IJCCN International Journal of Computing & Communication Networks

ISSN: 2664-9519 (Online); Vol. 1, Issue 1, August 2019

Spectrum Access Management for Cognitive Radio Sensor Networks: A Review

Talha Azhar, Abrar Ahmed, Hermain Shafiq and Nazir Malik

Department of Computer Science, Bahria University Islamabad, Pakistan

e-mail address: mohammadtalha01@gmail.com

* Corresponding Author: Talha Azhar

Received 11-February; Revised 5-April; Accepted 25-July; Published 15-August

Abstract: The spectrum scarcity problem, which was being faced by the traditional wireless sensor networks for the past few years, has finally been addressed with the advent of Cognitive Radio Sensor Networks (CRSN). This new promising technology can utilize the unused portions of the frequency spectrum opportunistically. Now the CRSN devices cannot only sense the unused spectrum but they can also allocate it to the secondary users present in the same geographical area. In this review paper, various aspects related to the spectrum management of CRSN are analyzed in multi-dimensional way. The research problems associated with CRSN are discussed and the enabling techniques have been reviewed. Finally, other open research problems related to this area are discussed. This paper help the researchers in this domain for further study and select their next milestone.

Keywords: *Cognitive Radio Sensor Networks, Spectrum Access Management.*

1. Introduction

For the past few years there has been a substantial increase in wireless communication services and applications. This advancement has brought us to the critical issue of efficiently utilizing the frequency spectrum, as it is known to be a scarce radio resource. Cognitive radio is one such technology that uses for the spectrum efficiently by dynamically accessing it rather than the traditional fixed access approach [1]. Cognitive radio is performing three steps in an opportunistic cycle where it senses the spectrum, and then it identifies the available bands and dynamically tunes its radio parameters to make its usage for these available bands. The cognitive radio, when employed in a multi-hop Wireless Sensor Network (WSN), yields a new sensor network model. i.e., Cognitive Radio Sensor Network (CRSN), as shown in Figure 1 [2]. This enhancement will benefit the WSN by solving many issues like power consumption, busty traffic, overlaying deployment, data collisions, and medium access delays [3]. A CRSN is a distributed network for WSN nodes, each having a cognitive radio transceiver along with a sensing unit [1]. These nodes have the capability to cooperatively communicate their information in a multi-hop manner and utilizing available spectrum bands. In a nutshell, a multi-hop WSN can provide high bandwidth to its end-user with more efficiency, extended service coverage, and ubiquitous connectivity by incorporating the dynamic spectrum access techniques of cognitive radios. However, this concept requires a new set of advanced techniques to solve the existing challenges that come with the combination of these two wireless technologies. Figure 1 shows a CRSN optimization technique and discussed the major challenges being faced by these CRSNs where one of the challenges is the spectrum assigned to the Secondary Users (SU). Because of this challenge, many new problems like delays in packet transmission, wastage of wireless channel resources and increase in frame loss ratio are occurring during data transmissions. The poor outcome of spectrum assignment is not only its effects on the SUs but it also affects the Primary Users (PU), which are transmitting within the same transmission range. In CRSN, the SU has the ability to operate in any wireless band because it has a reconfigurable transceiver. We, therefore, present a brief overview of the spectrum access techniques for enhancing the performance of a CRSN.

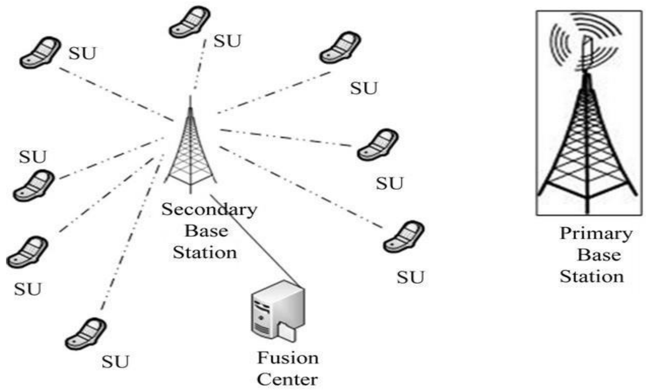

Figure 1. A Cognitive Radio Sensor Network (CRSN)

The scope of the study is narrowed down by only focusing on techniques including (i) Power Control, (ii) Routing Protocols (iii) Distributed Management (iv) Multichannel Allocation and (v) Control Channel. More than ten spectrum access management mechanisms have been surveyed to enhance network performance. Other aspects related to spectrum management (such as throughput rates, security, and fairness) are out of the scope of this review.

The remainder of the paper is structured in the following manner. Section 2 provides a brief overview of the spectrum access process in CRSN. In the corresponding subsections, each spectrum access mechanism has been surveyed with prime of the goal of enhancing network performance. In Section 3, the mechanism surveyed have been compared in a tabular form. Finally, Section 4 concludes the paper. Spectrum Access Techniques

Spectrum access technique is the most crucial operation when it comes to the smooth operation of CRSN and it also aids the process of spectrum sensing. This technique is responsible for allocating the most appropriate frequency band to the secondary users while avoiding interference at the primary users. In traditional WSN the transmission spectrum is divided into physical channels having fixed bandwidth and frequencies. However, in CRSNs with the presence of SUs, the available bandwidth and channels change dynamically with time.

2. CRSN Optimization

The spectrum assignment technique is a three-phase process. In the first phase, a criterion is established which defines the objectives of spectrum access. Then an approach is determined to model the spectrum access techniques to achieve those objectives. Finally, the spectrum access parameters are selected to optimize network performance.

2.1 Energy Efficient Power Control

As discussed earlier, the CRSN were developed under the assumption that the SUs will not create considerable interference. Furthermore, the performance of the network is enhanced by keeping the interference of the PUs, who bare the minimum. The following two techniques have been grouped as they both address the issue of power control in CRSN.

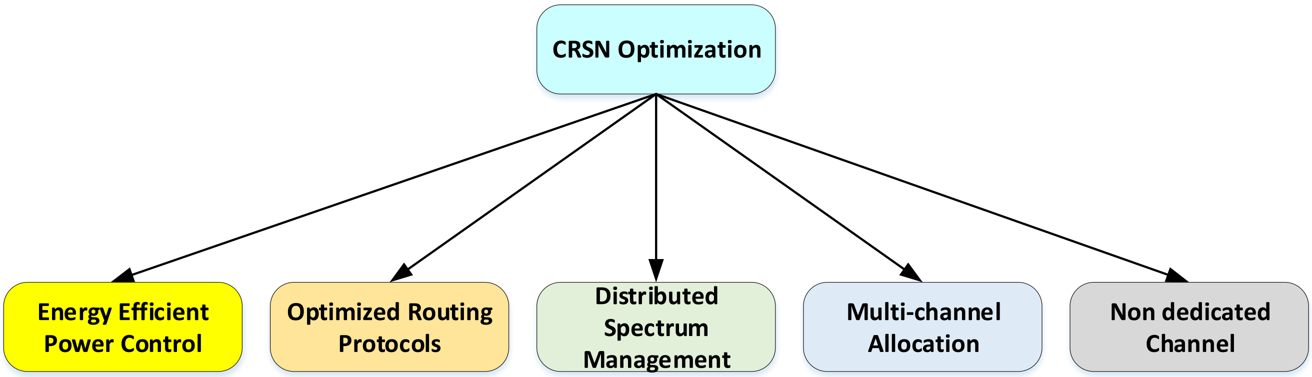

Figure 2. CRSN Optimization Techniques

In [4], the authors have proposed that the entire PU active at a given time to maintain an Interference Temperature Limiter (ITL). This is a threshold value, which measures the interference which is being sensed by the receiver node. This parameter is a ratio of the received power (antenna) and the RF bandwidth. This ratio is kept under a threshold value by manipulating the power control among SUs. This technique has a trade-off because it decreasing the transmission power of the SUs, the Signal to Noise Ratio (SNR) at the SU is also decreased which causes bad reception at the SU. Therefore, the power control process should be handled carefully to keep the SNR above the acceptable threshold.

An interference graph is proposed in [5], which is created dynamically based on the captured interference between a pair of communicating nodes. An undirected graph is created having the total number of vertices equal to the communicating nodes in the CRSN. The vertices are connected only if the two nodes cannot perform simultaneous communication on the given channel. At each step, the interference graph considers the aggregated interference caused by the transmitting nodes in previous steps. Therefore, the interference graph is adjusted dynamically. The communicating nodes are assumed to be exchanging data regarding their transmission power. Figure 2 presents the spectrum management in layers.

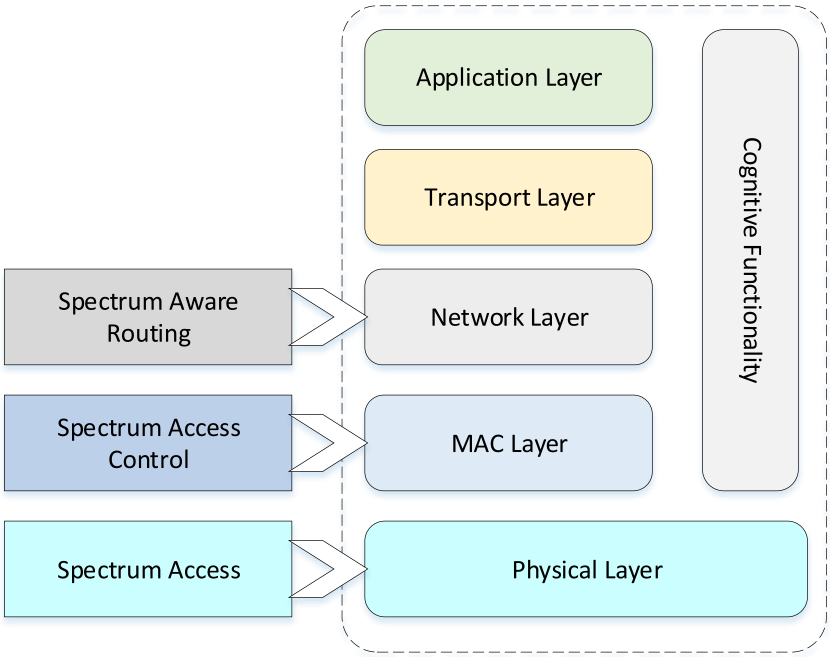

Figure 3. Spectrum Management in Layers

2.2 Optimized Routing Protocols

In multi-hop CRSNs, the routing algorithms play an important role in enhancing the performance of the network. An efficient routing scheme will decrease the switching delays and at the same time, it will decrease the end-to-end delay. The routing frameworks proposed in the following two protocols increase the routing efficiency of CRSN. Therefore, both have been studied together.

In [6], the authors have proposed a spectrum aware routing protocol that supports both multi-flow and multi-frequency scheduling. The main objective is to choose such frequency bands that have a minimum aggregate delay. The routing protocols monitors different flows at each node and calculates the consumed bandwidth. This information is utilized for multi-flow and multi-frequency scheduling. The proposed scheduling scheme is employed hierarchically. It first classifies, the traffic flows depending on their frequency bands. The selection criteria is chosen to keep into mind the spectrum switching and back off delays.

The work in [7] proposes a routing framework based on the channel and geolocation information. Each node in the CRSN configuration creates a table of nodes, in near geography of the receiver node. This, in turn, decreases the Expected Transmission Time (ETT), considerably. The table entries are then updated periodically based on the Primary User's transmission pattern and the relative distance between the communicating nodes. Other than that, link reliability is also taken into account. A parameter Expected Transmission Count (ETC) is also maintained for each transmission and it is compared within a predefined threshold. The next-hop transmission is based on this parameter.

2.3 Distributed Spectrum Management

CRSN can performs the spectrum management task in two modes, namely centralized and distributed. Generally, the centralized model has a requirement of a central controller that manages the overall processes of channel accessing and allocating. Other than this, the presence of a central controller creates an additional overhead in CRSN as all the signaling messages will be originated from the central controller and if it fails to perform its operation, the Secondary Users will have to take the channel allocation decisions on their own. This leads to the problem of fairness and misbehaving nodes. The following surveyed distributed management techniques are similar to each other in terms of operation. Thus, they have been grouped.

A distributed spectrum management framework has been proposed in [8]. In this scheme, all the nodes active in the CRSN within a certain hop-limit are responsible for exchanging control information and link quality measurements among themselves. Each node first calculates the traffic load presently on each channel. Afterward, the node selects the channel with the least traffic flowing for exchanging the management information. Therefore, the interference among the neighboring nodes will remain considerably low. This scheme is also prone to the errors due to mobility, as only the secondary users present inside a certain hop-limit will have to reconfigure their management tables, leaving the rest of the CRSN unaffected.

In [9], a Cognitive Spectrum Allocation is proposed which is distributed in operation. The nodes running this protocol exchange the management information with its intermediate neighbors (1-hop limit) to get the information of nodes up to a maximum of 3 hop-limits. A management information message containing the list of available channels and traffic to channel ratio is broadcasted to the 3-hop neighbors. Every node that receives this control information creates a backward connectivity graph based on the decided metric. This graph is then used for channel accessing and allocation. The operation is distributed as all the nodes within a 3-hop radius are taking a decision. The advantage due to localized management is that if a change occurs in the spectrum opportunities only the nodes present in the 3-hop radius will be affected, leaving no change in the overall performance of the CRSN.

2.4 Multi-Channel Allocation

Traditionally in WSNs, the channel assignment is simpler as the allocated channels have a specific center frequency and aligned bandwidth. Meaning, all the channels will be from adjacent bands. However, this poses a threat to the network performance because there can be severe packet collisions due to overlapping frequency channels. Contrary to this, by using multi-channel allocation the overlapping problem is solved as the primary user (Base Station) is assigned a separate frequency channel for each node, as shown in Figure 3. Both of the techniques proposed below share the same mechanism for channel allocation. This is the reason, that both have been grouped.

By using frames of discontinuous frequency bands, the authors in [10] have shown that the network performance in terms of bandwidth utilization can be increased considerably. These discontinuous frames are aggregated into a single frequency channel, resulting in an increase in the bandwidth of the secondary user. As the channel consists of aggregate frames, now it can fulfill the requirements of a large bandwidth application. The proposed scheme has been developed based on the assumption that the aggregated frame segments should not belong to the very far frequency band. Therefore, the bandwidth span of the aggregated frames is limited to 10 MHz's Meaning, two frames which are more than 10 MHz apart from each other will not be aggregated into a single channel.

The authors in [11] have enhanced the scheme discussed above by using a multi-radio node. The increase in the number of radios further enhances the spatial performance of the CRSN. The total bandwidth is distributed into k channels having the same bandwidth and orthogonal. The multiple channels within a single channel are referred to as logical links. These virtual channels are distributed among k different nodes. Therefore, a single communication channel has been distributed between two communicating nodes. Channel management is performed using in-channel signaling.

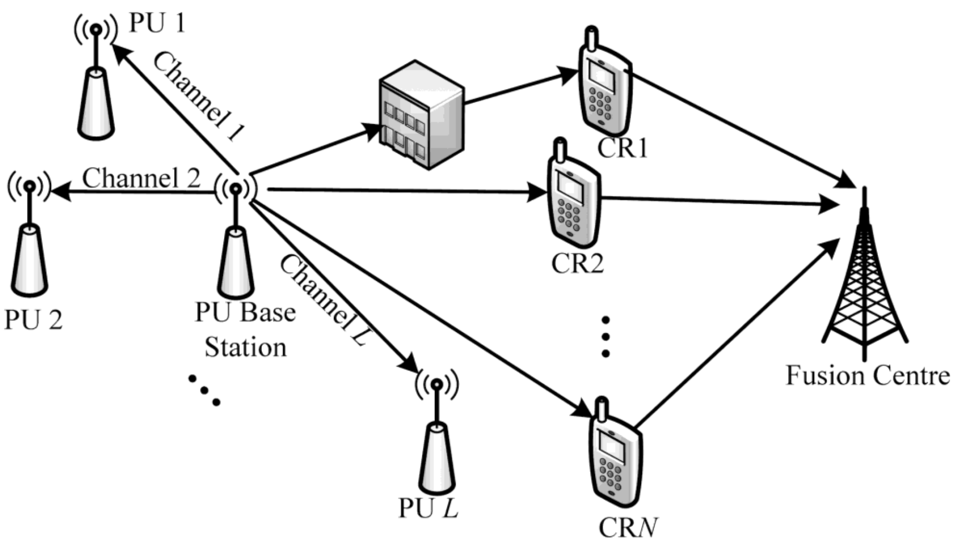

Figure 4. Multi-Channel Allocation Scheme

3. Common Control Channel

In CRSN, the network management functionality is carried out using a common control channel. The sole purpose of this channel is to exchange vital management information between the secondary users. It can be implemented as globally or locally depending on the predefined network configuration. A globally employed common control channel will take care of the management of all the active secondary users in a CRSN while a locally employed common control channel will only take care of the management of a specific cluster. The common control channel implementation is classified into two types: (i) a dedicated channel and (ii) a non-dedicated channel. The problem with the dedicated channel approach is that it is vulnerable to jamming attacks, resulting in the degradation in network performance.

In [12], the authors have proposed a non-dedicated common control channel. The mode of communication is based on a Flexible Transmitter and a Fixed Receiver. This mode enforces that the secondary users can use any channel for the purposed of transmission but when it comes to the reception phase, they are bound to receive on a fixed channel. All the neighboring nodes know this channel. Now, as all the nodes know the channel for exchanging control channel, they do not need a dedicated channel for this purpose. Moreover, the channel is divided into slots. Before the actual transmission start each node has to reserve a slot on this channel, within a specified duration.

Table 1. Techniques Overview

Technique	Objectives	Approach	Advantages	References
Power Control	1. To minimize interference between SUs and PUs	Interference temperature limiter	Minimize interference	[4]
	2. To minimize the required transmission power	Dynamic interference graph	Node lifetime	[5]
Routing Protocol	1. To minimize switching delays	Multi-flow and multi-frequency scheduling	Reduced	[6]
	2. To minimize end-to-end delay	Geolocation based routing	Transmission delays	[7]
Spectrum Management	1. To minimize overhead of control information	Distributed management based on hop-limit	Quick and	[8]
	2. To minimize the problem of fairness	Localized management based on graph	Flexible decisions	[9]
Multichannel Allocation	1. To minimize overlapping of frequency channels	Frame aggregation of discontinuous frames	Higher	[10]
	2. To minimize the packet collisions	Using a multi-radio transceiver node	Throughput	[11]
Control Channel	1. To minimize the collisions due to dedicated channel 2. Minimizes the required transmission power	Flexible Tx and Fixed Rx technique Using a multi-radio transceiver node	Spectrum utilization	[10]

Table 2. Protocols Overview

Protocols	Efficient Power	Optimized	Multichannel	Control
LAUNCH [13]	-	Yes	-	-
NDM AODV [14]	Yes	-	-	-
MMAC-CR [15]	-	-	Yes	-
DSA-MAC [16]	-	-	Yes	Yes

3.1 Techniques Overview

In this section, the surveyed approaches for spectrum assignments are presented. Table I summarizes the characteristics (objectives, approach, and advantages) of all these approaches. All the techniques related to spectrum management presented in this table have been discussed in Section 2. In Table 2, some of the widely adopted protocols will be discussed keeping in mind the issues discussed in the previous section. The protocol proposed in [13] is widely being used for CRSNs but this protocol lacks energy efficiency. Meaning, the overall network lifetime is being affected. In [14], the proposed protocol is an energy-efficient solution but it does not take other important metrics in the account. In [15] the proposed solution has multiple transceivers but it does not have a separate control channel. On the other hand, the authors in [16] have proposed a solution that incorporates both multichannel approaches and has a control channel but it is heavy on power consumption due to employing both techniques simultaneously.

4. Conclusion

The important aspect of Cognitive Radio enabled Wireless Sensor Networks is that these devices are fully adaptable to dynamic changes in the spectrum availability. At any instance, the CRSN nodes can sense and utilize a used spectrum band without causing any interference to the licensed primary users. Spectrum management is the key enabling technology for effective utilization of spectrum. In this paper, the challenges being faced by CRSN are discussed and corresponding solutions have been proposed. In particular, the problems related to power control, optimal routing paths, control channel, multiple channel allocation, and spectrum management were investigated. Besides the discussed issues, work in domains like (network connections, routing metrics, node clustering) must also be addressed. In the end, it can be said safely that CRSN is a forward step towards future networks. However, significant works need to be done.

References

[1] H. Anandakumar, K. Umamaheswari, and R. Arulmurugan, "A Study on Mobile IPv6 Handover in Cognitive Radio Networks," in *International Conference on Computer Networks and Communication Technologies*, 2019, pp. 399-408.

[2] K. N. Qureshi, F. Bashir, and A. H. Abdullah, "Real time traffic density aware road based forwarding method for vehicular ad hoc networks," in *2017 10th IFIP Wireless and Mobile Networking Conference (WMNC)*, 2017, pp. 1-6.

[3] K. N. Qureshi, A. H. Abdullah, and G. Ullah, "Sensor based Vehicle Environment Perception Information System," in *2014 IEEE 11th Intl Conf on Ubiquitous Intelligence and Computing and 2014 IEEE 11th Intl Conf on Autonomic and Trusted Computing and 2014 IEEE 14th Intl Conf on Scalable Computing and Communications and Its Associated Workshops*, 2014, pp. 697-700.

[4] H. Wang, J. Ren, and T. Li, "Resource allocation with load balancing for cognitive radio networks," in *2010 IEEE Global Telecommunications Conference GLOBECOM 2010*, 2010, pp. 1-5.

[5] A. T. Hoang, Y.-C. Liang, and M. H. Islam, "Power control and channel allocation in cognitive radio networks with primary users' cooperation," *IEEE Transactions on Mobile Computing*, vol. 9, pp. 348-360, 2009.

[6] G. Cheng, W. Liu, Y. Li, and W. Cheng, "Spectrum aware on-demand routing in cognitive radio networks," in *2007 2nd IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks*, 2007, pp. 571-574.

[7] J. Kim and M. Krunz, "Spectrum-aware beaconless geographical routing protocol for cognitive radio enabled vehicular networks," *Mobile Networks and Applications*, vol. 18, pp. 854-866, 2013.

[8] X. Li and S. A. R. Zekavat, "Distributed channel assignment in cognitive radio networks," in *Proceedings of the 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly*, 2009, pp. 989-993.

[9] R. Mochaourab, B. Holfeld, and T. Wirth, "Distributed channel assignment in cognitive radio networks: Stable matching and walrasian equilibrium," *IEEE Transactions on Wireless Communications*, vol. 14, pp. 3924-3936, 2015.

[10] A. Plummer and S. Biswas, "Distributed spectrum assignment for cognitive networks with heterogeneous spectrum opportunities," *Wireless Communications and Mobile Computing*, vol. 11, pp. 1239-1253, 2011.

[11] D. Chen, Q. Zhang, and W. Jia, "Aggregation aware spectrum assignment in cognitive ad-hoc networks," in *2008 3rd International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom 2008)*, 2008, pp. 1-6.

[12] J. Wang and Y. Huang, "A cross-layer design of channel assignment and routing in Cognitive Radio Networks," in *2010 3rd International Conference on Computer Science and Information Technology*, 2010, pp. 542-547.

[13] H. M. Almasaeid, "Spectrum allocation algorithms for cognitive radio mesh networks," 2011.

[14] K. Habak, M. Abdelatif, H. Hagrass, K. Rizc, and M. Youssef, "A location-aided routing protocol for cognitive radio networks," in *2013 International conference on computing, networking and communications (ICNC)*, 2013, pp. 729-733.

[15] S. Ding and L. Liu, "A node-disjoint multipath routing protocol based on AODV," in *2010 Ninth International Symposium on Distributed Computing and Applications to Business, Engineering and Science*, 2010, pp. 312-316.

[16] I. Joe and S. Son, "Dynamic spectrum allocation mac protocol based on cognitive radio for qos support," in *2008 Japan-China Joint Workshop on Frontier of Computer Science and Technology*, 2008, pp. 24-29.