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# Exploring Dynamic Spectrum Access with Cognitive Radio: A Review

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**Abstract:** The problem faced by wireless systems is to find the suitable spectrum bands for the fulfilment of future demands. All of radio spectrum has been allocated different services, user and applications; still it is shown in the observations that the spectrum usage is quite low. Therefore concept of cognitive radio has been used to overcome this problem with the utilisation of spectrum. Cognitive Radio is the type of wireless communication in which a transmitter and receiver are used to detect communication channel those in use and not in use .It helps in minimising the concept of interference among users with the fair use of the available radio frequency. Dynamic spectrum access is an approach used to decrease the spectrum scarcity in wireless communication. The reuse of sparsely occupied frequency bands and interference are the major aims.

**Index Terms:** Wireless communication system, CR(Cognitive Radio), DSA(Dynamic spectrum access), fuzzy logic, markovian chain, spectrum management.

## 1. INTRODUCTION TO COGNITIVE RADIO

The cognitive radio (CR) idea was first officially presented in an article in 1999 by Joseph Mitola IIIand Gerald Q. Maguire, Jr. Cognitive Radio was wireless communications new approach described by Mitola as: "The point in which wireless personal digital assistants (PDAs) and the related networks are sufficiently computationally intelligent about radio resources and related computer to-computer communications to detect user communications needs as a function of use context, for providing radio resources and wireless services most appropriate to those needs".

It is a form of wireless communication where communication channels which are in use and that are not in use, can be intelligently detected by transceiver and while avoiding occupied ones are instantly move into unused channels. The use of radio-frequency spectrum available is optimized while interference is minimized for other users. CR technology is a paradigm for wireless communication in which to avoid interference, transmission or reception parameters of network or wireless node are changed for communicate with the licensed or unlicensed users. The concept of the latent opportunities for the safest use of spectrum as non-interfering and considering them as multidimensional areas within frequency, time, and space is termed as spectrum hole in general. The ability to sense when secondary radio systems are within such a spectrum hole is the main challenge.

The two types of cognitive radio are:

i. Full cognitive radio: All parameters are considered by full CR. Every possible parameter that is observable by the wireless node or network is considered and a wireless node or network can be aware of it.
ii. Spectrum-sensing cognitive radio: The channels in a radio frequency spectrum is detected by the spectrum-sensing cognitive radio and considered as the radio frequency spectrum.

Two major features of cognitive radio are as following:

Cognitive capability: The radio technology ability of capturing or sensing the information from the radio environment provided.

Reconfigurability: Cognitive capability provides the spectrum awareness while reconfigurability enables the radio accordingly to the radio environment to be dynamically programmed.

### *1.1 Functions of cognitive radio*

#### *1.1.1 Spectrum Sensing*

The major goal of spectrum sensing by periodically sensing the target frequency band, determine the licensed user's activity and spectrum status. Spectrum detection which is not used or is a spectrum hole and also determining the accessing method of spectrum hole by the cognitive radio transceiver without interfering of a licensed user's transmission. Sensing of spectrum may be either centralized in which the target frequency band is sensed by the controller senses, and the information obtained is further shared with other nodes in the given system. Or it may be distributed in which the spectrum is independently sensed by the unlicensed users, and the spectrum sensing so achieved is either used by individual cognitive radios or is

shared with other users. The accuracy of non-cooperative is lower than that of spectrum sensing. Sensing techniques has been categorised as: Detection of transmitter, Cooperative based detection and Detection on the basis of Interference.

*1.1.2 Spectrum Management*

The classification of the management functions is done as Spectrum analysis, Spectrum Decision, Spectrum Mobility and Spectrum Sharing. To estimate the spectrum standard the sensing of spectrum results are analyzed. Average correlation, Signal to Noise Ratio (SNR) and the white spaces availability are used to characterise quality. The decision model is required by the Spectrum access.

As when a Secondary User contains multiple objectives, it makes the decision model much more complex. The solution to model and solve the spectrum access problem in a Cognitive Radio, an interesting tool stochastic optimization method is used. The preference influences the decision of spectrum access, when both primary and secondary users are in a system. In spectrum access, both users could be cooperative or non-cooperative. In a non-cooperative environment, each and every user has its own individual purpose. All users could work in integrity to achieve the goal in a cooperative one. Variation of operating frequency bands of the CR users is related to the Spectrum mobility function. Cognitive radio maintains its balance between the goal of efficient information transferring and sharing of the available spectrum with the other cognitive as well as non-cognitive users as there are number of secondary users who need to use available spectrum holes. The policy rule as behaviour of cognitive radio is determined in radio environment to do it.

## 2. DYNAMIC SPECTRUM ACCESS

The concept of determination of spectrum holes i.e. a frequency band that is free enough to be used or the white spaces and their use to communicate is termed as the Dynamic spectrum access [DSA]. DSA is defined as the major application of cognitive radios. The negligible interference is caused to the Primary Units when the Primary User bands are accessed by the Secondary User networks opportunistically. In response to changing objectives and circumstances, the adaption is done to available spectrum holes by radio system with dynamically limited spectrum use rights: the radio's state is changed by the created interference changes in environmental constraints. Main objective is the overcoming of the two types of interference by DSA:

i) interference caused due to the malfunctioning of device
ii) interference caused by venom user.

There are the main functions of the Dynamic Spectrum Access. When the different kind of ways are provided by the spectrum access to use the available spectrum opportunities for the efficient reuse, awareness is created by the Spectrum awareness about the Radio Frequency environment. Several subtasks like designing sensing efficient, access policies and learning of the radio environment are performed by the Cognitive processing that is intelligence and decision making function that manages interference for the SU networks with the PU networks coexistence.

## 3. DIFFERENT MODELS AND SCHEMES OF DSA

Cognitive network is widely using the Dynamic spectrum access (DSA) that has several approaches and applications.

### *3.1 Different approaches of DSA Models*

Strategies for Dynamic spectrum access can be classified as dynamic exclusive use, open sharing model, and hierarchical access model.

*3.1.1 Dynamic Exclusive Use model*

The current spectrum regulation policy basic structure is maintained in this model: For exclusive use, Spectrum band has been licensed to services. The flexibility is been introduced for the improvement of the spectrum efficiency Therefore, two approaches have been considered under the model:

i) The sale of licensees to and trade spectrum and to free technology choice is allowed by the Spectrum property rights approach.
ii) Through dynamic spectrum assignment, improvement in the efficiency of spectrum using spatial and temporal traffic statistics of different services is aimed by the Dynamic spectrum allocation approach.

*3.1.2. Open Sharing Model*

Equal rights to use the spectrum by every user are provided by the Open sharing model is also known as spectrum commons model. It has been applied for Wireless services make the use that is operated in the unlicensed medical (ISM) radio band and

industrial scientific (e.g., WLAN). The three types of spectrum commons model:

i) Uncontrolled- commons are the one in which a spectrum band management is done and use of the uncontrolled commons model is done where exclusive license to the spectrum band is not provided to any entity.
ii) Managed-commons represent an effort to lower the commons tragedy where a limited form of structure of spectrum access is imposed which includes resources owned or controlled by the individuals, groups or entities and characterized by the restrictions of when and how resource is to be used.
iii) Private-commons concept increases on the permit for use of advanced technologies where the spectrum could be accessed by multiple users.

### *3.1.3. Hierarchical Access Model*

In hierarchical access model, the interference to the Primary Unit is limited by the use the primary resources in Secondary Unit. The major three approaches are included under this model:
The idea of re-use the spectrum opportunistically in the spatial domain i.e., in the geographical areas the primary spectrum utilization is done by CRs where primary activity is absent, is used in the inter-weave model. Interest is been attracted by exploitation of so called spatial spectrum holes, since many of the current licensed systems such as, TV broadcasting cellular systems etc. At the rate of low power level underlay technologies are been operated in the used spectrum for the licensed or the license exempt uses but the users are not impaired. Underlay use is not made licensed. Underlay access has ideated CRs to its operation below noise floor of the PUs, which involves an undercurrent of Cognitive Radio communications without the awareness of the PUs. An overlay approach has allowed higher powers which could result in the interference to existing users but it overcomes this possibility by permitting the transmissions at times or areas with the unused spectrum .

## 4. METHODS OF DYNAMIC SPECTRUM ACCESS

### *4.1 Game Theoretic Approach*

For analyzing the iterative decisions behaviour of an individual's interest about their own benefit, mathematical framework which consists models and techniques is used. The analysis and planning is done of the interaction among the different decision makers about the mathematical tool. Three major components exist in the following approach:
i. Decision Makers (N): Each game is consists of players or finite number of decision makers or N.
ii. Action Space (A): Own action space is provided for every player that is set of actions including al actions that the player could choose. All action sets are multiplied to provide the total action space.
iii. Utility Set (U): This set consists of the payoff functions or utility for the players.
The games are classified into two types,
Cooperative Games: All players not much worrying about their own personal benefit, shows much of their interest in the overall benefits. To decrease the transmitting power of SUs for avoidance of interference generation to PU transmissions, Cognitive Radio had made use of the cooperative game theory in few recent works. Nash Equilibrium (NE) is the well known property among the game-theoretical approaches. Here, every player is could know the equilibrium strategies of the other players; therefore have nothing to gain by changing the strategy. The own benefit is the only factor taken care of by each rational network users and for maximising his/her pay off function the optimal strategy is chosen by them, thus the outcome is termed as Nash Equilibrium in the non-cooperative spectrum of sharing game.
Competitive Games: All of the decisions are made selfishly and competitively as being personal payoff the major concern of each user. In spectrum allocations for the networks of Cognitive Radio where the Primary User and Secondary User participate in a game, extensive use of such concepts is done. Their behaviour is rational for choosing strategies that maximize the individual payoffs.

### *4.2. A Measurement-based Model for Dynamic Spectrum Access*

A Measurement-based model is used as a Semi-Markov model which is used to capture behaviour of WLAN in a much better way to be used to obtain optimal control strategies within the decision frame work. Here, to achieve a complex base band data, vector signal analyzer is used, that is based upon the actual measurements in the 2.4GHZ ISM band. A VSA (vector signal analyzer) is used, for capturing of the raw and complex baseband data. These data identify the idle and busy periods of a channel. WLAN make use of the three computers having wireless adapter cards (two Netgear WG311T and one WG511T) and wireless router (Netgear WGT624)[5]. After capturing of the transmission of WLAN that is internally down converted from an internal Intermediate Frequency ata sample rate to 2.462GHz from 44MHZ, the complex data base band samples is collected by the

Vector signal analyzer. Continuous-time Semi-Markov process allows at each state for an arbitrary specification of temporary time distribution. While this model prevents the occurrence of collisions is prevented by this model and good accuracy is attained due to infrequent collisions.

### *4.3. Dynamic Spectrum Access Using a Network Coded Cognitive Control Channel*

To increase robustness, throughput and decrease delay, Network coding has been introduced for data dissemination in the wireless networks. Network coding provides store, code and forward technique in which all the incoming packets are stored in an internal buffer by each node stores and their linear combinations is successively sent, where some finite Galois Field is performed for combining over. For example, n packets, at least n independent combinations must be collected of the original packets by a node. This way is used to provide a high throughput gains in both of the multicast or broadcast network.
The users could opportunistically access the channels that are available for communications efficiently using Dynamic Spectrum Access scheme. Four important aspects of opportunistic spectrum access are as following:
1) control channel implementation,
2) multi-channel medium access control,
3) detection of the primary user,
4) secondary reuse of the available unused spectrum by primary users.
All the channels are visited by the secondary users in a pseudo random fashion and control information is exchanged as they come across in any of the channel. Each user run a resource allocation algorithm run independently, free channels are the only assigned with the transmission opportunities. The method defined is completely distributed and allocated spectrum resources are not needed for control purposes but the leverages of the virtual control channel which is used to carry network coding techniques and a cooperative detection strategy is exploited to identify the unused spectrum. This results in the degradation of spreading performance of the network coded cognitive control channel-DSA with respect to NC4-MAC.

### *4.4. Fuzzy Logic Based System*

The problem based on noisy, inaccurate and incomplete information is provided a favourable solution by the use of the Fuzzy logic. A set of fuzzy membership functions and indirect rules for obtaining the solution are used in the fuzzy logic which meets desirable objectives. Three important parts in a control system of fuzzy logic:
1) fuzzifier,
2) fuzzy logic processor
3) defuzzifier.
The actual inputs are plotted by making fuzzy by the fuzzifier, to achieve a solution based on sets of predefined rules, the fuzzy logic processor is provided an inference engine, and for conversion of the solution to real output, the defuzzifier is applied. The fuzzy logic is said to be a multi-valued logic. In it, decision is taken using many input parameters. Input parameters here includes signal strength, velocity, signal strength and spectrum efficiency. If there occurs channel (offered by PU) high signal and lower distance between PU and SU, the chance of taking decision is increased. If the distance is small, chance of the spectrum accessing is increased by the velocity.

### *4.5. Spatio-Temporal Spectrum Management Model*

The lower flexibility of spectrum allocation regime causes Spectrum scarcity problem, spatio-temporal bandwidth demand adapts more suitable spectrum allocation which increases the spectrum availability, thus solving the spectrum scarcity problem. In this model, multiple regions division is done to the service area. The wireless services are provided to the users by network service provider, in the region, and this service provider for spectrum demand RSB (Regional Spectrum Broker) own the spectrum of the region in which requesters are granted with the short time licenses. In Temporal Dynamic Spectrum Allocation (TDSA) method, the service providers of the given region send the demands for the spectrum to RSB. The continuous spectrum blocks are allocated to the requesters by the RSB and the guard bands separates the blocks. The Spectrum demands that come at the same time in multiple regions are dealt by Spectrum Dynamic Spectrum Allocation (SDSA). Adjustment of the multiple demands within multiple regions on the way is the main objective of the SDSA, where the least interference could be found in the overlapping regions.

### *4.6. Markovian Queuing Model for Dynamic Spectrum Allocation*

Markovian Queuing model makes use of the Centralized architecture for dynamic spectrum allocation. The bandwidth to the intended users is provided by the central controller of an ad-hoc network in centralized network. Thus, this provided CR ad-hoc network and the network of licensed users coexist with each other where the CR coordinating engine updates the controller of licensed user. A hidden terminal problem is eliminated by the centralized network, complete

database of unoccupied frequencies is obtained and better coverage is provided with the efficiency spectrum handover technique. Two transceivers are consisted by each SU, where one is dedicated for control and another is the software defined radio based. The availability of spectra in given area is scanned by the SDR based transceiver and the information of these spectrum holes is forwarded to the central controller in the case of secondary User forms an infrastructure less network or otherwise in case of infrastructure based network to the Base Station. Special case of stochastic processes contains these queues that are characterized by arrival process of requested service, requests waiting list that are to be processed. SUQ is defined as the queue which stacks all the entries of SUs and the entire request are served on the first come first serve (FCFS) basis entering this queue. Both the request from the SU and the PU are considered by head, and at any time when bandwidth is needed to be allocated for the Secondary User that needs its licensed channel. For accessing the frequencies with head, arrival rates of both the users are to be added, while distribution of the number of frequencies for both Primary and Secondary User. Bandwidth allocation queue (BAQ) is thus formed queue. Queuing model is studied using Markov process.

Table 1. Features of methods used for Dynamic Spectrum Access

| Method for DSA | Features |
|---|---|
| Game Theoretic approach | • Adaptable for competitive as well as cooperative environment<br>• Emphasis on solving and analysing nash equilibrium |
| Measurement based model for DSA | • Used to obtain optimal control strategies within the decision frame work<br>• Vector signal analyzer used to achieve a complex base band data |
| DSA using Network Coded Cognitive Control Channel | • Used for data dissemination in the wireless networks<br>• Used to increase robustness and throughput<br>• Decreases delay |
| Fuzzy Logic Based System | • Problem based on noisy, inaccurate and incomplete information solved<br>• Fuzzy membership functions and indirect rules used |
| Spatio-Temporal Spectrum Management Model | • Adjustment of the multiple demands within multiple regions on the way is the main objective<br>• Solves spectrum scarcity problem |
| Markovian Queuing Model for Dynamic Spectrum Allocation | • Models the interaction between users<br>• Users autonomy guaranteed<br>• Do not perform more complex processing |

## 5. FUTURE FOR DYNAMIC SPECTRUM ACCESS

The cognitive radio enabling DSA technology is expected to be more powerful in the future to meet diverse interests. The four components future cognitive radio will include are policy enforcement entity, incentive entity, security module, and coexistence module including four more capabilities as network topology awareness, network coding, cross-layer optimization, and multiple-input-multiple-output (MIMO). The enforcement entity ensures the use of spectrum usage rules. With the incentive entity, PUs is incentivized to provide information on channel activity to reducing spectrum sensing overhead. The security module is used to alleviate attacks. The coexistence module includes the coexistence of PUs and SUs from different domains on a spectrum band. Network coding would be used to capitalize on interference offering incentives to PUs and SUs. The cross-layer optimization will emphasis on the spectrum sensing along with channel switching coordination optimising performance and quality of service. MIMO technology would boost the throughput. With these additions, the capability of cognitive radio would expand from a primarily physical layer technology to a network technology. We term the future cognitive radio with these additions as network radio, to emphasize this technology expansion. It will facilitate the coexistence of multiple DSA networks with possible different technologies, security enforcement, topology formation and adaptation coordination, cross-layer optimization, and performance optimization.

## 6. CONCLUSION

To communicate efficiently avoiding interference with licensed or unlicensed users, cognitive radio is a pattern for the wireless communication, where transmission or reception parameters are changed by a network or wireless node. Here, different dynamic spectrum access models have been discussed. Game theoretic is one of the important and most authentic approaches in exploring, modelling and analyzing with the Cognitive interaction process. This process has been used in large degree for spectrum sharing which had become an interesting field of research for spectrum management. The equilibrium solutions are obtained to the problem of the spectrum sharing in the game theory. The continuous time semi Markov model is used in the measurement based model that is used to captures the idle periods between the bursty transmissions of a wireless LAN. The model provided a good compromise between computation complexity and accuracy. A centralized architecture is proposed for bandwidth allocation and finding blocking probability coexisting with licensed users, in the Markovian queuing model. The hidden terminal problem is overcome by considering sensing to get and to get decentralized along with complete database of the unoccupied frequencies. Delay of Secondary User subject is minimised to a Primary User collision probability constraint by the delay performance of threshold policies. The problem of spectrum allocation is simplified by the Spatio-Temporal spectrum management model and the complex problems splits into into temporal and spatial parts (TDSA and SDSA) according to the described architecture. Based upon the information of Regional Service Broker problem of interference can be handled in the overlapping regions. This model provides a solution to perform an optimal spatio-temporal allocation. Therefore, Game theoretic approach is the most favourable tool for CR systems. Further study may also be done using Game theory and Measurement model to provide more accurate and realistic results.

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