Multi Criteria Based Dynamic Channel Selection in Cognitive Radio Networks

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Declaration

We, hereby, declare that the work presented in this thesis is the outcome of the investigation performed by us under the supervision of Maheen Islam, Assistant Professors, Department of Computer Science and Engineering, East West University. We also declare that no part of this thesis has been or is being submitted elsewhere for the award of any degree or diploma.

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Abstract

The wireless networks are described by a complete range task arrangement. Here, a method named MCES is utilized. MCES gives a structure to researching answer for essential action. It is a technique for joining data as showed by their hugeness in settling on a given decision. In the MCES procedure, six criterion. The criterion are channel idle probability, PU & SU arrival rate, achievable channel bandwidth, channel holding time, reliability. We have expressed the standardization of criterion. We consider historical sensing data to compute the channel idle probability by using the instantaneous PU behavior. SINR is a sum used to give theoretical extreme points of control on alter constrain in cognitive radio wireless networks. The derivation of PU and SU arrival rates needs to analyze the channel usage pattern for all users in the network. We have used rank order method to regulate the weights. Channel ranking computation is shown to rank channels. Channel selection is represented by the MC-DCA at each SU algorithm. We have exposed impacts of varying PU & SU density. We have utilized our proposal through numerical and in addition test computation. Simulation results demonstrates that our approach can give better execution contrasted to multivariable algorithm for dynamic channel selection in cognitive radio networks.

Acknowledgments

As it is true for everyone, we have also arrived at this point of achieving a goal in our life through various interactions and help from other people. However, written words are often elusive and harbor diverse interpretations even in one's mother language. Therefore, we would not like to make efforts to find best words to express our thankfulness other than simply listing those people who have contributed to this thesis in an essential way. This work was carried out in the Department of Computer Science and Engineering at East West University, Bangladesh.

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There are numerous other people too who have shown us their constant support and friendship in various ways, directly or indirectly related to our academic life. We will remember them in our hearts and hope to find a more appropriate place to acknowledge them in the future.

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Chapter 1

Introduction

1.1 What is Network?

Networking means sharing. So if we have nothing to share, networking has nothing for us. If we anything to share, networking is everything for us. A computer networking is a process of connecting two or more computers for sharing. A system is a gathering of PCs, servers, centralized servers, organize gadgets, peripherals, or different gadgets associated with each other to permit the sharing of information[15].

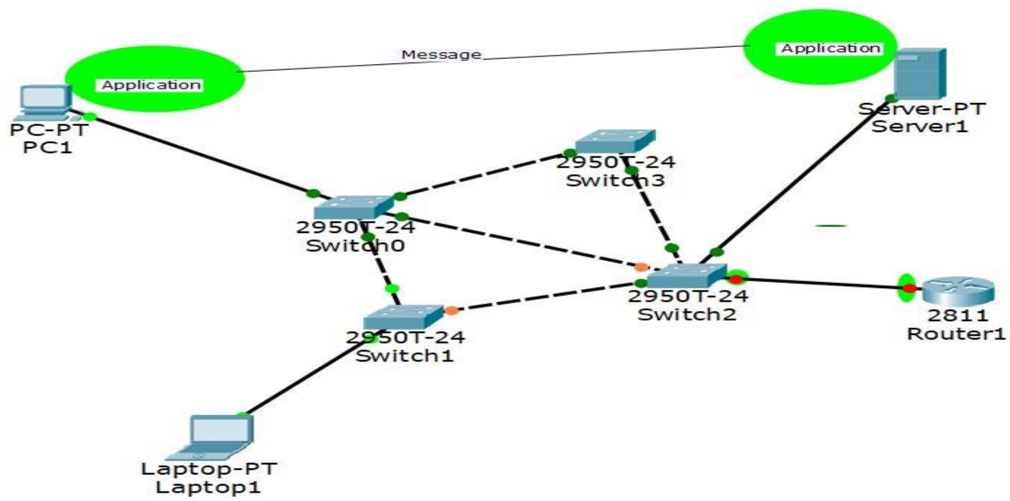

Fig.1.1: Elements of Network

1.2 What is Wireless Network?

A wireless network is a computer network that uses wireless data connectinos between network nodes. Wireless networking is a method by which homes, telecommunications networks avoid the costly process of introdusing cables into a building or as a connection between various equepment locations. Wireless telecommunication networks are generally implimented and administreted using radio communication[16].

A wired system interfaces gadgets to the Web or other system utilizing links. The most well-known wired systems utilize links associated with Ethernet ports on the system switch toward one side and to a PC or other gadget on the link's inverse end.

1.2.1 The Benefits of Wireless Network

Private companies can encounter many advantages from a remote system, including:

- Comfort. Access your system assets from any area inside your remote system's scope region or from any Wifi hotspot.
- Versatility. You're never again attached to your work area, as you were with a wired association. You and your workers can go online in gathering room gatherings, for instance.
- Efficiency. Remote access to the Web and to your organization's key applications and assets enables your staff to take care of business and supports joint effort.
- Simple setup. You don't need to string links, so establishment can be brisk and practical.
- Expandable. You can without much of a stretch extends remote systems with existing hardware, while a wired system may require extra wiring.
- Security. Advances in remote systems give vigorous security insurances.
- Cost. Since remote systems dispense with or decrease wiring costs, they can cost less to work than wired systems.

1.3 Cognitive Radio Wireless Network

Range choice is the capacity of a cognitive radio (CR) to choose the best accessible range band to fulfill optional clients' (SUs') nature of administration (QoS) necessities, without making unsafe impedance authorized or essential clients (PUs)[17]. Every CR performs range detecting to recognize the accessible range groups and the range choice process chooses from these accessible groups for artful utilize. Range choice constitutes an essential subject which has not been sufficiently investigated in CR inquire about. Range choice includes range portrayal, range choice and CR reconfiguration capacities. After the accessible range has been distinguished, the initial step is to describe it construct not just in light of the present radio condition conditions, yet in addition on the PU exercises. The second step includes range choice, whereby the most proper range band is chosen to fulfill SUs' QoS necessities. At long last, the CR ought to have the capacity to reconfigure its transmission parameters to permit correspondence on the chosen band. Key to range portrayal is PU action demonstrating, which is ordinarily in light of chronicled information to give the methods for anticipating future activity designs in guaranteed range band. In cognitive radio, every nodes sense the channel. Our work is to search if the channels are idle or active.

1.3.1Overview

Cognitive Radio Wireless Network is the quickest developing section of the correspondence business. With the fruitful organization of cell arranges in authorized groups and Wi-Fi organizes in unlicensed groups, clients have whenever, anyplace availability with the arranged frameworks prompting the Internet of Things (IoT). Conventional remote systems depend on static range task where the administration administrative bodies, for example, the Government Correspondence Commission (FCC) in the Assembled States, appoint the Radio Recurrence (RF) range to the specialist organizations in a selective way for long haul and immense geographic territory. The greater part of the usable RF range are as of now allocated to specific administrations leaving no groups for facilitate advancement of new remote frameworks. Moreover, while everything, (for example, cooler, microwave stove, brilliant auto, and so forth) is associated with web, this shortage would be more serious. In any case, late examinations demonstrate that the static RF range task prompts wasteful utilization of RF range since a large portion of the channels are utilized just from 15 to 85□% or sit still more often than not. In this way the bottleneck made isn't a result of absence of RF range but since of inefficient static assignments of RF range for long-lasting and tremendous geographic territory. In this part, we display an outline of intellectual radio system, range detecting strategies, and range get to techniques.

1.3.2 Architecture

The present remote systems are portrayed by settled range task strategy. The unearthly shortage and the wastefulness in the range use require another correspondence worldview to misuse the current remote range, sharply. Cognitive Radio (CR) is that very worldview for remote correspondence, in which either a system or a remote hub reconfigures its transmission or gathering parameters to discuss productively evading obstruction with authorized or unlicensed clients. CR adjusts to the more current condition on the premise of its savvy detecting and catches the best accessible range to meet client correspondence prerequisites. At the point when the radio connection highlights are reached out to the system layer, the subjective radios shape the psychological radio system. This book part is centered around intellectual radio system, engineering of the CR, and its significance in the remote and portable Specially appointed systems.

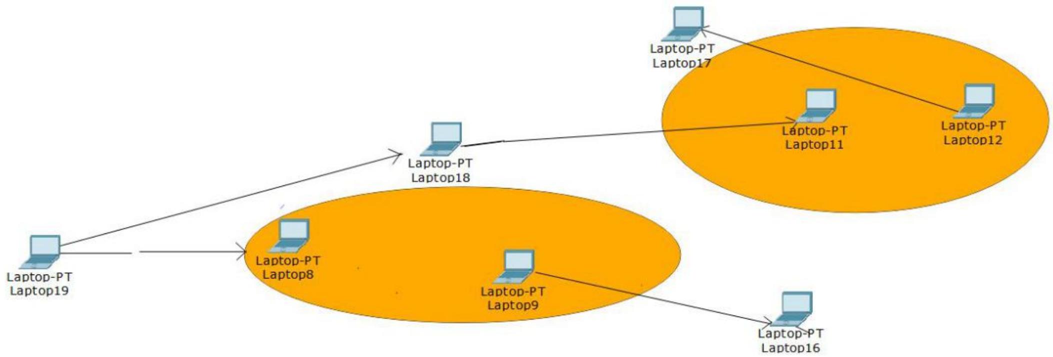

Fig. 1.2: Cognitive Radio Wireless Network

1.4 Properties of Cognitive Radios

The fundamental component of cognitive radio that vary it from traditional systems is, it finds the range gaps and progressively modify its parameter and utilize it.

1.4.1 Cognitive capability

Intellectual ability of cognitive radio is that it can detect the system. Range Sensing is fundamental advance for the operation of subjective radios. The cognitive radio finds that piece of the essential client's range which is accessible at specific time. Keeping in mind the end goal to utilize the range of authorized client there is a need of effective range sharing plan that outcomes in the ideal use of the detected range. The area recognizable proof is first element to enable the intellectual radio to alter its parameters like power and recurrence as indicated by the area of different clients.

1.4.2 Cognitive re-configurability

It can examine and learn detected data and change its parameters as per the earth. The CR ought to need to help numerous power levels. It likewise can take a shot at low power keeping in mind the end goal to expand the information rate.

1.5 Spectrum Sensing

Range detecting is the initial phase in the operation of cognitive radios. The subjective radio checks the entire range and finds the region which isn't underutilized by the essential client. The detecting procedure should be precise and predictable with the goal that optional client can transmit effectively. We can state that the accomplishment of the transmission of the helping clients is specifically dependant on the conduct of the detecting plans. The three fundamental strides of the subjective cycle are following.

1.5.1 Spectrum Analysis

The range band which is not used by the essential client is examined for their attributes estimation.

1.5.2 Spectrum Decision

Auxiliary client additionally decides its own particular attributes like information rate, transmission mode and data transfer capacity. Subsequent to figuring all these stuff it makes the suitable determination of range Fuzzy Based Throughput Maximization in Cognitive Radio Networks

Gaps decided in range detecting procedure. Since the radio condition changes time by time so the auxiliary client should mindful of the progressions of the radio condition[18].

1.6 Cooperation in cognitive radio

The key point in intellectual radio situation is to identify the nearness of essential client, with the goal that optional client can transmit as it discovered channel free. As we are working in Wireless there are many components that influence the detecting of essential client, for example, blurring and lessening[19].

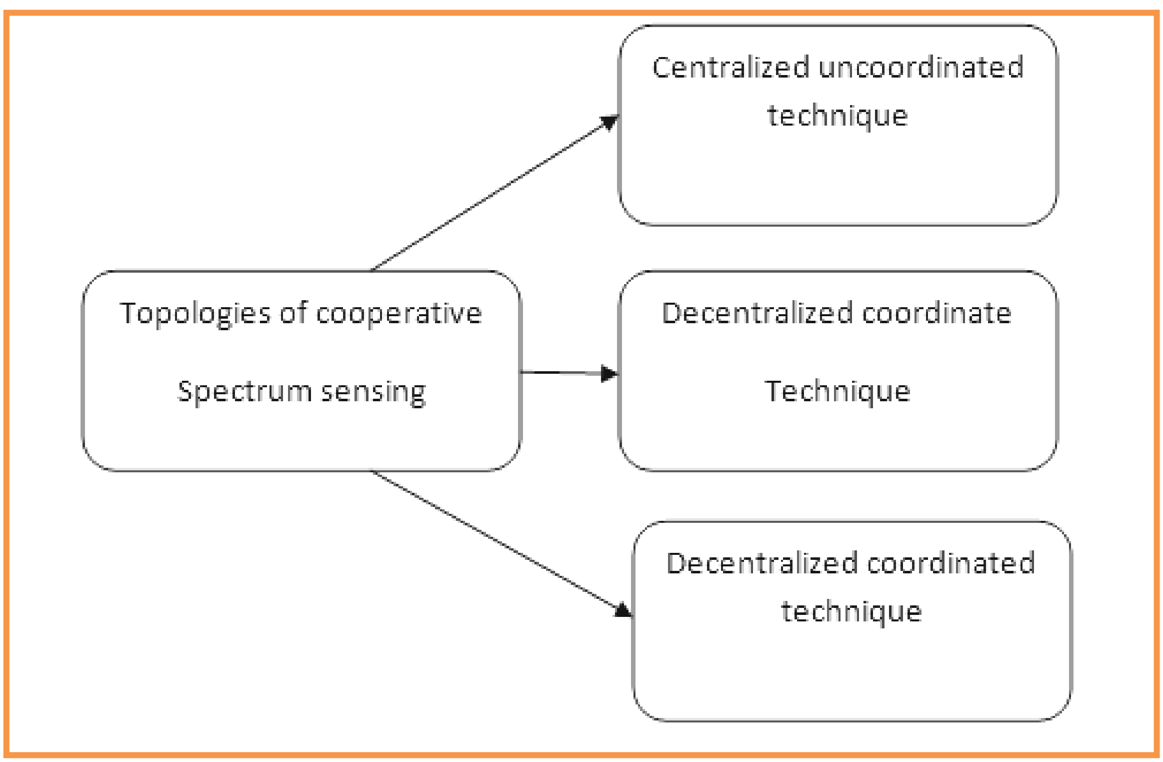

Fig. 1.3 : Analysis of Cooperative Techniques

1.6.1 Cooperative topologies in cognitive networks

The Cooperative systems that have been exhibited in the can be comprehensively characterized into three classifications as indicated by their level of participation.

1.6.1.1 Decentralized Uncoordinated Techniques

In this approach the CR client does not demonstrate any kind of participation and they work autonomously. Every CR client will freely identify range openings for transmission and if there should arise an occurrence of the landing of essential client it would leave the channel without educating the other CR clients.

1.6.1.2 Centralized Coordinated Techniques

It has focal controller which distinguishes the exercises of essential client and tell all other Secondary gadgets display in the system about the nearness of essential client.

1.6.1.3 Decentralized Coordinated Techniques

In this system a calculation named Gossiping calculation is proposed. It performs range detecting undertaking at bring down cost. The fundamental motivation behind this plan is to diminish transmission Fuzzy Based Throughput Maximization in Cognitive Radio Networks

1.7 Challenging Problem of Cognitive Radio Wireless Network

The unearthly handoff is imperative in cognitive radio system to assure a sufficient nature of administration and execution for auxiliary client interchanges. This work displays a multivariable calculation for dynamic direct determination utilized as a part of cognitive radio system. The channel determination depends on the fuzzy analytical hierarchical process (FAHP) strategy. The choose criteria for picking the best reinforcement channel are likelihood of channel accessibility, assessed channel time accessibility, flag to commotion in addition to obstruction proportion, and transfer speed. These criteria are dictated by methods for an altered Delphi Strategy and utilizing the FAHP procedure; the relating weight and hugeness is computed for two applications delegated best efforts (BE) and real time (RT)[20].

1.7.1 Dynamic channel selection

Expanded remote system knowledge and impedance mindfulness empowered by cognitive radio can prompt enhanced range usage and system execution. This postulation proposes a novel Dynamic Channel Determination (DCS) calculation based around an intellectual radio stage created by Correspondences Exploration Center Canada (CRC). The proposed calculation use the fundamental subjective radio stage to persistently screen and progressively alter the channels of the system in light of distinguished WiFi obstruction sources, hence mitigating the system administrator of having to physically design and refresh the channels over the system.

1.7.2 Merits of Dynamic Channel Selection

- A system by methods for a modified Delphi strategy to carefully choose the criteria to be utilized with the FAHP calculation is likewise displayed.
- The Delphi customization involves not just the specialists' choice yet in addition the high-positioned factors revealed in the writing on intellectual radio.
- The parameter determination was precisely decided for constant and best-exertion applications.
- As indicated by the outcomes acquired utilizing test information of the unearthly inhabitance, the proposed calculation gives a proficient determination process for a reinforcement channel with a low computational cost, low deferral, high accuracy, and diminished handoff rate, contrasted with other basic leadership calculations.

1.7.3 Dynamic Channel Allocation (DCA)

Three DCA techniques specifically the CS, the LI and the proposed GA are recreated and their separate got transient SNR reactions and bundle throughputs are looked at. The GA strategy focalizes to a SNR in overabundance of 20 dB while the CS and LI strategies don't unite. Indeed, even so the LI technique has a superior SNR execution than the CS strategy. The GA strategy has the most astounding bundle throughput took after by the CS technique with the LI technique having the least parcel throughput. The GA technique is appeared to have the capacity to merge from the most pessimistic scenario impedance situation at reenactment start up and is likewise equipped for adjusting to obstruction and recovering to another steady state.

1.7.4 Existing Dynamic Channel Allocation (DCA) methods

Existing Dynamic Channel Allocation (DCA) techniques are typically connected to frameworks conveying association situated voice calls. In this paper DCA utilizing a Genetic Algorithm (GA) is connected to a Broadband Fixed Wireless Access (BFWA) organize that gives information administrations. The execution of the GA strategy is contrasted utilizing a reproduction and two different DCAs to be specific the Least Interfered (LI) and Channel Segregation (CS).

1.8 MCES (Multi Criteria Evaluation System)

MCE is fundamentally called basic leadership process. MCE gives a structure to investigating answer for basic leadership issue. It is a strategy for joining information as indicated by their significance in settling on a given choice. At a theoretical level, MCE technique include subjective or quantitative weighting, scoring or positioning of criteria to mirror their significance to either a solitary or a different arrangement of destination. The fundamental preferred standpoint of MCE is that they make it conceivable to consider countless, relations a targets which are by and large present in a particular certifiable approach issue, so the current issue can be examined in a multidimensional design. Maybe the most straightforward MCE is the weighted direct summation framework.

1.8.1 Necessity of MCES method

MCEs technique include subjective or quantitative weighting, scoring or positioning of criteria to mirror their significance to either a solitary or a numerous arrangement of goals. The principle favorable position of MCEs is that they make it conceivable to consider countless, relations a targets which are for the most part introduce in a particular genuine approach issue, with the goal that the current issue can be contemplated in a multi- dimensional design.

1.8.2 Our Approaches for MCES method

We have visualized for multi criteria evaluation system in cognitive radio of wireless networks. We used six variables. The two variables- probabilities of channel being idle and achievable channel bandwidth are specially notified here.

1.9 Organization of the Report

We have structured our rest of the thesis works as following: In chapter 2, we have discussed about related works for MCES method. In chapter 3, proposed work is being elaborated. Chapter 4 introduces the implementation and result in details. In chapter 5 conclusion and further scope of our proposed work has been highlighted. Lastly, proper references of our thesis works, a list of acronyms and notations has been illustrated respectively.

Chapter 2

Related works

2.1 Related works

To maximize the performance of a CRN, one major challenge is to reduce interference that is caused to PUs, as well as interference among SUs. Interference results in additional noise at the receiver and lowers the Signal to Interference plus Noise Ratio (SINR), which in turn results in: (i) reduced transmission rate of the wireless interfaces, (ii) reduced utilization of the wireless resources, (iii) higher frame loss ratio, (iv) higher packet delay and (v) lower received throughput. In the absence of interference, a link should provide its maximum capacity, which depends on the available transmission rates and corresponding delivery ratios. Interference affects both the sender and the receiver of a link; the sender transmits at a rate less than its maximum, while there is a higher probability of unsuccessful packet reception at the receiver.

The interference that the CR transmissions create plays a key role in the operation of not only the CRNs, but also of the PNs that are operating in the same geographical area.

A SU has the ability to operate in any frequency band, because that user is equipped with a reconfigurable device, capable of transcribing in any frequency (in practice the device will be capable of transmitting at a specific frequency range and not at the whole spectrum). Since SUs are unlicensed users, this capability may cause problems to licensed transmissions if the SU selects a licensed band. Thus, one basic requirement for CR technology is that SUs should not interfere with the communication of Pus. This requirement makes the problem of interference management in CRNs even more complex than in traditional wireless networks, because another level of interference avoidance is included in the problem definition. The SUs should not only avoid interfering with each other but also with PUs which have higher priority in accessing the licensed spectrum bands.

Spectrum assignment is a basic function of CRNs because it affects the normal operation of the network and is closely related to spectrum sensing, which provides information on the available spectrum. SA is responsible for assigning the most appropriate frequency band(s) at the interface(s) of a cognitive radio device according to some criteria (i.e., maximize throughput, fairness, spectral efficiency, etc.), while, at the same time, avoid causing interference to primary networks operating in the same geographical area. Spectrum holes that are discovered by spectrum sensing are used as input to spectrum assignment, in order to find the optimum spectrum fragment that the SU should use according to its requirements.

In literature many techniques have been proposed for channel allocation in CRNs.

An efficient channel selection scheme in multi-user cognitive radio networks (CRN) is proposed in [1] where channel is selected by satisfying the individual quality of service demands of cognitive radios while enhancing the network-wide performance

The problem of channel quality prediction in cognitive radio networks is investigated in this paper [2]

In [8], dynamic spectrum access (DSA) in multi-channel cognitive radio networks (CRNs) is studied. First, spectrum sensing is investigated, where multiple SUs are coordinated to cooperatively sense the channels owned by the primary users (PUs) for different interests.

[9] presents a multivariable algorithm for dynamic channel selection used in cognitive wireless networks. The channel selection is based on the fuzzy analytical hierarchical process (FAHP) method. The selected criteria for choosing the best backup channel are probability of channel availability, estimated channel time availability, signal to noise plus interference ratio, and bandwidth. These criteria are determined by means of a customized Delphi Method and using the FAHP technique; the corresponding weight and significance is calculated for two applications classified as best effort (BE) and real time (RT). The insertion of the fuzzy logic in the AHP algorithm allows better handling of inaccurate information because, as shown the results, consider more options to evaluate in contrast to a conventional AHP.

Chapter 3

Multi Criteria Based Dynamic Channel Allocation

In cognitive Radio Networks cognitive user opportunistically utilizes the available spectrum which may have to leave to avoid the excessive interference to the primary users. Abrupt and frequent channel switching severely effects the ongoing communication of cognitive user. In order to reduce the severity of the channel switching, selection criteria must incorporate the primary user susceptibility on the channel and delay involve in channel switching. We formulate the Multi Criteria Evaluation System MCES.

3.1 System Model and Assumptions

We consider a CRN, as shown in Fig. 3.1, which has single BS, multiple SUs and multiple PUs, where the c number of licensed channels are conditionally and opportunistically accessible by the SUs. The channel set is referred as C = {1, 2, 3, …, c}. Each SU takes t time to sense a channel; we consider it as the sampling interval. We also assume that the users (PUs or SUs) arrive on channels independently and follow Poisson distribution, i.e., the arrival pattern is an iid. Each SU is assumed to equip with two transceivers; both the transceivers can be tuned to any of the c licensed channels, the first one is for channel sensing and the second one for data transmission. The SUs exchange control messages over a dedicated common control channel (CCC)[8].

We also assume that an SU can methodically sense the channel states and identify the channel of being idle or busy. A PU begins transmission over an idle channel immediately; however, if the channel is occupied by an SU, it waits for at most two sensing periods to allow the SU release the channel safely. Because, if the PU arrives at the middle or ending part of the SU's current sensing period (t), it may go unnoticed. Therefore, the tolerable maximum amount of time for PU is a system parameter and it is set as $t_{max} \leq 2 \times t$ [8].

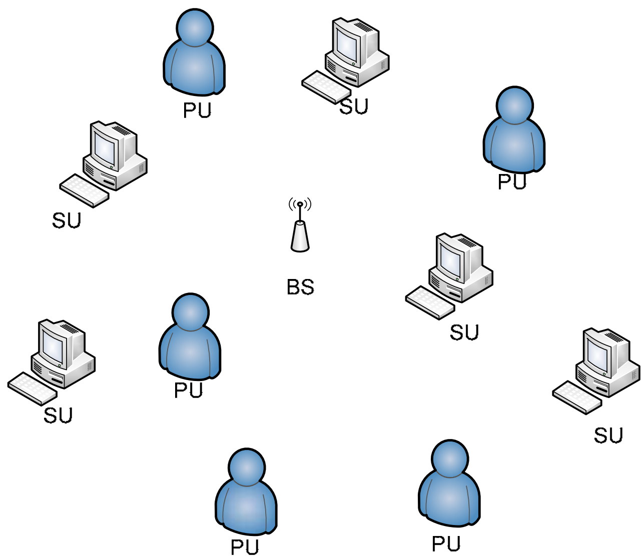

Fig. 3.1: Cognitive Radio Wireless Network (CRN)

3.2 Multi Criteria Based Channel Selection Algorithm

Our proposed MC-DCA runs over three phases – criteria selection, weight allocation and channel ranking calculation. The selection of the criteria is a fundamental task for proactive evaluation of the availability and optimal conditions for selecting a licensed channel. Once the selection criteria are established, the development of the multiple-criteria decision-making (MCDM) methodology is widely used as it is found in the literature. This MCDM method is based on two processes, the weights assessment of each criterion and the ranking estimation of each possible solution by means of one of the following techniques: the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Simple Additive Weighting (SAW), Multiplicative Exponential Weighting (MEW), or the Grey Relational Analysis (GRA).

3.2.1 Criteria selection

In CRN environment, each SU functions in a distributive and non-cooperative way. Every SU should work towards maximizing the utilization of available spectrum, which can be achieved only by maximizing individual SUs' utilization over the course of time. Efficient spectrum utilization can be increased by acquiring the most advantageous channel for data transmission. Channel reliability with legitimate knowledge of system's current state will allow SUs to gain the finest and most rational channel distribution. But, only consideration of channel reliability is not enough in a non-cooperative and competitive coexisting environment; a probabilistic glimpse of channel availability is also important. On the other hand, if every SU selects its channel based on the probability of being free only, a certain high-quality channel may become overloaded and the spectrum distribution would be unfair. In addition to that, the interference may increase significantly in such a non-cooperative environment of CRN. Thus effective computation of channel reliability locally enables the SUs of different to coexist with less interference and delay. The experience-based dynamic update of the channel reliability values and channel availability predictions eventually facilitate weighted-fair distribution with more allocation in high-quality channels.

In our work we have considered six parameters for the channel selection, channel idle probability, PU arrival rate, SU arrival rate, channel achievable bandwidth, channel holding time and channel reliability. In next sections, we discuss the process of measuring the selected criteria.

3.2.1.1 Channel idle probability

Since the spectrum perceiving methods are out of the scope of this work, we assume that each SU either uses a dedicated interface for channel sensing [REF] to keep a record of PUs' activity in each licensed band. Rather than using the instantaneous PU behavior, we consider historical sensing data to compute the channel idle probability. Each SU, s, considers last h number of sensing intervals to find the idle probability, ρ_s^i, of channel $i \in C$. Let the decision variable, $\rho_s^{i,t}$, contains 1 if the SU s senses the channel i to be idle in t-th sensing interval; and 0 otherwise. Then, the channel idle probability is computed as follows:

$$\alpha_s^i = \frac{\sum_{t=1}^{h} \rho_s^{i,t} \times t}{\sum_{t=1}^{h} t} \qquad (1)$$

Note that the calculation of gives higher weights to the recent data compared to older sensing results and thus, it enables more reliable channel prediction under random PU behavior.

3.2.1.2 PU and SU arrival rate

The derivation of PU and SU arrival rates is a continuous process, and it needs to analyze the channel usage pattern for all users in the network. As every BS has access to all the channel usage information over the time, a BS is able to provide a generalized arrival rate prediction of SUs and PUs of each channels in the environment. The autoregressive (AR) [REF] model can be used to forecast an arbitrary number of periods into the future and has been widely used to predict channel state transitions over fading channels. We are adopting the AR model as in [REF] to predict the arrival rates of each type of users. We consider PU and SU arrival rate on channel $i \in C$ to be λ_p^i and λ_s^i, respectively.

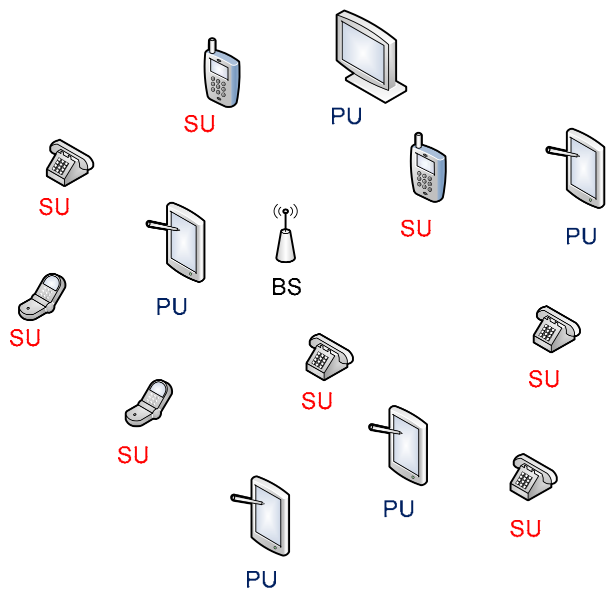

Fig. 3.2 : Secondary User (SU) rate in CRN

3.2.1.3 Achievable channel bandwidth

The SU calculates the maximum achievable data rate, β^i, of each channel $i \in C$ using Shannon's theorem, as follows:

$$\beta^i = B^i \log_2(1 + SINR^i) \qquad (2)$$

where B^i is the bandwidth of channel *i*, $SINR^i$ is the signal-to-interference-plus-noise-ratio on SU-BS transmission link over channel *i*. The SINR at each channel measures the possible interference due to simultaneous transmission of multiple SUs to a specific BS over a single channel. A SU, s, can receive simultaneous transmissions from |*Ni*| number of SUs on a certain channel *i*. In that case, the SU can calculate the SINR for the transmission to the BS over channel *i*, as follows:

$$SINR^i = \frac{S_s}{S_{noise} + \sum S_k} \tag{3}$$

where S_{noise} is the signal strength of Gaussian noise, which is determined depending on the environment, and S_s and S_k are the received signal strengths from SU s and other SUs

3.2.1.4 Channel holding time

What follow next is the details of how the expected transmission time for each channel $i \in C$ are calculated. The expected time an SU needs to transmit its current data packet can be derived using the maximum achievable data rate of each channel β^i and the amount of traffic the SU need to send T_s. The expected transmission time, τ_s^i, can be derived as follows:

$$\tau_s^i = \frac{T_s}{\beta^i} \tag{4}$$

3.2.1.5 Reliability

The amount of service received by using a specific channel can be used to find the reliability of that channel for an SU. We have proposed a mechanism to compute reliability of each channel by observing the service received by the corresponding forwarding SU over the particular channel during data transmission. When an SU s transmits over a channel $i \in C$, it can experience several outcomes. The set of possible outcomes is defined as follows:

$o1$: Successful transmission of data packet.

$o2$: Deferred transmission due to PU arrival.

$o3$: Deferred transmission due to collision with other SU transmission or bit error.

The outcome $o1$ over the selected channel contributes positive gain in computing channel reliability, whereas the outcomes $o2$ and $o3$, shows up negative gain on reliability value. In order to compute the channel reliability, SU considers last *n* number of attempts during which channel *i* was accessed by SU.

Thus the channel reliability for the *t-th* attempt is as follows:

$$\eta_s^{i,t} = \begin{cases} \kappa_g, o_1 \\ \kappa_p, o_2 \\ \kappa_s, o_3 \end{cases} \tag{5}$$

where the values of κ_p is a system design parameter and we have fixed the values as $\kappa_g = 1$, $\kappa_p = -1$ and $\kappa_s = -0.5$. Finally, the channel reliability is computed as weighted average of value of for last *t* number of samples:

$$\eta_s^{i,t} = \frac{\sum_{t=1}^{n} \eta_s^{i,t} \times t}{n} \tag{6}$$

These channel reliability calculation along with channel sensing information help to develop a sophisticated and stable channel usage mechanism in the long-run.

3.2.2 Standardization of criteria

Standardization criterion scores of their distance. Most MCE analysis, especially those using quantitative and mixed data sources, require some form of standardization of the scales of measurement used by the data layers. This is necessary to facilitate the comparison of factors measures using different units and scales of measurement. We may generate following equation for generating standardization scores. This standardization value belongs 0 to 1. The standardization value calculate based on two class such maximum or minimum. For example, if the maximum achievable bandwidth for a channel is considered as the best case and minimum bandwidth as the worst case, we assign 1 for the channel which has maximum bandwidth among the other channels, assign 0 for lowest bandwidth and other value is calculated as follows:

$$score = |max\_value - value| * \frac{1}{(maxvalue - minvalue)} \quad (7)$$

On the other hand, when PU arrival rate is less in a channel, the corresponding channel is considered to be the best case for an SUs. Therefore, we assign 1 for minimum PU arrival rate, 0 for maximum PU arrival rate and other value is calculated as follows:

$$score = |min\_value - value| * \frac{1}{(maxvalue - minvalue)} \quad (8)$$

Maximum and minimum value for variables of channel selection is shown as below **:**

Criteria for channel selection	**Maximum or minimum value**
1. Channel idle probability, α_s^i	Maximum = 1, Minimum = 0
2. Channel achievable bandwidth, β^i	Maximum = 1, Minimum = 0
3. PU arrival rate, λ_p^i	Minimum = 1, Maximum = 0
4. SU arrival rate, λ_s^i	Minimum = 1, Maximum = 0
5. Channel holding time, τ_s^i	Minimum = 1, Maximum = 0
6. Channel reliability, $\eta_s^{i,t}$	Maximum = 1, Minimum = 0

3.2.3 Assigning weights to criteria

A typical weights approach is directly assigning weights to criteria using a scale such as 0 to 10 or 0 to 100. The decision maker is asked to determine the least important criterion and then give that a value of 10, then compare the importance of the other criterion with the worse one and give it a desirable value, and finally normalize so that they all add up to one. Our proposed MC-DCA implements Rank Order method [REF] to prioritize criteria.

3.2.3.1 Rank order method

A decision is the result of a comparison of one or more alternatives with respect to one or more criteria that we consider relevant for the task at hand. In rank order method, among the relevant criteria some are considered as more important and some as less important; this is equivalent to assigning weights to the criterion according to their relative importance. If there are m numbers of criteria, then the weight of the criteria with j-th rank is computed as below:

$$\omega(j) = \frac{m - j + 1}{\sum_{k=1}^{m}(m - k + 1)} \tag{9}$$

The following table shows the ranks of our selected criteria and the corresponding weight computed using Rank order method.

Criteria	Rank	Weight
Channel idle probability, $\hat{\alpha}_s^i$	1	$\omega(\alpha) = 0.28$
Channel achievable bandwidth, $\hat{\beta}^i$	2	$\omega(\beta) = 0.23$
PU arrival rate, $\hat{\lambda}_p^i$	3	$\omega(\lambda_p)$ =0.19
Channel reliability, $\hat{\eta}_s^i$	4	$\omega(\eta) = 0.14$
Channel holding time, $\hat{\tau}_s^i$	5	$\omega(\tau) = 0.09$
SU arrival rate, $\hat{\lambda}_s^i$	6	$\omega(\lambda_s) = 0.04$

3.2.4 Channel ranking computation

Finally, we applied the MCES method. An MCES method may then multiply theses standardized scores by the weights for each of the data layers in stage 1 and sum these to allocate a score to each section on the secondary user data. Further evaluation of the results may be carried out by ranking the values in the results and maximum resultant value of secondary user show the top.

$$R_s^i = \omega(\alpha)\times\hat{\alpha}_s^i + \omega(\beta)\times\hat{\beta}^i + \omega(\lambda_p)\times\hat{\lambda}_p^i + \omega(\eta)\times\hat{\eta}_s^i + \omega(\tau)\times\hat{\tau}_s^i + \omega(\lambda_s)\times\hat{\lambda}_s^i \quad (10)$$

3.2.4 Channel Selection

Each BS periodically updates all SUs regarding list of current free licensed channels, C_0 , along with the PU and SU arrival rates on each channel. When each SU requires transmitting traffic, it computes the ranking of each channel, $i \in C_0$ using Eq. (10). Next, the list of free channels is sorted in descending order according to channel ranking. Finally, the SU s chooses the channel that has the highest rank for transmission. Then, the SU is tries to access the selected channel using standard MAC contention process.

Algorithm: MC-DCA at each SU

Input: $C_0; \lambda_s^i, \lambda_p^i, \rho_s^i, SINR^i, \eta_s^{i,t}, T_s$ for $\forall i \in C_0$

Output: $c \in C_0$ for transmission

Processing

1. Compute α_s^i, for $\forall i \in C_0$, using Eq. (1)
2. Compute β^i, for $\forall i \in C_0$, using Eq. (2)
3. Compute τ_s^i, for $\forall i \in C_0$, using Eq. (4)
4. Compute $\eta_s^{i,t}$, for $\forall i \in C_0$, using Eq. (6)
5. Compute $\hat{\alpha}_s^i$, $\hat{\beta}^i$, $\hat{\lambda}_p^i$, $\hat{\lambda}_s^i$, $\hat{\tau}_s^i$, $\hat{\eta}_s^i$ using Eq. (8) and (9)
6. Compute R_s^i, for $\forall i \in C_0$, using Eq. (10)
7. $c = \max(R_s^i)$

Chapter 4

Implementation and Result

In this section, we implement MC-DCA, I-DCA (that uses channel idle probability only), and a state-of-the- art protocol FAHP [2], and present the comparative performance results.

4.1 Experimental Setup

The CRN has varied 20 SUs and 10 PUs with one BS. Each SU opportunistically uses the licensed channels only; no unlicensed channel is considered. Here we consider 12 licensed channels. Each SU senses all the channels using 2-state sensing model [2]. The traffic of the SUs is randomly chosen

4.2 Performance Metrics

We have used following metrics for the comparative performance analysis.

- Aggregated flow throughput: Throughput is one of the major performance metrics used to evaluate the performance. It indicates the number of data bits that are delivered per second to the receivers. Network aggregated flow throughput is the total amount of data bytes received at destinations in unit time.
- SU flow fairness: To investigate the fairness ability of the considered approaches, we use Jain's fairness index . The fairness index could vary between 0 and 1. The closer the fairness index is to 1, the fairer is the bandwidth allocation.

4.3 Impacts of Varying PU Density

In this experiment, to analyze the performance results of the studied channel allocation techniques under varying PU densities, we control the PU arrival rate such that their channel occupancy percentages vary from 10% to 80% at a given time. Here, the number of SUs is considered to be 20 and 10 - 20 flows were randomly generated from each SU with a data rate of 10 Mbps each.

When less PU activity is experienced in the network, more channel resources are available to the SUs to accommodate their traffic, which entails higher network performance as shown in figure below. As revealed from the simulation result analysis in Fig. 4.1 our proposed MC-DCA approach provides the higher throughput performance even in tight resource constraints than other state-of-the-art approaches. Though the channel selection is done at each SU independently, neighboring SUs collaboratively contribute to enhance their flow throughput through multi criteria based weighted channel selection. The FAHP outperforms MC-DCA under high PU activity, as the central controller has more complete view of PU presence and interference in the network. On the other hand, the SUs employing MC-DCA locally selects better quality channels to accommodate their traffic flows, degrading the neighborhood interferences and thus the aggregated network throughput is maximized.

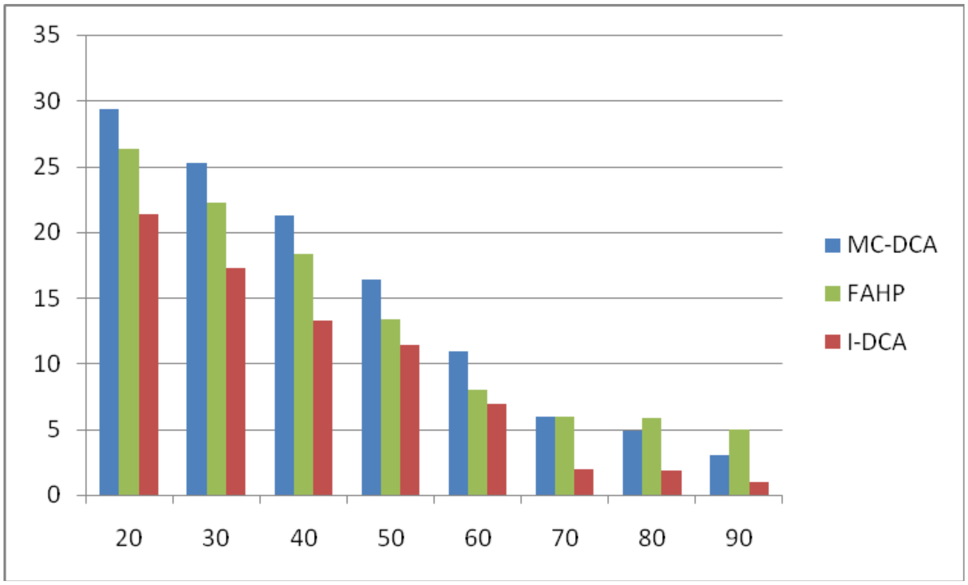

Fig. 4.1 : Impacts of Varying PU Density

When the primary channels are more occupied, the usable bandwidth per node is reduced and thus the flows are prohibited from acquiring a free channel to be forwarded. However, as the channel allocation is carried out by the central agent in FAHP considering the individual flow's demand, channel availability and congestion, the resource allocation is quite fair. But, MC-DCA also incorporates individual SU demand along with channel condition, helping to improve fairness, as revealed in Fig 4.2

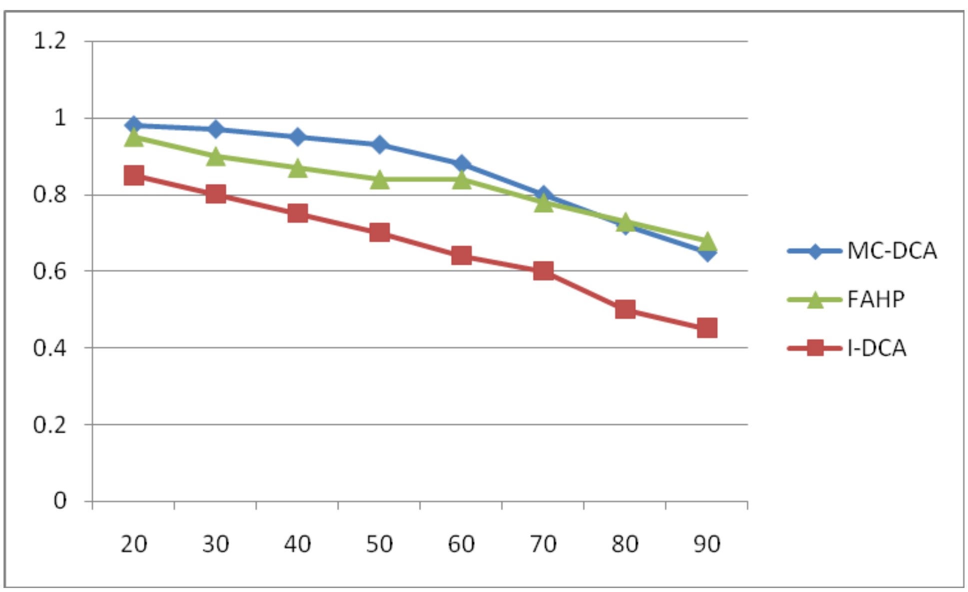

Fig. 4.2 : MC-DCA Improves Fairness of PU Density

4.4 Impacts of Varying SU Density

In next experiment, to analyze the performance results of the studied channel allocation techniques under varying SU densities, we vary the number of SUs from 5 to 30. Here, the number of PUs is considered to be 10.

When less number of SUs in the network, each SU require to compete with less neighboring SUs to access channel, which entails higher network performance as shown in figure below. As revealed from the simulation result analysis in Fig. 4.3, our proposed MC-DCA approach provides the higher throughput performance even with increasing number of SUs than other state-of-the-art approaches. Though the channel selection is done at each SU independently, neighboring SUs collaboratively contribute to enhance their flow throughput through multi criteria based weighted channel selection. The FAHP outperforms MC-DCA under high SU activity, as the central controller has more complete view of SU and PU presence and interference in the network. On the other hand, the SUs employing MC-DCA locally selects better quality channels to accommodate their traffic flows, degrading the neighborhood interferences and thus the aggregated network throughput is maximized.

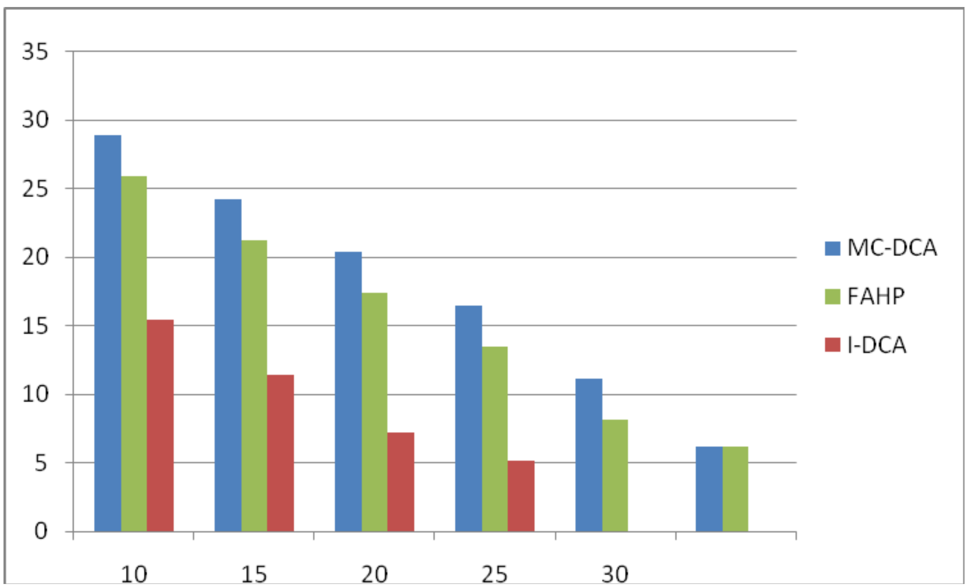

Fig. 4.3 : Impacts of Varying SU Density

When there are more SUs in the network, the usable bandwidth per node is reduced and thus the flows are prohibited from acquiring a free channel to be forwarded. However, as the channel allocation is carried out by the central agent in FAHP considering the individual flow's demand, channel availability and congestion, the resource allocation is quite fair. But, MC-DCA also incorporates individual SU demand along with channel condition, helping to improve fairness, as revealed in Fig.4.4

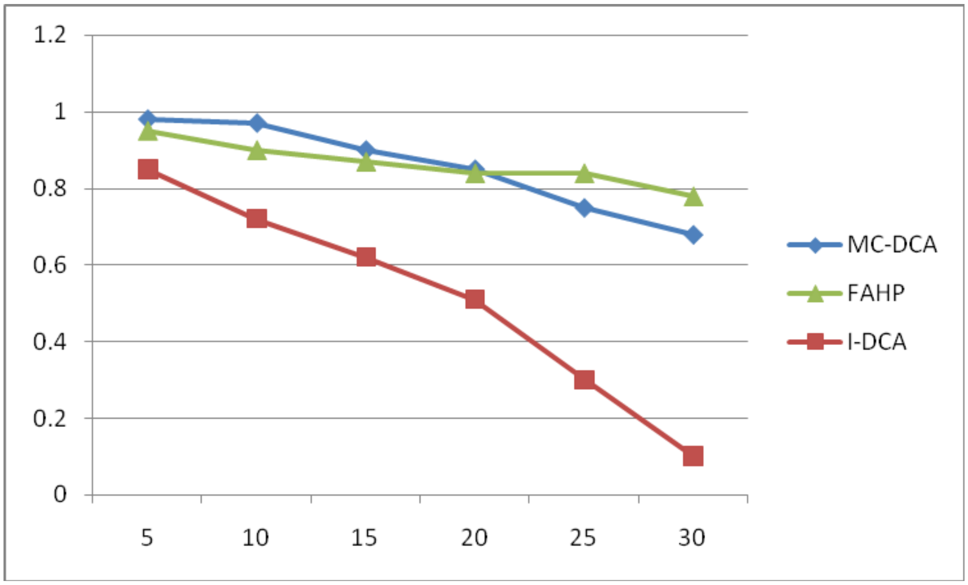

Fig. 4.4 : MC-DCA Improves Fairness of SU Density

Chapter 5

Conclusion

5.1 Conclusion

MCES gives a architecture to find answer for necessary plan. Our proposed MC-DCA overflows three phases – criteria selection, weight allocation and channel ranking calculation. In our work, we have included six parameters for the channel selection, channel idle probability, PU arrival rate, SU arrival rate, channel achievable bandwidth, channel holding time and channel reliability. Here, standardization of criterion is applied. Rank order method is showed to determine weights. Channel ranking calculation is used here to rank channels. Channel selection is expressed by the MC-DCA at each SU algorithm. We implement MC-DCA, I-DCA (operation for channel idle probability), and a state-of-the- art protocol FAHP and present the comparative simulation results. Aggregated flow throughput & SU flow fairness are applied to perform metrics. We have visualized impacts of varying PU & SU density.

5.2 Future Works

Though the initial motivation for this approach is to be able to provide multi criteria based dynamic channel selection process that can expose the impacts of varying PU & SU density; there are also many steps for further implementation. The further steps of this procedure that we want to work in future are:

a. Proposing another new method to calculate the weights.
b. Using delay reliability, bit error rate or packet error rate in the simulation results case for enhancing the throughput and the fairness of PU & SU densities.

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Appendix A

List of Acronyms

IoT Internet of Things

CR Cognitive Radio

CRN Cognitive Radio Wireless Network

DCA Dynamic Channel

Allocation

PC Personal Computer

LAN Local Area Network

SU Secondary User

QoS Quality of Service

PU Primary User

FCC Federal Communications Commission

RF Radio Frequency

FAHP Fuzzy Analytic Hierarchy Process

BE Best Effect

RT Real Time

DCS Dynamic Channel Selection

AppendixB

List of Notations

=	This is equal sign
+	This is plus sign
-	This is minus sign
_	This is underscore sign
*	This is multiplication sign
—	This is division sign
τ_s^i	Channel holding time
β^i	Bandwidth of channel *i*
$\eta_s^{i,t}$	Channel reliability
κ_s	system design parameter
α_s^i	Channel idle probability
λ_p^i	PU arrival rate
λ_s^i	SU arrival rate
$\omega(j)$	Weight of the criteria with j-th rank