



Survey on Channel Allocation and Spectrum Sensing in Cognitive Radio Networks

Ms. Niroshini Infantia.C

Assistant Professor, Department of Information Technology
St Joseph's Institute of Technology
OMR, Chennai – 119

ABSTRACT

Cognitive radio network (CRN) is a network that depends on spectrum sensing and opportunistic spectrum access. This network can improve the wireless networks' spectrum efficiency. Here, spectrum sensing and channel allocation techniques form a major research in recent trends. This paper presents the survey on channel allocation and spectrum sensing techniques in cognitive radio networks. The existing works on channel allocation are classified as game theory based, distributed and multimedia based. The spectrum sensing works are classified as compressed sensing and cooperative sensing. A comparison table is also provided which lists out the strengths and weakness of each approach.

Keywords- Channel; Spectrum; CRN; AHCRN; SU; FCC

INTRODUCTION

Cognitive radio network (CRN) is a network that depends on opportunistic spectrum access and spectrum sensing for improving the wireless networks' spectrum efficiency. Federal Communications Commission (FCC) says that the secondary users (SUs) periodically sense the activities of the primary user (PU). SU can opportunistically use the channel when a channel is not occupied by a PU. The main characteristics of cognitive radio (CR) are that the SUs should adapt to the dynamic changes of the channel availability and the activities of PUs change dynamically [1]. The significant part of CR studies is the dynamic spectrum access (DSA) that is used to provide SUs' access to white spaces or spectrum holes such that SUs can send information in a licensed band without interfering with PUs [2].

CRNs provide enhanced service quality, thereby allowing a SU to find and exploit the spectrum opportunities without interfering with the PU. Spectrum sensing is a key enabling functionality of CRNs, which is used to monitor the PU activities and detect spectrum holes for DSA [3]. Nowadays, a popular topic in signal processing and telecommunications is wideband spectrum estimation and sensing. CR is a popular application in which unlicensed users sense a broad frequency range for locating the unoccupied licensed spectrum before setting up a communication link [4].

This paper presents the survey on channel allocation and spectrum sensing techniques in cognitive radio networks.

EXISTING SURVEY WORKS

In this section, existing survey works on channel allocation and spectrum sensing has been discussed.

A. Channel allocation

Uma Sharma et al [5] have introduced the method of using game theory to model several interactions among CRs in AHCRN. Game theory is utilized at various layers such as data link layer, physical layer, network layer, and other higher layers.

Ejaz Ahmed et al [6] have presented an inclusive survey on the recent channel assignment algorithms in CRNs. By presenting a thematic taxonomy of the current channel assignment algorithms in CRNs, the algorithms are classified. Furthermore, they analyzed the significant aspects of the current channel assignment algorithms in CRNs for determining the strengths and weaknesses of such algorithms. According to the important parameters, such as routing dependencies, channel models, assignment methods, execution model, and optimization objectives, they investigated the similarities and differences of the algorithms. The open research issues and challenges of channel assignment in the CRNs are also discussed.

B. Spectrum sensing

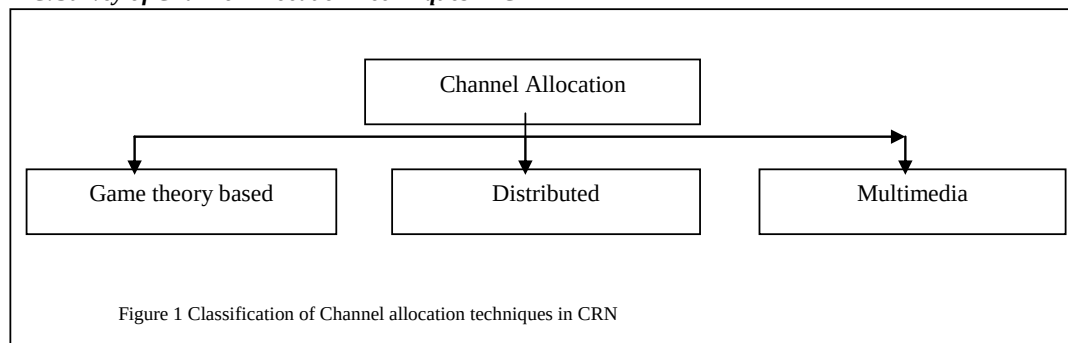
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Mansi Subhedar et al [7] have presented the survey of various spectrum sensing techniques where the challenges and issues while implementing the spectrum sensing techniques are discussed thoroughly and the comparative study of various methodologies are provided.

Hongjian Sun et al [8] have presented various wideband spectrum sensing algorithms along with a discussion of the strengths and weaknesses of each algorithm and its challenging issues. Special attention must be paid to sub-Nyquist techniques that have multi-channel sub-Nyquist sampling and compressive sensing techniques.

Ian F. Akyildiz et al [9] have studied the state-of-the-art of cooperative sensing for addressing the concerns of cooperation method, cooperation overhead, and cooperative gain. Particularly, the elements of cooperative sensing, including cooperation models, sensing techniques, hypothesis testing, data fusion, control channel and reporting, user selection, and knowledge base analyzed the cooperation method. They also discussed the open research challenges regarding each issue in cooperative sensing.

C. Survey of Channel Allocation Techniques in CRN



The existing works on channel allocation techniques in CRN can be classified as shown in Figure-1.

a. Game Theory based channel allocation

In this section, channel allocation techniques utilizing Game theory mode are discussed:

Uma Sharma et al [10] have utilized Game theory for solving channel allocation problem. Game theory analyzes the interactions between different nodes and provides an optimized solution for this situation. They established a route between source and destination with minimum interference to other nodes, minimum delay, and maximum packet delivery ratio. According to the requirements, these terms are assigned with some weight. By varying weights of terms, the network performance has been compared.

Long CAO et al [11] have formulated the channel allocation problem as the 0-1 integer programming optimization by taking the overall utility of primary system and secondary system into account. A many-to-one matching game is inspired by matching theory for remodelling the channel allocation problem. They proposed the corresponding PU proposing deferred acceptance (PPDA) algorithm for yielding a stable matching. The performance and computation complexity between these two solutions are compared. Results show the efficiency and achieve the communication overhead of the proposed scheme.

Amulya Bhattarai et al [12] have developed policies for channel allocation in CRN. Game theory is a tool used for allocating the limited resources among the selfish users in CRN. The system drives the distributed users' actions and decisions into an equilibrium state. The Nash Equilibrium (NE) solution has been analyzed for different CRN scenarios ranging from simple scenarios ('Fixed: 3 link, 2 ch' and 'Fixed and Random: 5 link, 3 ch') to a more complex one ('Random: 10 link, 4 ch'). The policies for channel allocation for CRN have been developed on the basis of the obtained results. In order to reach equilibrium solutions with less computation resources and time, these general policies can be utilized in other CRN scenarios.

Vani Shrivastav et al [13] have presented a game theoretic-based model with the aid of the concept of Nash Equilibrium for spectrum sharing where number of radios on each link and interference are considered as the parameters for designing the game. They presented an algorithm for channel allocation among the users. Simulation analysis shows that the system executes satisfactorily in terms of network utilization. In addition, they applied the Taguchi method and performed an analysis of variance (ANOVA). They proved that the design parameters considered in the proposed method are impactful.

b. Distributed Channel Allocation

In this section, distributed channel allocation techniques in CRN are discussed:

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Zhihui Shu et al [1] have proposed an adaptive channel allocation and routing scheme that is flexible so that it can react to the dynamic change of channel availability and maximize the throughput by exploiting the network coding opportunities. Initially, the PUs' activity, channel availability, and the interference are modelled among the SUs in a CRN environment and showed the method for implementing a network coding scheme and a backpressure algorithm in multi-hop CRNs. After that, an optimization problem is formulated for maximizing the throughput of the network. The channel availability constraint is considered and the network coding opportunity is used. They proposed a distributed channel allocation and route selection algorithm for reducing the computing complexity.

Sandro Machado Ribeiro et al [2] have proposed a novel approach for channel allocation in CRNs with the help of a predictive and adaptive database. They improved the performance of the SM on the channel allocation procedure in CRNs. For allocating those channels with higher probability of being idle, SM utilizes the predicted data, obtained via a spectrum-modeling algorithm for emulating the channel utilization. Through periodic updates of the database, the adaptive characteristic is ensured, depending on channel sensing results. Thus, they ranked the channels in order that those with best performance are used for SU allocation.

Sitadevi Bharatula et al [14] have proposed an efficient channel allocation scheme for SUs in CRNs on the basis of their priority. With traffic-less model, the frequency or spectrum resources are allocated to SUs. They proposed a new algorithm for allocating efficient channel to the SUs with traffic-less mechanism and reducing the interference between the PUs and the SUs. By using the optimal (efficient) channel allocation for traffic less mechanism is achieved.

Jianjun Yang et al [15] have proposed a new bipartite-graph based model and design channel allocation algorithms for improving the minimal channel gain in order to attain relative fairness. The heterogeneous network environment is mapped to a weighted graph. The augmenting path is used to update channel allocation status and utilize canonical form for comparing the new status with previous status to attain better fairness.

Jie Jia et al [16] have investigated the problem of congestion avoiding in wireless cognitive radio mesh networks. They presented a mathematical formulation by constructing bandwidth-guaranteed topology graph for accounting the complex relationships among the effect of network interference, flow conservation, and link capacity. In addition, they proposed a nested optimization strategy for solving the complicated problem that has a genetic approach for route scheduling, a genetic approach for channel allocation, and an optimal path selection algorithm to discover maximum bandwidth path. Both the combination and sequence-based encoding rules are designed with appropriate constraint control mechanisms for ensuring the fast convergence and individual validity.

c. Multimedia Channel Allocation

In this section, multimedia channel allocation techniques in CRN are discussed:

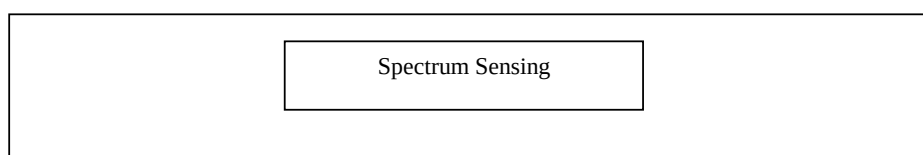
Tigang Jiang et al [17] have proposed a novel Markov-Chain based model of centralized CRN (CCRN) consisting of APs and user equipments with several antennas (one antenna for channel sensing and the others for data communication). Here, AP scans the idle primary channels that are not used by PUs and send the data via selected idle channels. Moreover, they considered three types of communications and pre-assigned an appropriate number of time slots for ensuring QoS of various types of multimedia traffic. To model time slot allocation, a multi-dimension Markov chain is used. A general channel allocation model has been proposed for multimedia traffic over CCRN.

Ansuman Bhattacharya et al [18] have proposed a novel channel allocation technique for solving the shortcomings in a CRN by utilizing several non-contiguous channels each with smaller width than the required bandwidth, but whose sum equals at least the required bandwidth. Along with transmission and reception protocols with two different implementations based on FDM – FDMA and OFDM – FDMA techniques, the algorithms for channel sensing, reservation, and deallocation are presented.

Malathi et al [19] have proposed CR as a general approach for higher EE in wireless communication systems to increase the energy efficiency in resource allocation of cognitive base station operating in television system (TV white spaces) on the basis of frequency and power allocation protocol. A design is proposed for routing and resource distribution for CR in TV networks.

Md. Jalil Piran et al [20] have proposed a method for channel allocation based on the quality of the available channels and video content requirements in CRNs where according to scene complexity and PSNR, the content is split into clusters. Based on the licensee's activities using a Bayesian nonparametric inference model, short and long time transmission opportunities are classified. In addition, the underlay mode for transmission of the clusters with a lower bitrate is considered for preventing transmission interruption. According to both the requirements of the clusters and the quality of the channels, the available spectrum opportunities are then mapped to the content clusters. After that, according to the network transmission mechanism, a distortion optimization model is constructed. An optimization problem is defined to find the best bit rate for each cluster by maximizing the sum of the logarithms of the frame rates. This is done for improving the average quality of the delivered video.

D. Survey of Spectrum Sensing technique in CRN



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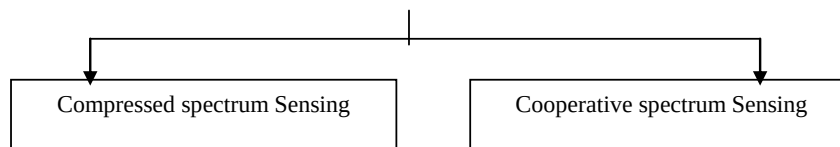


Figure 2 Classification of spectrum sensing techniques in CRN

The existing works on spectrum sensing techniques in CRN can be classified as shown in Figure-2.

a. Compressed spectrum sensing

F. L. Liu et al [3] have presented a new wideband spectrum sensing algorithm based on compressed sensing theory for providing an effective sparse signal representation method for the wideband spectrum sensing problem. Therefore, by finding the sparse coefficients, this method can effectively detect all spectral holes. Simultaneously, by using the compressive sampling technique, the acquisition costs and signal sampling rate can be substantially reduced.

Dyonisius Dony Ariananda et al [4] have presented a solution based on a simple least-squares reconstruction method and a periodic sampling procedure. The reconstruction process is evaluated in the time and frequency domain. Two possible implementations are performed for the compressive sampling procedure such as multicaset sampling and complex Gaussian sampling, though they are mainly focused on the latter. Based on the minimal sparse ruler problem, a new type of multicaset sampling is introduced. The statistical properties of the estimated power spectrum are analyzed. For calculating the analytical normalized mean squared error (NMSE) of the estimated power spectrum, the computation of the mean and the covariance of the estimates are used. The computed mean and covariance derive a suitable detection threshold when the received signal is assumed to have only circular complex zero-mean Gaussian i.i.d. noise.

Jens P. Elsner et al [21] have showed that linear compression with time-shifted random preintegration is equal to compressed sensing with Toeplitz-structured random matrices. It preserves the autocorrelation properties that help in efficient compressed signal detection and joint compressed spectrum estimation in CR terminals.

Qi Zhao et al [22] have proposed a WSS scheme that includes both multi-band joint detection and compressed sensing technique for reducing the energy consumption. They identified the three key factors that affect the sensing performance based on extensive analysis and simulation, namely, the received signal-to-noise ratio (SNR) of the primary signal, the sparsity order of the wideband spectrum, and the compression rate employed in sampling. Specially, a closed form analytical model of the scheme is derived. From these observations, it is concluded that under the sensing performance constraints, the energy efficiency, which is defined as the ratio of the spectrum access opportunity to the energy consumption, will be increased through the optimization process of the compression rate. The uniqueness of the optimal compression rate is indicated for improving the energy efficiency.

b. Co-operative spectrum sensing

Le Thanh Tan et al [23] have proposed a semi-distributed cooperative spectrum sensing (SDCSS) and channel access framework for multi-channel CRNs where SUs are used to sense and exchange the sensed outcomes with each other for locating the spectrum holes. Moreover, the p-persistent CSMA-based cognitive medium access control protocol is devised by integrating the SDCSS for providing efficient spectrum sharing among SUs. The throughput analysis is performed and an algorithm is developed for determining the spectrum sensing and access parameters. This will enhance the throughput for a given allocation of channel sensing sets. Furthermore, the spectrum sensing set optimization problem is considered for SUs in order to improve the overall system throughput. Both exhaustive search and low-complexity greedy algorithms are presented for finding the sensing sets for SUs and analyzing their complexity. Finally, they defined the concept of how their design and analysis can be extended to report errors.

Yingjiao Zhao et al [24] have proposed a soft fusion scheme based on LLR. This scheme simplifies the analysis of the data at FC and defines the exact closed-form expressions for the distribution of the data at FC. This forms to be the Gaussian Distribution. They considered that the closed-form expressions for the probabilities of false alarm derived and miss detection are analytically tractable. Hence, the global optimality is efficiently guaranteed with low computational complexity.

Hongjuan Li et al [25] have considered the problem in cooperative spectrum sensing scheduling (C3S) in CRN when multiple primary channels present. They focused on a scenario where each SU can decide whether participating in cooperative spectrum sensing or not. If it is not participating, the SU becomes a free rider who can eavesdrop the others' decision about the channel status. At a risk of scarifying the spectrum sensing performance, such a mechanism can

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preserve the energy for spectrum sensing. For this, a framework is modelled as an evolutionary game where each SU makes its decision on the basis of its utility history and performs an action more often when it brings a relatively higher utility. An entropy based coalition formation algorithm is developed where each SU selects the coalition (channel) that brings the most information related to the status of the corresponding channel. All the SUs that choose the same channel to sense form a coalition.

Di He et al [26] have proposed a cooperative spectrum-sensing technique in CRNs based on the data fusion of various chaotic stochastic resonance (CSR) energy detectors. Detection performance of conventional energy detection cannot be guaranteed because of noisy uncertainty in unpredictable wireless communication environments. The detection probability is improved under the same constant false-alarm rate, particularly under low signal-to-noise ratio circumstances. This can be done by introducing the CSR system with various CSR noise types and with the data fusion on these CSR-based energy detectors.

COMPARISON TABLE

Table 1 presents the comparison of channel allocation techniques in CRN. It analyzes each work in terms of interference reduction, route handling and multi channel capability.

Table 1 Comparison of Channel allocation techniques in CRN

Approach	Type	Interference Reduction (Yes/No)	Routing Handled (Yes/No)	Multichannel (Yes/No)
Back Pressure Algorithm [1]	Distributed	Yes	Yes	Yes
Spectrum modelling Algorithm [2]	Distributed	No	No	Yes
Greedy Algorithm [14]	Distributed	Yes	No	Yes
Channel Allocation Algorithm [15]	Distributed	Yes	No	Yes
Optimal path Selection Algorithm [16]	Distributed	Yes	Yes	Yes
Deferred Algorithm [11]	Game Theory Based	No	No	Yes
Cognitive radio based algorithms [12]	Game Theory Based	No	No	No
Coin Algorithm [13]	Game Theory Based	Yes	No	Yes
A novel Markov-Chain based model [17]	Multimedia Based	Yes	No	Yes
Channel Assignment Algorithm [18]	Multimedia Based	No	No	Yes

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Threshold Algorithm [19]	Multimedia Based	No	Yes	Yes
Bayesian nonparametric inference model [20]	Multimedia Based	Yes	No	Yes

Table 2 presents the comparison of spectrum sensing techniques in CRN. It analyzes each work in terms of energy saving, wideband support and multi channel capability.

Table 2 Comparison of Spectrum sensing techniques in CRN

Algorithm name	Type	Energy Saving (Yes/No)	Wideband (Yes/no)	Multichannel (Yes/no)
Wideband spectrum sensing [3]	Compressed Sensing	Yes	Yes	No
Periodic sampling procedure [4]	Compressed Sensing	Yes	Yes	No
Toeplitz-structured CS matrices [21]	Compressed Sensing	Yes	Yes	No
Wide band Spectrum Sensing [22]	Compressed Sensing	Yes	Yes	Yes
Semi-distributed cooperative spectrum sensing [23]	Cooperative sensing	No	Yes	Yes
Cooperation of several cognitive radio sensors(CRSs) [24]	Cooperative sensing	Yes	Yes	Yes
Novel cooperative framework [25]	Cooperative sensing	Yes	Yes	Yes
A cooperative spectrum-sensing technique [26]	Cooperative sensing	Yes	Yes	Yes

CONCLUSION

In this survey paper, different channel allocation and sensing techniques have been studied with their algorithms. From the comparison table of channel allocation (Table 1), it can be concluded that almost all the works possess multi channel facility. However, nearly half of the works only handle interference reduction along with channel allocation. Similarly, one two among the works handle routing functionality along with channel allocation. From the comparison table of spectrum sensing (Table 2), it can be concluded that majority of the works support multi channel facility. Almost all the works support wideband sensing. However, some of the works did not provide energy conservation. Hence there is a need

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for developing a joint channel allocation and spectrum sensing technique which should reduce the interference significantly and reduce the energy consumption.

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