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Routing In Cognitive Radio Ad-Hoc Networks

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Abstract

Cognitive radio (CR) is a promising technology used to solve the problem of spectrum scarcity by identifying the vacant portions of the spectrum opportunistically and transmitting in them, and at the same time ensuring that the licensed (also known as a primary user or PUs) of the spectrum are not interfered or hindered from using their licensed spectrum band. This capability of cognitive radio calls for designing flexible and dynamic spectrum access strategies in order to opportunistically reuse portions of the spectrum temporarily vacated by licensed primary users, but it is not easy to design such communication protocols. This paper focuses on designing effective routing solutions for multi-hop CRNs, which is an important issue in order to fully utilize the potentials and capabilities of the cognitive networking paradigm. In cognitive radio networks, multi-hop communication with efficient routing can improve the connectivity and spectrum efficiency for cognitive users. Many routing algorithms have been proposed, but they may provide unnecessarily long routing paths as the existence of primary users and especially their locations have not been explicitly taken into consideration. This paper investigates distributed routing in cognitive radio networks based on joint selection of the spectrum with the choice of the next hop forwarder node, the location information of the primary users, and joint spectrum decision and re-configurability, where the route can be adapted with local spectrum changes or by selecting a different set of forwarding nodes altogether.

Keywords- Cognitive radio ad-hoc network (CRAHN), Dynamic Spectrum Access (DSA), Multi-hop network, Routing protocol.

1. Introduction

Wireless networks today are regulated by governmental agencies i.e., the spectrum is characterized by a fixed spectrum assignment policy. The spectrum is assigned to license holders for vast geographical regions on a long term basis [1]. The huge success of wireless applications, in recent years has led to an increase in requests to regulatory authorities for spectrum allocation. Recent studies by the Federal Communications Commission (FCC) shows that the use of licensed spectrum is quite uneven i.e., the spectrum usage is concentrated on certain portions of the spectrum while a significant amount of the spectrum remains unutilized and that many spectrum bands allocated through static assignment policies are used only in bounded geographical areas or over limited periods of time. According to Federal Communications Commission (FCC) the average utilization of such bands varies between 15% and 85% [2].

The limited spectrum availability and the inefficient spectrum usage calls for a new communication paradigm to utilize the existing wireless spectrum opportunistically which can adapt to the dynamically changing spectrum resource, learn about the spectrum occupancy, make decisions on the quality of the available spectrum resource, including its expected duration of use, probability or likelihood of interference caused by the licensed users (PUs). As a result, FCC has approved the use of unlicensed devices (also called cognitive radio or secondary users) in licensed bands i.e., unlicensed users or secondary users (SUs) may use licensed spectrum bands opportunistically in a dynamic and non-interfering manner. Consequently, dynamic spectrum access (DSA) techniques are proposed to solve these current spectrum inefficiency problems. The new networking paradigm which employ these techniques is referred to as NeXt Generation (xG) Networks as well as Dynamic Spectrum Access (DSA) and cognitive radio networks(CRNs) [3].

2. Cognitive radio

Cognitive radio technology is the key technology that allows a CRAHN to use spectrum in a dynamic manner. The term, cognitive radio, can formally be defined as follows [6]:

A ‘‘Cognitive Radio” is a radio that can change its transmitter parameters based on interaction with the environment in which it operates.

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From this definition, two main characteristics of the cognitive radio can be defined as follows [4,5]:

1) Cognitive capability: Cognitive capability refers to the ability of the radio technology to capture or sense the information from its radio environment. The cognitive capability of a cognitive radio enables real time interaction with its environment in order to determine appropriate communication parameters and adapt to the dynamic radio environment [1]. Through this capability, the portions of the spectrum that are unused at a specific time or location can be identified. Consequently, the best spectrum and appropriate operating parameters can be selected.

2) Reconfigurability: The cognitive capability provides spectrum awareness whereas reconfigurability enables the radio to be dynamically programmed according to the radio environment. More specifically, the cognitive radio can be programmed to transmit and receive on a variety of frequencies and to use different transmission access technologies supported by its hardware design [7].

Thus, the ultimate objective of the cognitive radio is to obtain the best available spectrum through cognitive capability and reconfigurability as described before. The most important challenge is to share the licensed spectrum that too without interfering with the transmission of other licensed users, as most of the spectrum is already assigned. This scenario has been illustrated in Fig. 1.

The temporarily unused spectrum vacated by PUs that the cognitive radio use, is referred to as spectrum hole or white space [4]. If this band is further utilized by a licensed user, the cognitive radio moves to another spectrum hole or stays in the same band, lowering its transmission power level or modulation scheme in order to avoid interference as shown in Fig. 1.

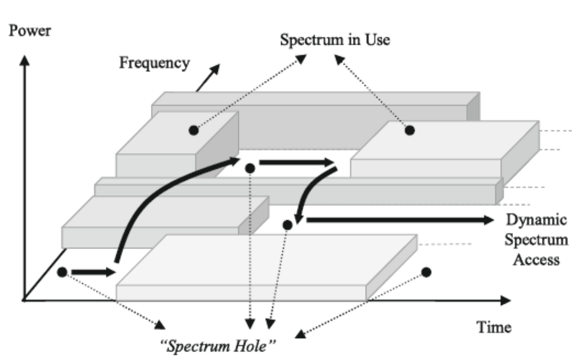

Figure 1. Spectrum hole concept

3. CRAHN architecture

In CR ad-hoc networks (CRAHNs), the distributed multi-hop architecture, the dynamic network topology, and the time and location varying spectrum availability are some of the key distinguishing factors. The components of the cognitive radio ad-hoc network (CRAHN) architecture, as shown in Fig. 2, can be classified in two groups as the primary network and the CR network components.

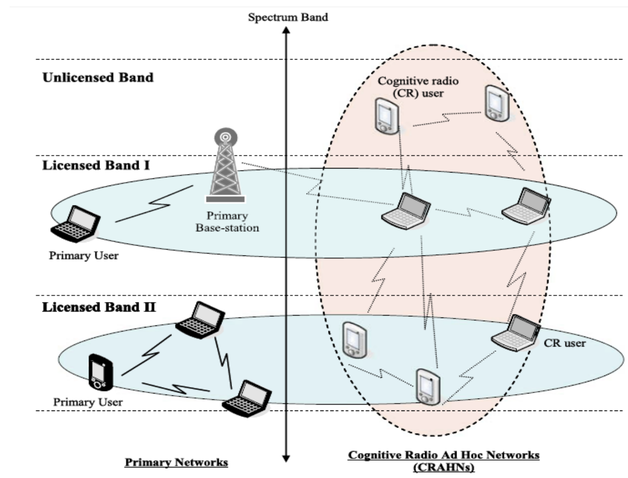

Figure 2. The CRAHN architecture.

The primary network is the one which already exists and where the primary users (PUs) have an exclusive right to a certain spectrum band. Examples include the common cellular and TV broadcast networks. The CR network consists of CR users. As the CR network does not have a license to operate in a desired band, additional functionality is required for CR users to share the licensed spectrum band. These CR users are mobile and can communicate with each other in a multi-hop manner on both licensed and unlicensed spectrum bands. Usually, CR networks do not have direct communication channels with the primary networks i.e., they are assumed to function as stand-alone networks. Thus, in CRAHNs, each user needs to have all CR capabilities and is responsible for determining its actions based on the local observation, as shown in Fig. 3.

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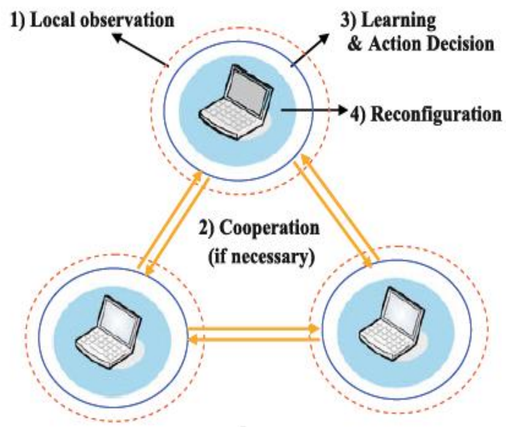


Figure 3. Cognitive Radio Ad-Hoc Network

4. Routing schemes in CRAHNs

For CRAHNs, the establishment of end-to-end route has various challenges as the CR users have to find a route considering the presence of PUs. According to [8] the existing works in CR routing protocols are classified based on their support for: (i) Spectrum decision, i.e., joint selection of the spectrum with the choice of the next hop forwarder node (ii) Joint spectrum decision with PU awareness, where the CR users have the ability to identify the locations where PUs are present and allow the routes to avoid them, and (iii) Joint spectrum decision and re-configurability, where the route can be adapted with local spectrum changes or by selecting a different set of forwarding nodes altogether. This classification is summarized in Fig. 4.

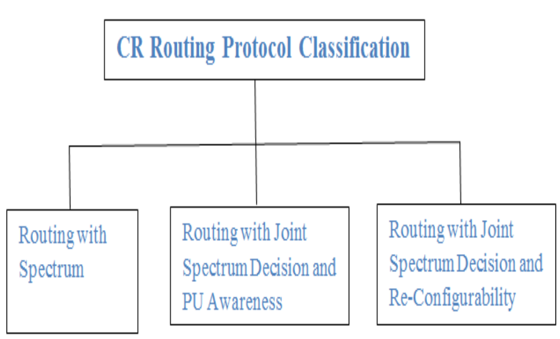


Fig.4. Classification of CR routing protocol.

4.1 Routing with spectrum decision

Under this scheme, the routing protocol selects the next hop node among the possible candidate forwarders while taking into consideration the spectrum that may be used on the chosen link. Thus, the spectrum as well as the path selection occurs jointly, which ensures that the route remains connected during the network operation as each link maintains a set of feasible spectrum bands, which is called the channel set of a node.

The CR users which form the route should be able to assign the link spectrum so that the delay in changing the spectrum at a node is minimized over the path. However, the spectrum access time is shared by the nodes on the link that are within range of each other, if the same spectrum is used at consecutive links. As only one node on the link can send or receive packets at a time, the throughput is adversely affected. The multi-hop single-transceiver CR routing protocol (MSCRP) proposed in [9] balances these two conflicting approaches. MSCRP is an on demand protocol, based on ad-hoc on demand distance vector (AODV) [10], doesn't base on control channel. Therefore, routing protocol messages are being exchanged without common control channel.

Due to the heterogeneous spectrum availability, links may be available only a fraction of time in CRNs. To set up multi-hop connections between node pairs with heterogeneous spectrum availability, intermediate bridge nodes have to switch between multiple channels based on their availability that is, links on each path need to communicate on different channels. This introduced the new problem called "deafness", which is switching among available channel set to maintain the route or avoid the interference on primary users. This causes extra delay in CRNs communications [9]. To avoid the deafness problem, the two consecutive nodes in a flow cannot switch to different channel simultaneously. Communicating with a switching node is complicated, therefore MSCRP switching node uses LEAVE or JOIN messages to inform its neighbours about the channel it is working.

According to MSCRP, a route request (RREQ) message is broadcast on all the possible channels to the destination for route discovery. The channels availability information is appended in the RREQ message and is forwarded in broadcast process. All intermediate nodes append their state and available channel set to RREQ message. The reverse path to the source node is established as RREQ is forwarded. Destination node receives the channel information and number of nodes on each channel at the end and decides on the spectrum selection for the shortest path based on analytical estimates of the time for spectrum switching, channel contention, and data transmission and thus assigns channel for this flow. It binds the assigned channel information in route reply (RREP) message, which is sent back to the source on the decided route.

MSCRP incurs an extra overhead of broadcasting RREQ message on all available channels rather on single channel and this overhead becomes may adversely affect the efficiency, in case there are many channels available for each node in the network.

4.2 Routing with joint spectrum decision with primary user (PU) awareness

Here, the routes in a CR network must explicitly take into consideration the on going communication of the PUs and provide a measure to protect it. For this, the route may entirely avoid the regions where the PUs frequently use their licensed band.

A Location-Aware Distributed Routing in Cognitive Radio Networks proposed in [12], can avoid routing through those areas where PUs are located and thus has the potential to improve the utilization of spectrum holes at different locations in cognitive radio networks.

Consider the cognitive radio network as shown in Fig. 5, where PUs as well as CUs exist in the same area. Among the CUs, there is a cognitive source-destination pair (CS-CD) and all others are cognitive relays (CRs). Every CU has the same transmission range R, within which other CUs can successfully receive the transmitted message and the transmission range of PU is called guard zone, within which no CU can transmit. PU guard zones have been shown as hexagons with the same sizes in the Fig. 5. It has been assumed that all the PUs work in the same frequency band and there is no overlap between any PU guard zones. The CUs have full knowledge of where the PU guard zones as well as their neighbours in their transmission range are located. A distributed routing algorithm is developed based on this information. According to it, a navigation direction is planned first, which is assumed to be a narrow strip from the CS to the CD at the same time avoiding the PU guard zones.

The shortest geometric path between the CS and CD, which doesn't pass through the PU guard zones can be determined by the CUs. This path, shown in Fig. 6(a) is termed as the guide path. The green lines are the edges between the CUs that can see each other. As the CRs may lie anywhere, it is not possible to route on this path exactly. However, the guide path can help in routing and plan the navigation direction. Instead of a guide path, a guide strip can be followed for routing. It is a narrow strip formed starting from CS to the CD in the navigation direction by expanding the guide path equally as shown in Fig. 6(b). The guard zones are also expanded or grown. With this narrow strip followed the path formed can be guaranteed to be close to the shortest visibility path between CS and CD.

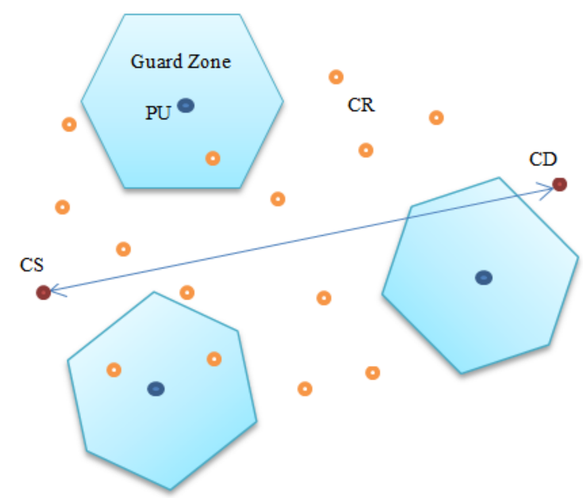
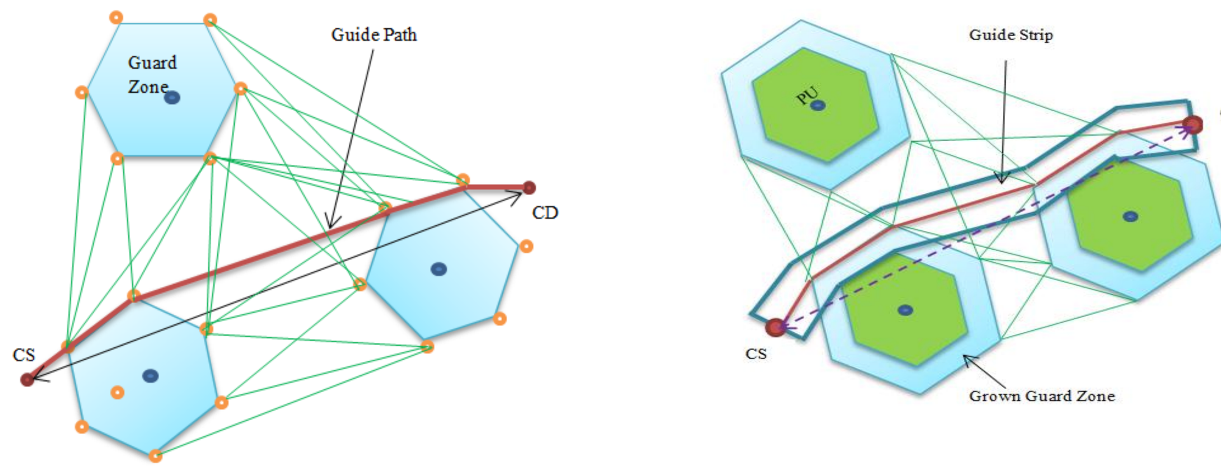


Figure 5. System model.

4.3 Routing with joint spectrum decision and re-configurability

The routing protocols falling under this class has the key ability to recover from changes in the spectrum caused by PU arrival. The route re-configuration can be done either by locally choosing a new spectrum on the affected links or reconstructing the whole path.

The spectrum-aware routing protocol (SPEAR) identifies all possible routes during the route-setup stage [12]. A SPEAR source node does so by broadcasting a RouteRequest (RREQ) message on the dedicated control channel, with a list of available channels which are not occupied by PUs and not reserved by other cognitive users nearby. This list is maintained by every node. It ensures that a single spectrum is used throughout the route and takes measures to avoid broadcast congestion by limiting the number of paths discovered in the network. One of the way it uses is to keep a per-flow counter and allow only some fixed number of RREQ messages to be forwarded. The other way is that the destination node, after receiving the first RREQ, starts a per-flow timer and when it expires makes selection of the best possible route out of the routes received based on hop count, delay, maximum end-to-end throughput, and other potential routing metrics and does the channel assignment. It then frames a RouteReply (RREP) message and sends it back to the source on the selected route. The intermediate nodes reserve the channel assigned as well as the timeslots when they receive the RREP and forward channel reservation message to all



(a) (b)

Figure 6. (a) The guide path. (b) The guide strip.

neighbours coming under their transmission range. They also discard the additional RREQ messages for this flow, if they further receive them.

As and when there is a change in channel availability due to the actions of PUs, nodes perform Local Adaptation by modifying their local channel usage in order to maintain flow connectivity. If this fails, then a new and fresh route is formed from the source.

The various operations of SPEAR can be explained using Fig. 7. The source S sends the RREQ on two possible routes, Route 1 and Route 2. Destination D selects route 2 as the optimal route based on some routing parameters and sends RREP appended with channel assignment information to it on route 2.

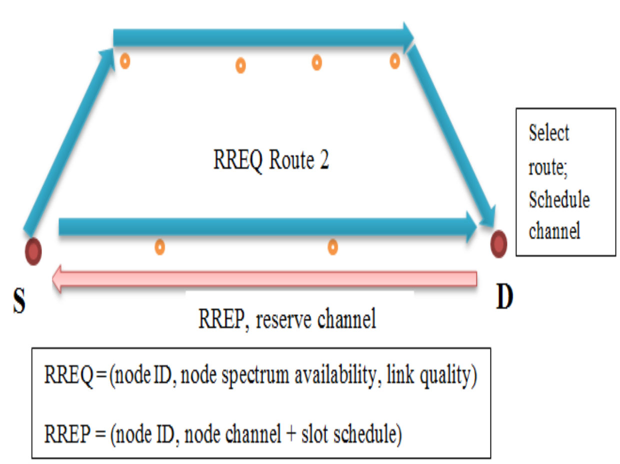


Figure 7. Setting up a multi-hop route between source S and destination D using the SPEAR protocol.

5. Conclusion

Due to heterogeneous spectrum availability and data rates, routing in CRN is a great challenge. In routing multi-hop cognitive network, hops learn information from neighbours and then find the route by learning the dynamism. This paper first discusses the CRAHN architecture and then studies classification of CR routing techniques based on their support for spectrum decision, joint spectrum decision and awareness about PU location and joint spectrum decision and re-configurability in order to change routes whenever there is change in local spectrum. Multi-hop communication with efficient routing which fully exploit the dynamic characteristics of CRN, can improve the connectivity and spectrum efficiency for cognitive users. Therefore, researches are going on to design some more novel routing techniques.

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