A Review: Routing Protocols for Cognitive Radio Networks

(IJCSNT) International Journal of Communication Systems and Network Technologies
ISSN Number: 2053-6283
Volume 6, Issue No. 1, 1–7

https://journals.mirlabs.in/index.php/ijcsnt
DOI-10.18486/ijcsnt/6.1.075
IJCSNT

Gaurav Singh Negi[1], Naveen Chandra Arya[2], Yogesh Chandra Tripathi[3], Varun Kumar Kakar[4]

Abstract

Research works in cognitive radio networks mainly focus on spectrum sharing and sensing, and scheduling for single and multi-hop communication systems. Routing is an important issue in multi-hop cognitive radio networks and is responsible for the performance of a network under different network conditions. Recent advances have led to many protocols designed specifically for CRNs where different approaches are used. In this paper we present a review of various routing protocols for CRNs like CogLEACH, SEARCH, etc.

Keywords

Cognitive, Cluster Head, Spectrum, Routing, Communication Segment

Received: 24 December 2016; **Revised:** 30 March 2017; **Accepted:** 23 April 2017; **Published:** 30 April 2017;

[1, 2, 3, 4]B.T. Kumaon Institute of Technology, Dwarahat, Uttarakhand, India.

Corresponding author:
Email: gauravsnegi747@gmail.com

Introduction

According to a report by the Federal Communications Commission, the spectrum bands allotted on the basis of static allocation strategies are used over a bounded geographical area or for a limited amount of time, resulting in underutilization of resources. Cognitive radio network is a new paradigm and is now seen as a solution to the 'spectrum scarcity' problem in wireless communication systems. A cognitive radio network takes benefit of the vacant spaces, also called 'white spaces' or 'spectrum holes', present in spectrum licensed for T.V. broadcast, public services etc., and uses them for communication purposes. In this paper the author proposes a hybrid routing protocol which selects the optimal route with highest and lowest rate and delay respectively. Figure 1 illustrates the white spaces or spectrum holes in the spectrum[1–3].

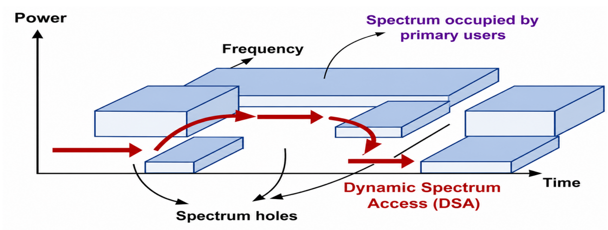

Figure 1. White Spaces or Spectrum Holes in Spectrum.

In cognitive radio networks, two types of users share the same spectrum band but with different strategies: primary or licensed users and secondary or unlicensed users. Primary users have been allotted a specific band of spectrum to carry out the communication. This spectrum, when not being used by the PU, is used opportunistically by the SU without causing any disturbance to the PU. A secondary user must be equipped with a good sensing capability and an efficient radio control because it has to change various operating parameters such as frequency, transmission power etc. frequently. This ability to change its operating frequency is known as Dynamic Spectrum Access, which gives CRNs the ability to use the white spaces available in the spectrum.

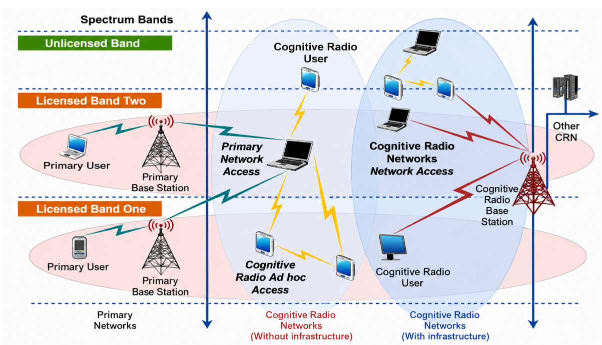

Figure 2. Cognitive Radio Network.

Figure 2 shows how a primary user can only access the licensed band while a cognitive user can use both licensed and unlicensed band in an opportunistic manner. CRNs can be classified on the basis of architecture into two types: Infrastructure-based CRNs, where the communication has centralized control known as a Base station, and Infrastructure-less CRNs, where the control is decentralized, also known as Ad-hoc Networks. A cognitive user basically works in the following steps:

(1) it first senses the spectrum environment,
(2) then it searches the vacant or white spaces,
(3) after that it selects the optimal band according to availability and uses it.

Routing is different in cognitive radio networks than in conventional ad-hoc networks. Cognitive radio networks are more adaptive to changes taking place in spectrum availability. Some of the problems faced in designing a routing strategy for CRNs[4] are:

(1) change in topology of the network due to activity of PUs;
(2) channels have different characteristics like delay, bandwidth etc.;
(3) large number of handoffs due to the frequent change in operating frequency of the PU; and
(4) limitations on power supply and computational capability.

Literature Review

In this section we describe the working operation of various routing protocols for cognitive radio networks as follows.

On-Demand Hybrid Routing for Cognitive Radio Ad-Hoc Networks

Mahdi Zareei et al. (IEEE ACCESS 2016). In this paper the author proposes a hybrid routing protocol which selects the optimal route with highest and lowest rate and delay respectively[5]. It is a hybrid protocol which uses proactive routing for intra-cluster communication and reactive routing for inter-cluster communication[6]. In this protocol, clustering is defined as a maximum vertex biclique problem and a cluster head election value is defined to select the optimal cluster head. The cluster head is selected taking into account the mobility of the node and total number of neighbors to avoid frequent clustering, providing stability to the cluster.

Source nodes send the CHRReq packet to the cluster head, which in response sends CHRRep to the source if the destination is in the same cluster. Otherwise, it broadcasts the request packet attaching its ID, hop count, achievable data rate, density and cluster channel. After the destination receives the CHRReq packet it will calculate the weight for available routes and will choose the path with minimum value of $M(r)$. Path optimization is done by using an Evolutionary dynamic weighted aggregation method, and optimal route selection is formulated as

$$M(r) = \min\left(w_1 \cdot \mu_T^C(r) + w_2(r) \cdot \frac{1}{R_T(r)} + w_3(r) \cdot H_T(r)\right) \tag{1}$$

$$\text{s.t. } w_i(r) \geq 0 \quad \text{where } \sum_{i=1}^{3} w_i(r) = 1$$

where $w_1(r)$, $w_2(r)$, $w_3(r)$ are the weights assigned to density ($\mu_T^C(r)$), achievable data rate ($R_T(r)$) and hop count ($H_T(r)$) respectively. Values of these weights change periodically between 0 and 1, resulting in a set of Pareto-optimal solutions instead of a single solution. OCHR performance does not get affected by an increase in the number of PUs due to the adaptive clustering mechanism[7].

Cog-LEACH: A Spectrum Aware Clustering Protocol for Cognitive Radio Sensor Networks

Rashad M. Eletreby et al. (CROWNCOM 2014). This protocol is an extension to the state-of-the-art LEACH[8] protocol with spectrum-aware characteristics. Primary user activity is modeled as a semi-Markov on-off process. To protect PUs from interference from SUs, an Interference Protection Range (IPR) is defined[9–12]. The primary objective is to minimize $P_i(t)$, which is given by

$$P_i(t) = \min\left(k\frac{C_i}{\sum_{j=1}^{N} C_j}, 1\right) \tag{2}$$

where c_i and c_j denote the number of idle channels for node i and node j respectively, and k is the total number of clusters in the network. This protocol works in four phases:

In Phase 1 every node senses the available channels and determines the number of idle channels; in Phase 2 the cluster head is selected on the basis of the value obtained in Phase 1; Phase 3 is the cluster formation phase in which the cluster head sends a CH_Tentative_Announcement message replied by non-CH nodes with a Tentative_Join_Request. Then the channel which is common for the most requesting nodes is selected, CH_Final_Announcement is broadcast and a TDMA schedule is transmitted to all nodes. Finally, Phase 4 accounts for data transmission to the cluster head using a DSSS spreading code.

In this protocol, clustering is performed using a minimum number of message transmissions for different network models. Protocol performance is studied under three models differentiated on the basis of spatial and spectrum similarities between the primary users:

1. *Spatial and Spectrum Similarity model:* Every node is in the range of PUs and has the same stationary probability of idle channel (p_f) for different channels ensuring a similar on-off characteristic:
$$P_i(t) = \min\left(k\frac{C_i}{N\mu}, 1\right) s \tag{3}$$
where μ represents the mean of the binomial distribution responsible for the number of channels that can be sensed.
2. *Spectrum similarity model:* Some nodes are not in the range of PUs with different p_f but the same on-off characteristics:
$$P_i(t) = \min\left(k\frac{C_i}{N_1 \cdot p_{f1} \cdot m + N_2 \cdot p_{f2} \cdot m}, 1\right) \tag{4}$$
where N_1 and N_2 are subsets of nodes within range and out of range of PUs selected according to the PU effective area.
3. *Arbitrary Model:* Every characteristic discussed above of PU systems is different in this model. $P_i(t)$ is broadcast by the base station after sensing idle channels, resulting in a centralized solution of the estimation.

Energy-Aware Routing Protocol for Cognitive Radio Ad Hoc Networks

S. M. Kamruzzaman et al. (IET Communications 2012). In this paper, the author proposes a routing protocol based on Dynamic Source Routing to increase the network lifetime by combining the selection of route and channel timeslot allocation[7]. A pair of channel and timeslot is known as a ‘communication segment’. The frame is divided into three windows:

(i) a *Sensing window*, in which vacant channels not used by primary users are searched;

(ii) *Ad-hoc traffic indication messages*, in which beacon sensing is performed in a time division mode to become aware of free segments, and then control packets are exchanged which have information regarding the routes; and

(iii) a *Communication window*, in which CR users transmit or receive data.

The routing problem is formulated as choosing the path with maximum nodal residual energy and minimum hop count with these three constraints:

Hop count $\leq$ time to live; residual energy $\geq$ threshold energy; and communication segments available $\geq$ bandwidth required. This routing protocol works in three phases:

(1) Route discovery: RREQ is broadcasted by the source node. Lowest battery energy value (ME res) is received by the destination node which is known as ‘minimal residual path energy’. Battery energy of node should be higher than the threshold energy level (E th) to ta ke part in route discovery.

(2) Route selection: After RREQ packets are received by the destination, it replies by sending RREP packet containing the route utility and route record. Source node receives the RREP packet, changes the state of channels to re serve and begins data transmission.

(3) Route maintenance: Communication segment is reassigned in case of destination unable to receive data and is known as ‘Segment Reassignment’. If source finds no segments free for allocation or destination goes far from transmission range then source decides to change the route and process is known as ‘Local Recovery’. If local recovery is not feasible then RERR packet is sent to source which is called ‘Route Rediscovering’. In ‘Route Discovery by Cached route’ backup p aths are searched in route cache stored in the previous step chosen according to highest priority.

SEARCH: A Routing Protocol for Mobile Cognitive Radio Ad-hoc Networks

Kaushik R. Chowdhury and Marco Di Felice (IEEE 2009). The author proposed a geographical location based protocol primarily designed for multi-hop CRNs. It selects short paths based on geographical forwarding routing, keeping the route out of the regions of PU activity[5]. Then the channel switching is scheduled by the destination node, minimizing the hop count[13–15]. This protocol works in two phases:

A. *Route Setup:* A route request is sent from the source node to every channel free from PU use. Each intermediate node adds its ID, current location, time stamp and flag status to the RREQ packet. Two modes are designed:
   (1) Greedy forwarding, deciding which node should be chosen to pass RREQ to minimize the hop count while remaining out of the PU coverage region and within a ‘Focus Region’ having an angular range of 2θ centred around the line joining source to destination;
   (2) PU avoidance, activated when nodes in the focus region come into the PU activity region; and
   (3) Joint path channel optimization, where the destination chooses the channel and end-to-end path.

B. *Route Enhancement:* A feasible path is discovered by the destination node, checking the gain of the paths on different channels within η hops from the decision point and selecting after comparing latency with the previously used paths.

Conclusion

Routing in multi-hop CRNs is different from conventional networks due to variation in channel availability with time and parameters other than distance affecting network availability. In this paper, we discussed the difference in suggesting a routing strategy for CRNs from conventional networks and a survey of the available routing techniques with different approaches, highlighting the routing operation. Present-day techniques use conventional routing metrics which are unable to exploit the dynamic characteristics of CRNs. So there is a need to design new routing metrics according to the behaviour of CRN's.

References

[1] Federal Communications Commission. Fcc adopted rules for unlicensed use of television white spaces, tech. rep. et docket no. 04-186, second report and order and memorandum opinion and order, 2004.

[2] Haykin S. Cognitive radio: Brain-empowered wireless communications. *IEEE Journal on Selected Areas in Communications* 2005; 23(2): 201–220.

[3] Akyildiz IF, Lee WY, Vuran MC et al. Next generation / dynamic spectrum access / cognitive radio wireless networks: A survey. *Elsevier Computer Networks Journal* 2006; 50: 2127–2159.

[4] Heinzelman W, Chandrakasan A and Balakrishnan H. An application-specific protocol architecture for wireless microsensor networks. *IEEE Transactions on Wireless Communications* 2002; 1(4): 660–670.

[5] Chowdhury K and Di Felice M. Search: A routing protocol for mobile cognitive radio ad-hoc networks. *Computer Communications* 2009; : 1983–1997.

[6] Zareei M et al. On-demand hybrid routing for cognitive radio ad-hoc network. *IEEE Access* 2016; .

[7] Kamruzzaman SM et al. Energy-aware routing protocol for cognitive radio ad hoc networks. *IET Communications* 2012; .

[8] Al-Karaki JN and Kamal AE. Routing techniques in wireless sensor networks: A survey. *IEEE Wireless Communications* 2004; .

[9] Cesana M, Cuomo F et al. Routing in cognitive radio networks: Challenges and solutions. *Ad Hoc Networks* 2011; : 228–248.

[10] Pandey PS and Singh R. Ecg monitoring system in wireless personal area network: Simulation and design using zigbee transceiver module for health care solution. *International Journal of Computer Applications* 2012; 46(18).

[11] Pandey PS, Gupta N, Raturi A et al. Design and simulation of message display on lcd integrated with power line carrier communication modem with biometrics system. *International Journal of Computer Applications* 2014; 85(13).

[12] Eletreby RM, Elsayed HM and Khairy MM. Cog-leach: A spectrum aware clustering protocol for cognitive radio sensor networks. In *9th International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM)*. pp. 179–184.

[13] Bagwari A and Tomar GS. Cooperative spectrum sensing with adaptive double-threshold based energy detector in cognitive radio networks. *International Journal of Wireless Personal Communications (Springer)* 2013; 73(3): 1005–1019.

[14] Bagwari A and Tomar GS. Cooperative spectrum sensing in meds based crns using adaptive double-threshold scheme. *International Journal of Electronics (Taylor & Francis)* 2014; 101(4): 37–41.

[15] Bagwari A and Tomar GS. Cooperative spectrum sensing with multiple antennas using adaptive double-threshold based energy detector in cognitive radio networks. *Journal of the Institution of Engineers (India), Series B (Springer)* 2014; 95(2): 107–112.