, transmission and broadcasting of information and data is, explaining the importance of it would be a waste of time. Radio frequency range is from 300 GHz to 9 kHz. The whole idea of transmitting a piece of information [10] or data between a transmitter and receiver through a single or various channel system, happen to occur over this frequency range. The band of frequency called Radio frequency with the help transmitter and antennas, can be used for several type of wireless communication. [13][9]

From cell phones to police scanners, from TV sets to garage-door openers, virtually every wireless device depends on access to the radio frequency wireless spectrum. As a result, the over usage of the spectrum of the radio frequency now results in the scarcity frequency range [12]. As a growth of the applications, the spectrum allocation has become very scarce. In such scenario, CR has been a relief which tackles with the problem of spectrum scarcity. [8]

Cognitive radio works on the principle of CR device relies on a cycle of observation, analysis, and decision and an opportunistic access to the available bandwidth.

Hence the CR device has to sense the presence of primary user and then opportunistically transmits whenever a frequency/time slot is vacant. Considering the spectrum utilization at various bands, there is a clear opportunity to use them again in future. By the priority of users in the usage of the frequency band in the CR, there are two types of users namely. [12]

Primary users often termed as licensed user and secondary users. Usually the SU's are allowed to use the frequency spectrum so that they do not overlay with PU's or cause any disturbance for the primary user. There are various methods of spectrum sensing done by cognitive radio. Sensing can be done methods namely, Energy detection method, Matched filter, Cyclo- stationary based detection, [8] [11] Fuzzy based detection.

Each method has its own drawback and advantages. Fuzzy based detection is the latest detection method that is being

implemented and has great advantages over the other methods. Because fuzzy theory helps dealing with the the uncertain noise and conditions, when RF environment is changing too fast Fuzzy logic is implemented at the FC (fusion centre). [14]

Single threshold is also considered for detection where a single threshold is decided and presence and absence of primary user is decided on the basis of that whereas in double threshold method λ_1 and λ_2 , two thresholds are calculated and the region between them is considered as confused region or fuzzy region. [8] The decision at Fuzzy region is taken by FLD (fuzzy logic detector). While calculating the thresholds; there is n Number of samples taken.

In the existing literature, most of the work was done for channel selection, [4] PU detection and to reduce the channel switching rate while considering various parameters affecting the performance of the CRNs. However, a hybrid approach can ensure better channel utilization with minimum handoff rates.

Furthermore, it can also ensure the suitable channel selection using parameters that have great influence on these two phenomena to improve that which is lacking. This paper resolves the issue of minimizing the channel switching rate by using two effective approaches [14]. First, we use the interweave approach by selecting the best channel for transmission. Second, we use the underlay approach by minimizing the SU's transmission power to increase the final throughput of the network while minimizing the channel handoff rates.

III. SPECTRUM SHARING

1. Introduction:

CR technology makes it possible to reuse valuable spectrum resources without changing the existing spectrum allocation policy, thus addressing the problem of low utilization rate. The core idea of CR is to realize spectrum sharing through dynamic spectrum access, and the implication of spectrum sharing is that SUs can use the idle spectrum of PUs, but only if they cannot interfere with the communication of PUs. Typically, spectrum sharing includes four steps, as shown in figure.

1.1 Spectrum sensing: Spectrum sensing is the first step of spectrum sharing, which is the fundamental to ensure PUs from interference, to complete spectrum sharing, to improve spectrum utilization, and to realize various CR applications. SUs continuously detect the frequency bands that are being used by PUs in multi-dimensional space (such as time domain, spatial domain, frequency domain, etc.). Spectrum sensing is utilized to detect whether a PU appears and to determine if the spectrum hole is available. Therefore, the accurate perception of spectrum holes

is the first step in spectrum sharing.

1.2 Spectrum allocation: Spectrum allocation is based on the availability of spectrum holes and distributes the spectrum to SUs. Since the number of spectrum holes is not fixed, SUs need to use them through competition while the QoS of SUs are different. Therefore, the spectrum holes have to be used fairly and efficiently [11] [13]. The key of spectrum allocation is to design efficient spectrum allocation algorithms and rules, which can improve the efficiency of spectrum utilization in the case of conflict minimization or conflict-free, preferably as close to the optimal target as possible.

1.3 Spectrum access: PU has the priority access rights of the frequency band, while the SU as subordinate relationship access it. Therefore, spectrum access requires an efficient access algorithm to coordinate multiple SUs access spectrum holes, avoiding conflicts between PUs and SUs.

1.4 Spectrum handoff: SU must switch to the appropriate spectrum when one of the following three situations occurs. First of all, when the SU using a current spectrum hole, the appearance of PU will cause collisions between them, thus SU must quit this frequency band, and then switch to the other spectrum holes for communication. Secondly, when the geographical location of the SUs changes, while the PU's geographical location does not change, the optional spectrum holes for the SUs will be different, and they need to switch to the appropriate frequency band. Finally, when the frequency bands used by SUs cannot meet their communication requirements, they must switch to other frequency band that can meet their communication needs.

Relatively speaking, the spectrum resources over 6GHz are more abundant, and the service division is relatively simple and can provide continuous large bandwidth spectrum [10]. Therefore, the utilization of new spectrum resources over 6GHz has become the focus of current research. In order to meet the higher 5G spectrum requirements, it will be effective to utilize all kinds of spectrum resources, including low and high frequency bands, licensed and unlicensed frequency bands, and continuous and discontinuous frequency bands [8][4].

Compared with the existing limited spectrum sharing, this is a kind of full spectrum sharing. Different frequency bands and multiple application scenarios pose some challenges to the implementation of full spectrum sharing such as the spectrum hole in the high frequency channel may not be accurately detected by using the conventional spectrum sensing algorithms, how to allocate low/high and continuous/discontinuous frequency bands for SUs to meet their needs, and energy consumption needs to be considered while maximizing spectrum efficiency. Next, we will make a comprehensive survey of several key technologies for implementing full spectrum sharing

aiming at different application scenarios.

2. Spectrum Sharing Techniques:

Fifth Generation networks provide high bandwidth to mobile users via heterogeneous wireless architectures and dynamic spectrum access techniques. Spectrum sharing in a CRN can be classified based on three different aspects.

2.1 Centralized and distributed: According to the network architecture spectrum sharing is classified into centralized and distributed sharing. In centralized method, there will be a central entity usually called spectrum broker to control the spectrum allocation and access procedures. A distributed sensing approach is suggested such that each SU forward their sensing measurements to the spectrum broker. It is the spectrum broker which constructs spectrum allocation map and coordinate allocation among the SUs. In distributed approach, each user is responsible for the spectrum allocation and access is based on its own local policies. Such a sharing technique is adopted in cases where an infrastructure is not preferable.

2.2 Cooperative and Non-Cooperative: This classification is based on the access behavior. In cooperative spectrum sharing, each node is aware of the existence of neighboring nodes. They exchange their interference information with each other. This allows a reduced interference transmission in the network which results in the improvement of sum utility of the network. On the other hand, users in non-cooperative sharing mode is selfish and don't bother the existence of other nodes. Non-Cooperative solutions may result in reduced spectrum utilization.

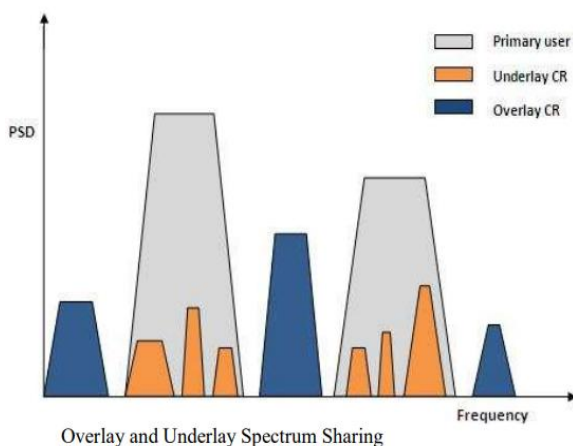


Fig 3. Over Relay & Under Relay Spectrum Sharing.

2.3 Overlay and Underlay: This classification is based on access technology. Overlay Cognitive Radios identifies the white spaces and opportunistically use the radio spectrum in the absence of PU. Spectrum sensing technique relies mainly on PU detection. Any type of modulation can be used in this type of sharing. One of the major limitations is that interference will be created to PU when SU takes to vacate the hole. In

underlay CR, SU co-exist with PU in the same spectrum so that continuous transmission is possible for SU. The transmission power of SUs is so adjusted to avoid interference to PU. PU uses spread spectrum communication and thereby considers SU transmission as noise. SU transmits using Ultra wideband modulation in order to get high data rate with low transmission power. Since UWB modulation is used, only short range communication is possible. The difference in the two techniques can be easily depicted from figure.

3. Spectrum Allocation Problem:

SA is responsible for assigning the most appropriate frequency band at the interface of a cognitive radio device according to some criteria (i.e., maximize throughput, spectral efficiency, etc.), while, at the same time, avoid causing interference to primary networks operating in the same geographical area. The SA function for each SU should determine not only the central frequency, but also the spectrum bandwidth to be used by that SU. Moreover, the available frequencies and spectrum holes dynamically change with time and location. SA problem lies under NP-complete based on its complexity. The procedure for solving SA problem in CRN is through following three steps: The criteria which define the target objective is selected.

Eg. Criteria like maximize throughput, maximize data rate, minimize the interference, spectral efficiency, energy efficiency, etc. • the selection of an appropriate technique to model the SA problem that best fit to the target objective. E.g.: approaches such as Heuristic method, linear problem programming, Graph theory, Game theory etc • Final step is to select a procedure or algorithm that will simplify and help solving SA problem to achieve the target objective.

Methods for solving SA problem in this section a few of the existing methods that are used for solving SA problem will be discussed.

3.1 Linear Programming: The Coordinated spectrum access problem in a multi-user single-transceiver CR network is formulated as a mixed integer non linear programming problem (MNLPP). The problem in MNLPP can be converted to binary linear programming (BLP). Due to its integrality in nature it can be solved using linear programming in the programming time.

3.2 Heuristics: One of the simplest techniques that are used for solving the spectrum allocation is the heuristic approach. In cases where exhaustive search is impractical, Heuristic methods can be adopted as a good candidate to find out a quick solution. They permit the use of models that are more representative of the real-world problems. In [20] channel assignment is done based on Heuristic model in which node cooperation is incorporated to improve spectrum

sensing performance.

- 3.3 Fuzzy Logics:** A Fuzzy Logic System (FLS) is unique in that it is able to simultaneously handle numerical data and linguistic knowledge. Fuzzy can be used in cases where a specific conclusion is needed based on vague, ambiguous, imprecise input information. In a novel approach using FLS is proposed which is used to control the spectrum assignment and access procedures in order to prevent multiple users from colliding in overlapping spectrum portions. One of the demerits using Fuzzy logic method is that it is really hard to determine accurate rules when many numbers of parameters are taken into account.
- 3.4 Graph Theory:** In Network conflict graph coloring technique is used as the technology to solve spectrum allocation problem. Network graphs have been extensively used in cognitive spectrum assignment, mostly for cases where the structure of the network is considered known a priori. Allocation problem is solved by mapping the cognitive network to a graph. The main drawback of graph modeling is that it is difficult to incorporate all parameters of CRN such as QoS requirements, ACI etc simultaneously.
- 3.5 Game Theory:** Game theory is found to be the most suitable mathematical tool to deal with conflicts among the users. It tries to find an optimal solution which maximizes every ones need without harming one another. Although first applied in economics, it has been applied in many fields of study and recently used to study coexistence and self-coexistence in cognitive radio networks.

IV. FUZZY LOGIC

1. Fuzzy Set:

Customary set hypothesis has a fresh idea of enrollment: a component either has a place with a set or it doesn't. Fuzzy set hypothesis contrasts from conventional set hypothesis in that halfway enrollment is permitted.

This level of enrollment is generally alluded to as the participation esteem and is spoken to utilizing a genuine incentive in $[0, 1]$, where 0 and 1 relate to full non enrollment and enrollment, separately.

2. Fuzzy Logic:

Fuzzy logic was proposed as a strategy to stretch out paired logic to cover the issue of thinking under vulnerability. Fuzzy logic can be utilized to settle on choices by utilizing deficient, surmised, and ambiguous data.

To put it plainly, rather than utilizing muddled scientific definitions, fuzzy logic utilizes human-reasonable fuzzy sets and induction rules (for example IF, THEN, ELSE, AND, OR, NOT) to acquire the arrangement that fulfills the ideal framework goals. Predicates in fuzzy logic can have incomplete degrees of truth, similarly as components

can have halfway enrollment in fuzzy set hypothesis. The evaluation of truth of a predicate is spoken to utilizing a genuine number in $[0, 1]$. The evaluation of truth of a conventional predicate P in the structure "x is an" is given by $\mu P = \mu A(x)$.

The customary logic administrators \neg (NOT), \vee (OR), and \wedge (AND) are re-imagined regarding how they alter reality estimation of the predicate(s) to which they are connected so as to deliver reality estimation of the last articulation.

3. Fuzzy Design Implimentation Skelton:

The First endeavor made to idea of fuzzy logic was made by Lotfi Zedeh. He revealed the idea and system of semantic factors. Here we use Mamdani model in order to oversee and control the various parameters of cognitive radio utilizing fuzzy tasks [1]. Thus we have two strategy to handle the issue ie. Fuzzy logic base framework and other is non fuzzy logic base framework.

In fuzzy logic structure, we have three stages:-

Comprehend physical framework.

Control necessity.

Plan the controller by utilizing fuzzy principles which incorporates the recreation of the structure and execution of configuration on further dimension.

4. Fuzzy Logic Process:

There are mainly five processes.

4.1 Fuzzyfication:

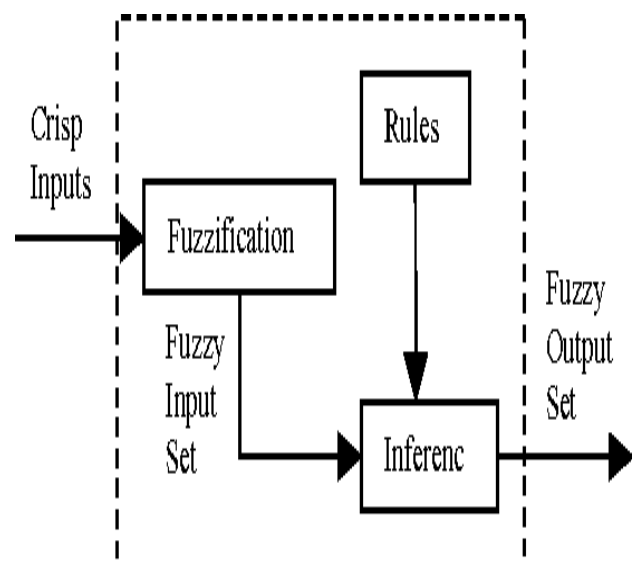


Fig 4. Text Here Your Fig Title.

Fuzzy logic depends on the thoughts of fuzzy set hypothesis and fuzzy set participation regularly found in normal (e.g., verbally expressed) language rather it is a way to deal with vulnerability genuine qualities $[0... 1]$ and logic tasks [10].

This procedure is completed for each information variable at each induction cycle, by assessing the enrollment

estimation of each trait describing it.

4.2 defuzzification:

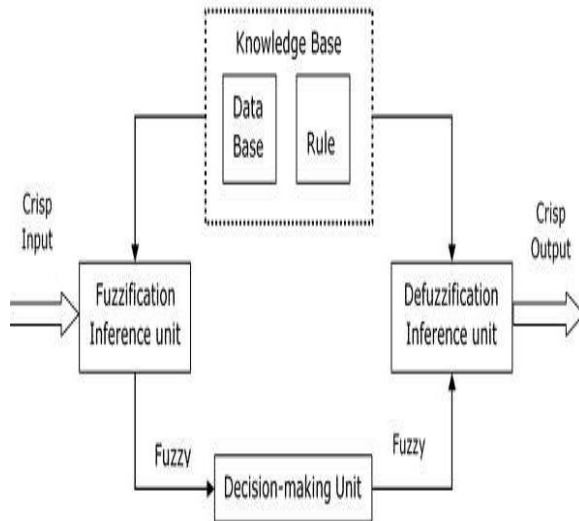


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The standard assessment and basic leadership process has delivered, for each yield variable, a participation work $\mu_C(c)$ speaking to the suitability of each yield esteem c . Defuzzification is the way toward deciding a proper fresh incentive to be utilized as the genuine yield.

A standout amongst the most generally utilized procedures for this intention is the focal point of region strategy [13], wherein the yield is resolved from the focal point of gravity of the participation work from the result of the arrangement of guidelines.

Let $\Theta = \{c \mid \mu_C(c) > 0\}$ indicate a lot of yields c with enrollment esteem bigger than zero, the proper fresh incentive at the yield of the fuzzy logic surmising framework is determined as pursues:

$$C = c\mu_C(c)$$

4.3 Membership Function Domain:

The enrollment capacity of a fuzzy set extending its incentive from 0 to 1 measures the degree or the evaluation of participation of the component of the fuzzy set.

The going qualities are with the end goal that the esteem 0 accentuation that the component isn't the individual from the fuzzy set while the esteem 1 of the participation work accentuation that it is completely an individual from the Fuzzy set. Additionally the mid going estimations of the fuzzy set accentuation that it has a place with the set in part.

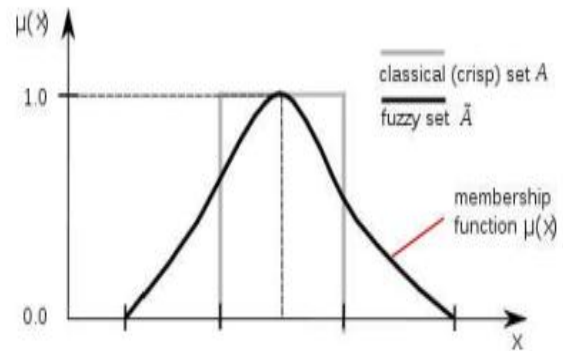


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4.4 Linguistic Variable and Rules:

Many fresh correlations are not expected to coordinate accurately a solitary esteem: fuzzy examinations are accessible to tackle the quandary [5]. The fresh supplanted with a fuzzy correlation that represents a scope of information.

We base an examination on three information esteems: the correlation point, go until the correlation has fizzled, and the present variable esteem. Delta correlation stops to be significant. Etymological factors give a characteristic smooth progress between contending rules depicting various methodologies.

4.5 Fuzzy Logic Inference:

The straightforward engineering of a fuzzy logic derivation framework is referenced beneath. The further modules creating a fuzzy logic induction framework are depicted in the remainder of this subsection.

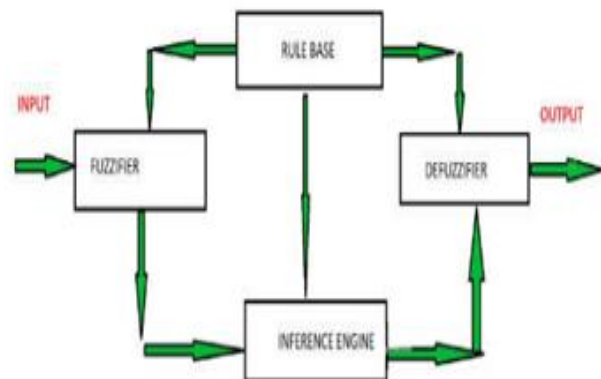


Fig 7. Text Here Your Fig Title.

5. Fuzzy Logic Controller (FLC):

So as to finish the methodology to settle on choice, in fuzzy logic hypothesis, we use "Fuzzy Logic Controller" (FLC) to execute this capacity. Basically, FLC is a lot of controlling standards. We can utilize these guidelines to settle on the yield of choice. A general FLC comprises of four modules: a fuzzy guideline base, a fuzzy induction motor and a fuzzification/defuzzification module [4].

A FLC works by rehashing a cycle of five stages executed by these four modules. Initially, estimations are got of all factors that speak to applicable states of the controlled procedure. Next, these estimations are changed over into fitting fuzzy sets to express estimation vulnerabilities. This progression is called fuzzification.

The fuzzified estimations are then utilized by the induction motor to assess control rules put away in the fuzzy guideline base. The aftereffect of this assessment is a few fuzzy sets characterized on the universe of talk of potential activities. This fuzzy set is then changed over, in the last advance of the cycle, into a fresh esteem. This change is called defuzzification.

The defuzzified values speak to moves made by the FLC in individual control cycles. Basically, the fuzzy logic controller is a calculation which can change over the semantic control technique dependent on master learning into a programmed control methodology. Particularly the philosophy of FLC seems valuable when the procedures are unreasonably confused for investigation by the conventional quantitative systems [2].

In the CR organize, accessible wellsprings of data are deciphered quantitatively, inaccurate or uncertainly, the utilization of fuzzy logic controller can take care of these difficult issues.

V. SYSTEM MODEL

Our system model comprises a primary network (PN) and a secondary network (SN). Therein, the PN consists of N PUs, and the SN consists of M SUs. We use a hybrid channel selection approach that includes characteristics of both overlay and underlay channel models [3].

The PU is a privileged user and can use its licensed channel any time without interruption. However, the SU is an opportunistic user, and can only exploit the licensed channel when the PU is not using it or when its generated interference remains below a predefined threshold.

If the SU's generated interference goes beyond the specified limit, then, the SU needs to vacate the licensed channel, and thereafter, must find some other suitable channel for its subsequent transmissions. The SUs are mobile and have self-configuring abilities. Therefore, we use random waypoint as the mobility model, which represents the properties of next-generation wireless networks by characterizing the mobility of random nodes, showing that their locations, accelerations, and velocities can vary with time.

Moreover, SUs maintain a list of usable channels and update it periodically after a certain time period, t . The SU makes a channel selection decision (or handoff) based on the parameters $ChRank$ and $Chtr$ to assign values (i.e.,

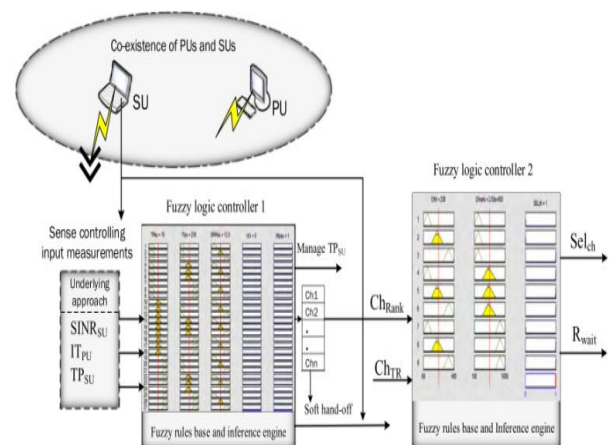
high, medium, or low) to every channel in the list based on the properties of that particular channel (e.g., transmission range, idle time, and channel capacity, noise, and interference rate).

We assume an error-free channel model, and that data packet loss happens only due to PU-SU collision. Furthermore, we assume that the quasi-static Rayleigh fading is present, and the channel coefficients between communicating SU pair are considered to be independent Rayleigh distributed variables.

1. Proposed Fuzzy-Based Channel Selection And Switching Decision System:

In this section, we first present a short working discussion about fuzzy logic and then, we present our selected parameters, which we select to minimize the SU channel switching rates and to improve the throughput of the system while selecting the best available channel.

We further discuss the architecture and workings of the proposed FLB-DSS, which comprises two fuzzy logic controllers (fuzzy logic controller 1 and fuzzy logic controller 2), as shown in figure.



Proposed fuzzy logic-based decision support system.

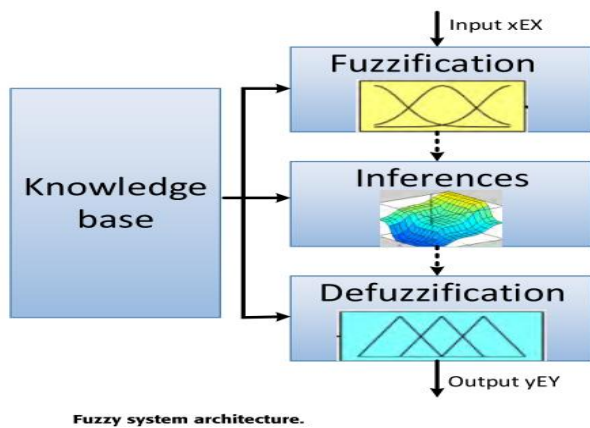
Fig 8. Text Here Your Fig Title.

2. Significance and Working of Fuzzy Logic:

In this section, we briefly present the working of the fuzzy logic. The basic purpose of the discussion is to deliver the elementary information required to understand the basics of fuzzy logic. Fuzzy logic is known as a purely mathematical tool that is used most appropriately for decision making in scenarios where all the input values are imprecise and qualitatively uncertain [14].

Moreover, the information received from the SU is in mostly heterogeneous form, and a fuzzy logic mathematical tool has a quality to transform heterogeneous input into basic homogeneous membership functions. Later, crisp results can be produced using inference fuzzy rules.

The objective of the fuzzy logic scheme is to introduce smarter control systems considering the fact that, most of the time, actual problems can never be professionally stated with the use of mathematical models. However, in order to implement the decision making process, fuzzy logic controllers are used which further need input parameters in terms of fuzzy set.



Fuzzy system architecture.

Fig 9. Text Here Your Fig Title.

A fuzzy set, which is a general form of a crisp set when all values have to be categorized into two basic groups, i.e., member values and non-member values. A set of linguistic control rules is an important part of an FLC that is based on expert knowledge in the form IF (antecedent) THEN (consequent). Figure illustrates the general working modules of a fuzzy system.

Generally, a fuzzy decision system is divided into three different phases (fuzzification, fuzzy reasoning, and defuzzification). The input values are first fuzzified using the predefined membership functions in the fuzzification phase. In fuzzy reasoning, fuzzy input sets are fed into a knowledge base, and it generates fuzzy output sets that are defuzzified to get the final crisp output.

A general fuzzy logic controller contains the following simple modules:

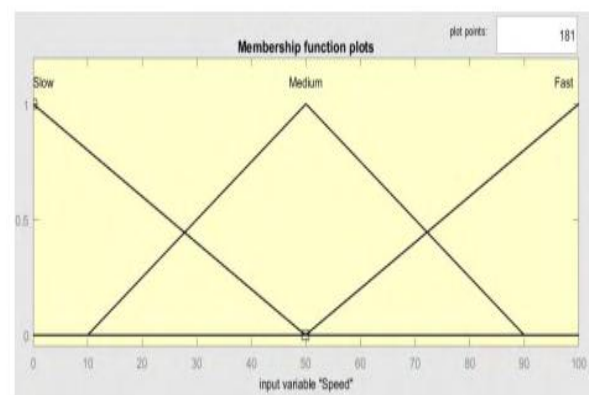
- A fuzzifier,
- An inference engine
- A defuzzifier
- A knowledge base.

The fuzzy set can minimize the vagueness of real-world scenarios. According to fuzzy logic theory, a value, A, will be part of a fuzzy set, Z, where the condition of being its member cannot always be true or false. It will be counted as the degree to which A belongs to set Z.

In fuzzy sets, the degree of membership can be expressed within a set of intervals, [0, 1], where 0 and 1 are the extreme values of this interval, which correspondingly represent the total denial or acceptance of the membership in a fuzzy set.

Every x object can be named as a linguistic term in a fuzzy set, where a linguistic term can be a word like low, medium, high, etc.; so, x can be defined as a linguistic variable. The term “set T (x)” is used to describe each linguistic variable, and it can be a set of names for the linguistic values of x. Every single element in set T (x) is a fuzzy set [8] [10].

Let us consider a simple example in order to understand the concept of the fuzzy set and the membership functions. If speed can be interpreted as a linguistic variable, then we can define its set T (speed) as $T = \{\text{slow, moderate, fast,}\}$, where every term in T is a fuzzy set in the universal set of discourse [0, 100].



Membership function “Speed (km/h)”.

Fig 10. Text Here Your Fig Title.

All these terms are characterized as fuzzy sets, and their membership functions are shown in figure.

Speed can be interpreted as slow when it falls below a certain value (i.e., 40 km/h), as moderate when the speed is close to 55 km/h, and as fast when the speed is more than about 70 km/h, as shown in figure9.

3. Parameters Selection:

This subsection presents our selected parameters. We select five parameters: SINRSU, ITPU, TPSU, ChRank, and ChTR.

3.1 Interference Temperature: ITSU is defined as a measure of radio frequency (RF) power available at the receiving PU antenna. More specifically, ITSU is also defined as temperature equivalent of the RF power available at the receiving PU’s antenna, measured in Kelvin. ITSU is generated by the SU transmitter and other noise sources. ITSU allows the SU and the PU to use the licensed channel simultaneously. However, the SU need to ensure that it’s generated interference is below an ITSU threshold; otherwise, the SU immediately needs to vacate the operating licensed channel. ITSU is calculated as follows:

$$IT_{SU}(f_{ch}, B_{ch}) = \sum_{i=1}^{N_{SU}+1} \frac{P_i(f_{ch}, B_{ch})}{kB_{ch}}$$

Where $IT_{SU}(f_{ch}, B_{ch})$ is the interference temperature measured over the PU licensed channel, ch , where the central frequency is f_{ch} and the bandwidth is B_{ch} . N_{SU} is the number of SU transmitters producing interference with the PU. $P_i(f_{ch}, B_{ch})$ is the average value of interference power measured in watts and k is Boltzmann's constant, the value of which is (1.38×10^{-23}) measured in joules per kelvin.

3.2 SU Transmission Power: TP_{SU} is the value of available power at which the SU can transmit its data towards the receiving SU antenna. Controlling this parameter allows the SU to utilize the licensed channel simultaneously while maintaining a certain QoS level for its transmissions. In case when no PU is operating over the licensed channel, the SU can transmit with the maximum power to improve the reception probability and to improve the QoS for its transmissions. However, if the received data at the SU is not successfully decoded. Then, the communicating pair of SUs need to switch to some other appropriate channel for their successful transmissions [6][9]. The initial value of the TP_{SU} is calculated by using the path loss estimation and the common pilot channel (CPC) in the open-loop control cycle, which is given as follows:

$$TP_{SU} = TP_{cpc} - TP_{cpc}^{R_x} - L_{glt} + SINR_{Req} + M_{SU} + \sum_i l_i$$

Where TP_{SU} is the initial value of the power for the SU transmitter, and TP_{cpc} is the predetermined power value of the CPC. $TP_{cpc}^{R_x}$ is measured power of the CPC at the receiving SU antenna, and L_{glt} represents an additional gain, tolerance, and loss. $SINR_{Req}$ is the value of required SINR, and is the value of calculated noise plus interference at the SU. The initial value of TP_{SU} is used for initial communication between the communicating pair nodes, and later on, this value can be adjusted to avoid the harmful interference with the PU and other SUs operating over that particular licensed channel.

3.3 SINRSU: To ensure the SU transmission power below a given threshold while maintaining a certain QoS level at SU receiving antenna is critical and challenging task. However, SINR measured at the SU receiving antenna can be used to determine the QoS of SU transmissions. Moreover, it can be used to determine the minimum value of transmission power required by SU to minimize the potential interference with the PU. Thus, controlling the SINR parameter permits the SU to simultaneously utilize the licensed channel while maintaining a certain QoS level for its

own transmissions too. $SINRSU$ measured at the SU receiving antenna is given in Eq.

$$SINRSU = \frac{|h_{22}|^2 TP_{SU-B}}{\sum_{i=1, i \neq B}^N |h_{22}|^2 TP_{SU-i} + \sum_{j=1}^K |h_{11}|^2 TP_{SU-j} + \sigma_{SU-B}^2}$$

Where N and K represent number of co-channel PU and SU users. $|h_{ij}|^2$ is power gain of fading channel coefficients. TP_{SU-B} , and TP_{SU-i} , are transmitted powers of the co-channel SUs, and σ_{SU-B}^2 is the variance of additive white Gaussian noise at the SU.

3.4 ChRank: Provides the PU activity-aware channels availability. Channel indexed under ChRank are more stable and provide fewer collisions as well as less interference with PUs. Thus, selecting a channel based on ChRank provides the minimum channel switching rates as well as the opportunity to make known switching decisions. ChRank is calculated as follows:

$$Ch_R = \frac{TFT_t^{ch}}{(TUT_t^{ch} \times \text{No of Arrivals}_t^{ch}) + TFT_t^{ch}}$$

Where TFT_t^{ch} is the total idle time and TUT_t^{ch} is the total busy time measured over channel ch at time t . $\text{No of Arrivals}_t^{ch}$ denotes the total value for all arrivals of the PU detected over channel ch in time period t .

3.5 Channel Transmission Range (ChTR): Channels available to the SUs are remarkably heterogeneous in terms of channel error rates and transmission ranges. Moreover, channels having lower transmission ranges are located in higher frequency bands. Therefore, ChTR has a significant impact on channel switching under the SU mobility.

Hence, channel selection based on ChTR can significantly reduce the channel switching rate by providing sufficient transmission range to cover the communicating pair of SU nodes. Our proposed FLB-DSS which is not only focuses on minimizing the channel handoff rates but also considers the best and most appropriate channel for the SU transmission to increase throughput. The following subsections discuss our proposed fuzzy logic controllers, their input parameters, and their output.

4. Proposed Fuzzy Logic Controllers:

4.1 Fuzzy Logic Controller 1: The first fuzzy logic controller (FLC1) is designed to make a qualitative estimation of the power at which the SU transmits its data without interfering with the other transmissions of the PU and SUs while maintaining a certain QoS for its own transmissions.

The objective of FLC1 is to minimize the channel switching rate while adjusting TPSU in overlay transmissions, which happens only when the SU's transmission is ongoing and the PU has also arrived, and thus, the SU has to either keep using the channel according to the underlay approach or immediately switch to some other appropriate channel by making the decision to hand off [13] [12].

The FLC1 takes the fuzzy inference rules shown in Table 1 as input and takes the appropriate decision to manage TPSU, or to otherwise hand off. In the case of a handoff, the workings of the FLC2 take place. The input parameters of the FLC1 and their corresponding membership functions are shown in figure.

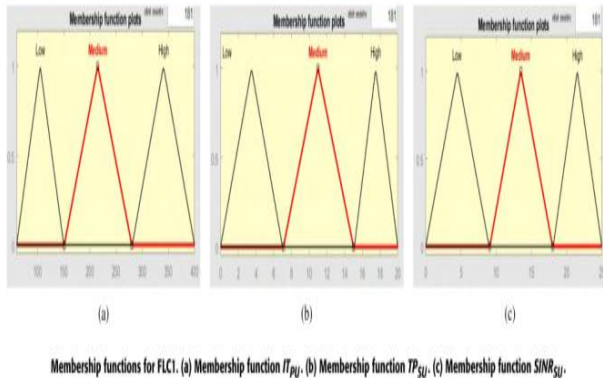


Fig 11. Text Here Your Fig Title.

Table 1. Inference Rules for FLC1.

Rule no.	TP_{SU}	IT_{PU}	$SINR_{SU}$	MTP_{SU}	HO
1,2,3	Lw	Lw	Lw, Med, Hgh	✓	
4,5,6	Lw	Med	Lw, Med, Hgh	✓	
7	Lw	Hgh	Lw		✓
8,9	Lw	Hgh	Med, Hgh	✓	
10	Med	Lw	Lw	✓	
11	Med	Lw	Med	✓	
12	Med	Lw	Hgh		✓
13, 14	Med	Med	Lw, Med	✓	
15	Med	Med	Hgh		✓
16	Med	Hgh	Lw		✓
17, 18	Med	Hgh	Med, Hgh	✓	
19	Hgh	Lw	Lw		✓
20	Hgh	Lw	Med	✓	
21	Hgh	Lw	Hgh		✓
22, 23, 24	Hgh	Med	Lw, Med, Hgh		✓
25, 26, 27	Hgh	Hgh	Lw, Med, Hgh		✓

4.2 Fuzzy Logic Controller 2: The FLC2 is designed to select the best channel from the list of available channels, which allows the SU to utilize a channel for a long time and eventually minimizes the channel switching rate. When the SU has to select a new channel for seamless transmission, it considers ChRank and ChTR as input

parameters. After that, it puts them into the fuzzy-fier to get the membership functions or antecedents.

The inference engine applies the fuzzy rules presented in Table 2 on antecedents, and forwards the antecedent to the defuzzifier to get the crisp consequent on which the SU will make the most appropriate decision. The input parameters and the corresponding membership functions of FLC2 are shown in figure.

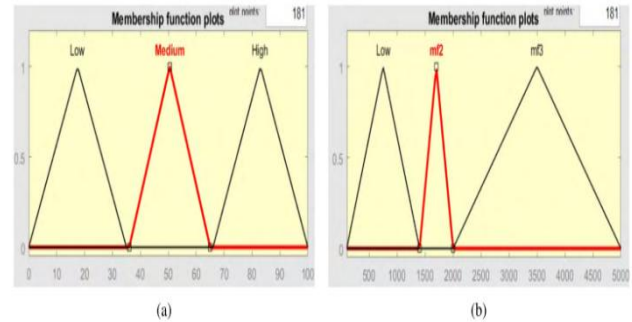


Fig 12. Text Here Your Fig Title.

Table 2. Inference Rules for FLC2.

Rule no.	Ch_{Rank}	Ch_{TR}	SEL_{ch}	R_{wait}
1	Lw	Lw		✓
2	Lw	Med		✓
3	Lw	Hgh	✓	
4	Med	Lw	✓	
5	Med	Med	✓	
6	Med	Hgh	✓	
7	Hgh	Lw		✓
8	Hgh	Med	✓	
9	Hgh	Hgh	✓	

VI. PERFORMANCE ANALYSIS

Evaluated the performance of the proposed scheme against the conventional scheme by using Matlab, which is a meta-paradigm numerical computing environment using fourth-generation programming language.

The conventional, or baseline, scheme operates only on an overlay channel selection model. It exploits the licensed channel when no PU is operating on it, and vacates licensed channels immediately when the PU arrives.

We evaluated the performance in terms of

- The number of hard handoffs
- The number of soft handoffs
- The time used in channel searching, selecting, and switching to resume suspended (or start new) transmissions
- System throughput.

Vacating the licensed channel instantly upon the arrival of the PU and switching to some other available licensed channel later is referred as a hard handoff, whereas selecting the best channel from a list of available channels before vacating the operating channel is referred as a soft handoff.

Time used in channel selection and switching in order to resume a suspended transmission, or start a new one, is the delay/time calculated starting from vacating the operating licensed channel till selecting and switching to another channel. It takes channel search time, channel selection time and communicating with the node pair about the new channel in order to resume suspended transmissions.

Throughput is measured as the number of packets received successfully at the receiving (destination) SU node in unit time.

1. Simulation Settings:

Table 3. Text Here Your Table Title.

Parameters	Values
Simulation Area	1000 X 1000 m
Simulation Total Time	25 - 125 s
Number of PUs	5-18 (each licensed channel correspond to its single PU)
Number of SUs	10-50
PU Detection Time	1 ms
Detection Threshold Value	1.16 db
Time required for channel searching, selecting and switching	5 s
SU waiting time when no licensed channel is idle	5 s
Mobility model	Random way point
Pause time	0 - 100 ms
Node Speed	0.5 - 5 m/sec
Channel Capacity	2 Mbps
Packet Size	1024 bytes

2. The simulation results for hard and soft handoff rates under the proposed and conventional schemes for varying transmission times.

In figures (a)-(b), the results evaluated were for 120 seconds of SU data transmissions by 10 SU nodes using five licensed channels. Due to the proactive channel searching, selection, and switching adopted in our proposed scheme, it outperformed the conventional scheme.

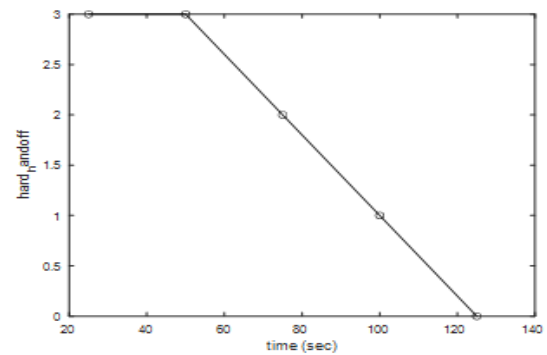


Fig 13. Number of hard handoffs.

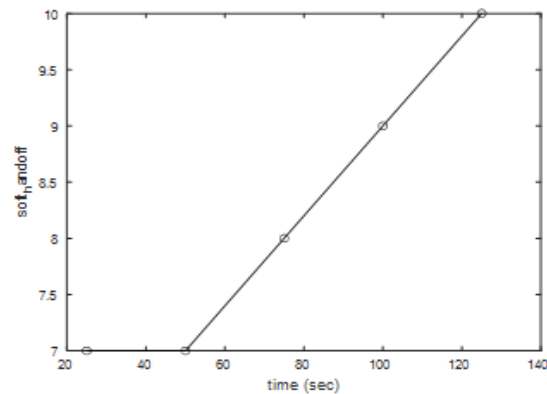


Fig 14. Number of soft handoffs.

However, in Figure (a), a few hard handoffs happened under our proposed scheme, because sometimes the generated interference by the operating SU exceeded the given threshold, and the SU and the PU cannot operate on the same channel simultaneously.

3. Performance analysis of the proposed and the conventional schemes when varying the number of SUs.

Figures (a)-(b) are an evaluation of five licensed channels used for 50 seconds of data transmissions. Figure (a) shows that the number of hard handoffs increases under the proposed scheme with an increase in the number of SUs.

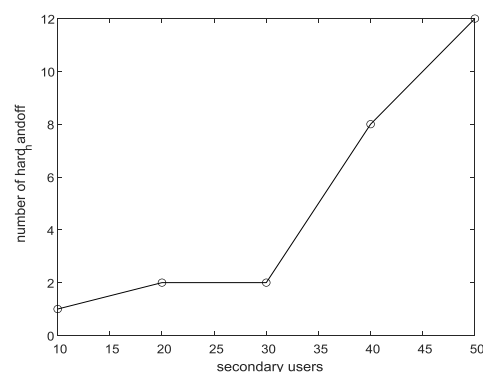


Fig 15. Number of hard handoffs.

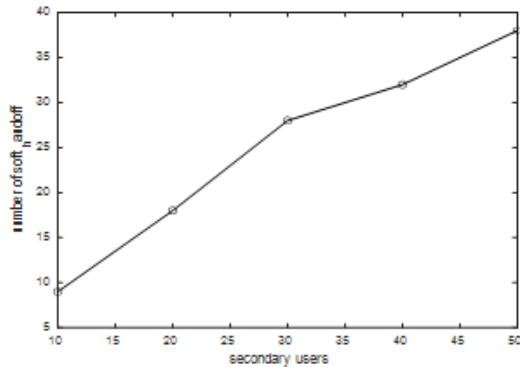


Fig 16. Number of soft handoffs.

This happens because sometimes licensed channels become unavailable for prior-switching decisions when all licensed channels are occupied by other SUs, or they become unavailable for SUs' transmissions by exceeding the interference threshold limit of the operating PU. Hence, the PU and the SU cannot execute transmissions simultaneously.

4. Performance analysis of the proposed and the conventional Schemes when varying the number of licensed channels.

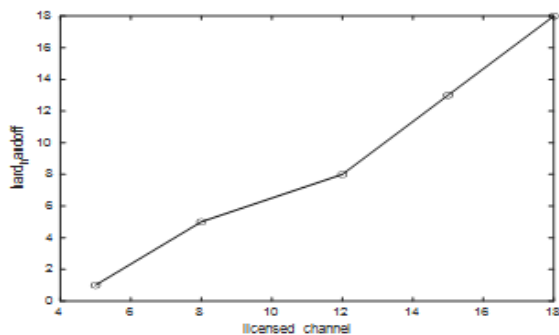


Fig 17. Number of hard handoffs.

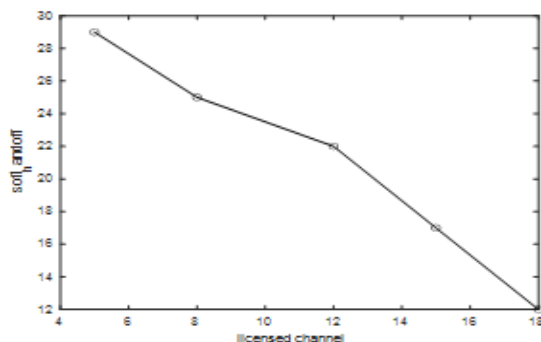


Fig 18. Number of soft handoffs.

Figures (a)-(b) evaluated fewer than 30 SUs for 50 seconds of data transmissions. However, the number of licensed channels varies between five and 18. Figure (a) demonstrates that the number of hard handoffs decreases with an increase in the number of licensed channels.

This happens because more licensed channels are available for switching decisions. Both figures show that the proposed scheme performs better in terms of hard- and soft-handoff rates when varying the number of operating SUs and the number of licensed channels.

5. Figures (a)-(c) present the throughput analysis of the proposed and conventional schemes when varying the transmission times, varying the number of usable licensed channels, and varying the number of operating SUs, respectively.

In Figure (a), throughput is measured for 10 pairs of SUs operating over five licensed channels for total 125 seconds of data transmissions.

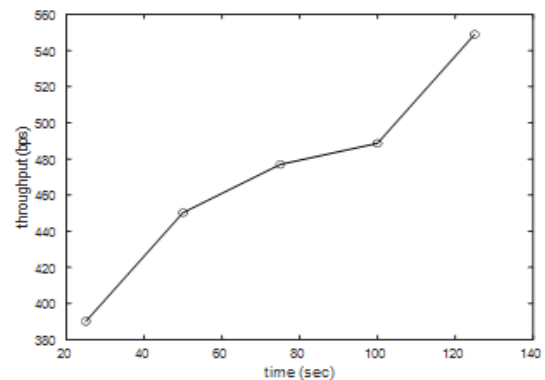


Fig 19. Throughput under varying transmission times.

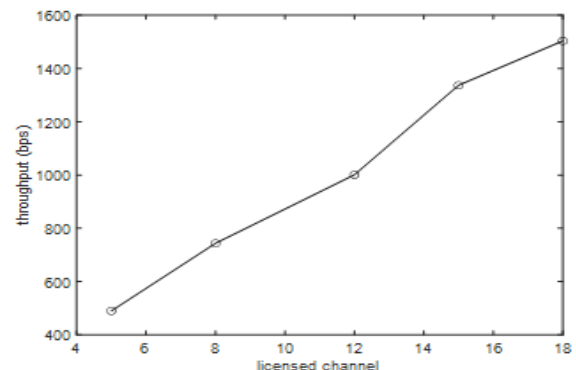


Fig 20. Throughput under varying number of licensed.

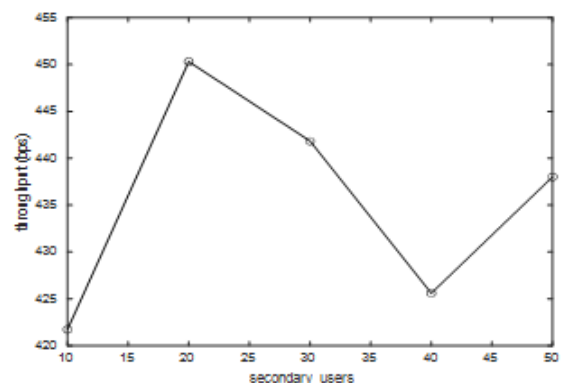


Fig 21. Throughput under varying number of Sus.

Figure (a) shows that the proposed scheme performs better in terms of successfully transmitting data packets. This is because the proposed scheme selects the best channel based on susceptibility (e.g., the duration of its availability) and the channel transmission range.

The channel that will be less susceptible to PU transmissions will be available for a longer time, and thus, provides less channel switching and also provides a sufficient range to cover transmissions with the communicating SU node pair.

Moreover, the parameter ChRank provides an opportunity to take a soft handoff decision based on the known availability time of the operating licensed channel. Hence, the fewer hard handoff decisions lead to spending less time searching for and selecting a new channel, and eventually increases the throughput of the system. Figure (b) plots the throughput results for 30 pairs of SUs communicating for a total of 50 seconds.

Figure (b) shows that increasing the number of licensed channels provides more opportunities to select the best channels in terms of long availability and better coverage range, which sufficiently increases the system's overall throughput.

Figure (c) presents the throughput analysis when varying the number of SUs for a transmission period of 50 seconds over five licensed channels. Figure (c) shows that the proposed scheme still performs better under an increasing number of SUs over the limited availability of operating licensed channels. However, the throughput of the system decreases with an increase in the number of SUs due to the unavailability or lesser availability of channels.

6. Figures 12 (a)-(c) present a performance analysis of the proposed scheme and the conventional scheme in terms of SUs' total time spent in channel searching, selection, and switching under varying transmission times, varied numbers of operating SUs, and varied numbers of usable licensed channels, respectively.

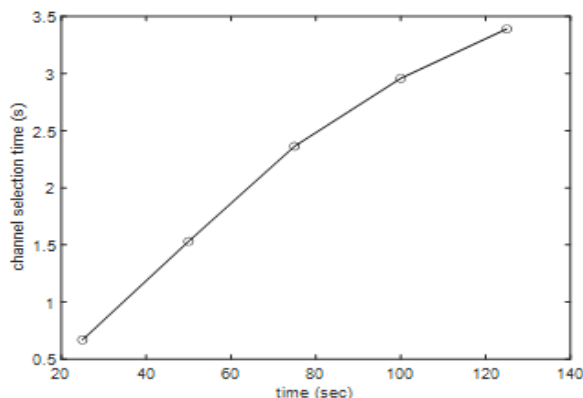


Fig 22. Time consumed in channel selection under varying.

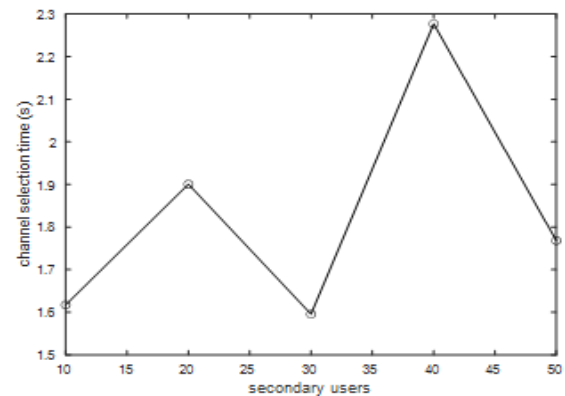


Fig 23. Time consumed in channel selection under varying.

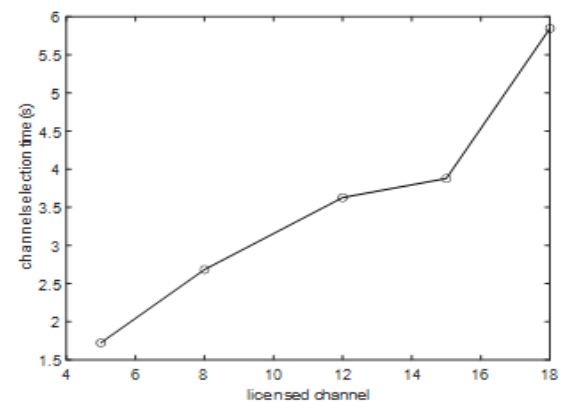


Fig 24. Time consumed in channel selection under varying.

In Figure (a), time is measured for 10 pairs of SUs transmitting data for the total of 125 seconds by using five licensed channels. Figure (a) shows that the conventional scheme spends a lot of time in the channel searching, selection, and switching processes. The more time SUs spend in switching may seriously affect the overall performance of the system.

The conventional scheme makes more switching decisions because it only selects licensed channels for SU communications based on availability and does not consider other important parameters, such as channel susceptibility value, duration of availability, and coverage range. Moreover, the conventional scheme needs to vacate a licensed channel immediately upon the arrival of its licensed user.

However, the proposed scheme selects the best channel from the list of available channels based on ChRank and ChTR, which not only offers it the opportunity of using the selected channel for a longer time but also allows soft handoff decisions.

With a soft handoff decision, the communicating SU starts searching for other options in channel switching before leaving the currently licensed channel. Thus, the proposed

scheme utilizes more time for data transmissions, rather than wasting time searching and switching among the available channels.

Moreover, under the proposed scheme, the SU keeps transmitting data on the licensed channel simultaneously with the PU by controlling its generated interference, keeping it below the specified threshold, which it observes by considering the ITPU and TPSU parameters. Furthermore, the proposed scheme does not make a channel switching decision until the operating licensed channel fulfills its minimum requirements for quality of transmission, which we measure by using the SINRSU parameter.

Figures (b)-(c) measure the time spent channel searching, selecting, and switching when varying the numbers of SUs and licensed channels, respectively. Figure (b) plots the results for five licensed channels available for SU data transmissions for a total of 50 seconds.

Similarly, Figure (c) presents the results for 30 SUs' data transmissions for a total of 50 seconds. It is clear from Figures (b) and (c) that the proposed scheme outperforms the conventional scheme in terms of efficient time utilization.

VII. CONCLUSION

Cognitive radio is an emerging technology to fulfill the increasing demand for a scarce spectrum resources in future networks. Due to tremendous progress in the number of wireless devices and their traffic, large scale use of these technologies may soon cause a shortage of spectrum as all these technologies use unlicensed bands.

So, CR is a vital choice for their survival. The proliferation of mobile devices and the heterogeneous environment of wireless communications have increased the need for additional spectrum for data transmission. It is not possible to altogether allocate a new band to all networks, which is why fully efficient use of the already available spectrum is the demand of the day.

Cognitive radio (CR) technology is a promising solution for efficient spectrum utilization, where CR devices, or secondary users (SUs), can opportunistically exploit white spaces available in the licensed channels. SUs have to immediately vacate the licensed channel and switch to another available channel when they detect the arrival of the incumbent primary user.

A valuable amount of spectrum resources is always wasted by rightful users, so to resourcefully utilize these frequency bands, we proposed an efficient spectrum utilization scheme with the objectives to provide minimum number of handoffs, and to ensure a certain level of quality of service for SU transmissions.

Our simulation results and the evaluation proved that the fuzzy logic decision support system is more sophisticated tool to improve the throughput of brain empowered cognitive radio networks.

Our proposed scheme has shown more effective results, compared to a conventional cognitive radio network that makes its decisions on spectrum utilization based upon vague and imprecise sensing results taken by secondary users.

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