

Routing in Multi-Hop Cognitive Radio Ad-Hoc Networks: A Review

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ABSTRACT: Cognitive Radio (CR) technology is used to solve the inefficiency of spectrum usage in wireless networks as it allows sharing of licensed spectrum band in opportunistic and non-interfering manner. However CR users should be aware of channel availability and Primary User (PU) activities. Routing, link availability and spectrum management are the main challenges in Cognitive Radio Networks (CRN). On-demand routing protocols applicable for cognitive radio ad hoc networks (CRAHNS) are classified and reviewed, and then challenges and open issues in multi-hop cognitive radio ad-hoc networks. After explaining their basic principles then discussed qualitative compare the on demand routing protocols in terms of inherent characteristics and performance.

KEYWORDS: Cognitive radio ad-hoc network, PU avoidance, routing protocol for CRN.

I. INTRODUCTION

Nowadays governmental agencies regulate fixed spectrum assignment policy in wireless networks. Rights are granted for the use of various, relatively small, frequency bands on a long term basis over vast geographical regions by giving licenses [2].

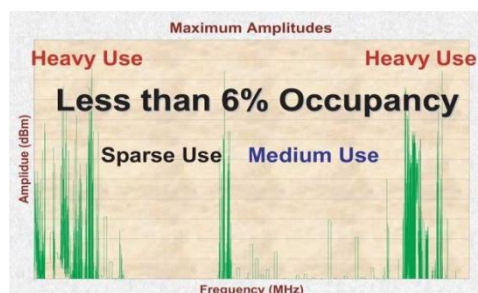


Figure 1.Spectrum Utilization [2]

Shown in Figure.1 Federal Communications Commission (FCC) is an agency has analysed that only less than 6% frequency is occupied and other remaining frequency is unused [2].

Cognitive Radio [2]

A “Cognitive Radio (CR)” is a form of wireless communication in which a transceiver can intelligently detect which communication channels are in use and which are not, and instantly move into vacant channels while avoiding occupied ones.

The cognitive radio enables the usage of temporarily unused spectrum, which is referred to as spectrum hole. Spectrum band is further utilized by a licensed user, the cognitive radio moves to another spectrum hole or stays in the same band, altering its transmission power level or modulation scheme to avoid interference as shown in Figure.2.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

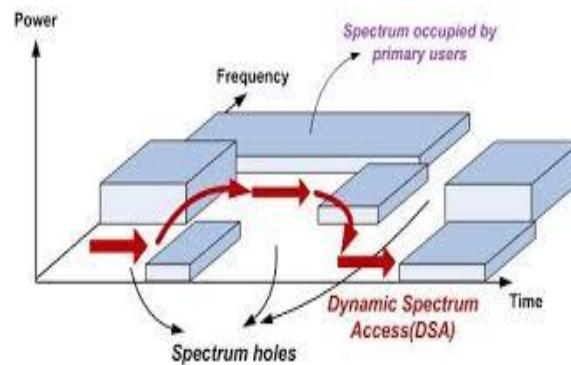


Figure 2. Dynamic Spectrum Access [2]

Characteristics of Cognitive Radio

Two main characteristics of the cognitive radio can be defined [2]

1. Cognitive capability
Cognitive capability is the ability of the radio technology to sense the information from its radio environment. Cognitive capabilities have requirement of temporal and spatial variations in the radio environment and avoid interference to other users.
Based on cognitive capability, the unused spectrum is identified at a specific time or location. Consequently, the best spectrum and appropriate operating parameters can be selected.
2. Reconfigurability
Reconfigurability provides the radio to be dynamically changed according to the radio environment. The cognitive radio can be programmed to transmit and receive various frequencies and to use different transmission access technologies supported by its hardware design.

Cognitive Radio Network Architecture

The CRN can be classified into two categories [2]

1. Infrastructural CRN
Here the communication is done with the help of a fixed infrastructure or base station.
2. Infrastructure less CRN
Here the communication is done without the support of fixed infrastructure or base station. This type is similar to ad-hoc network.

Show in below figure 3, the elements of the primary and the cognitive network are defined as follows

1. Primary network: It has its own individual radio frequency spectrum band for its services.
2. Primary User (PU): Primary user or licensed user has main rights to operate in its radio frequency spectrum band.
3. Primary based station: It is a fixed infrastructure component that controls the access of its licensed users. This component does not have any ability to share radio frequency spectrum band with cognitive radio users.
4. Cognitive network: It does not have any radio frequency spectrum band for their communication.
5. Cognitive user (CU): It does not have its own frequency band, therefore these users are called unlicensed users or secondary users (SU).
6. Cognitive based station: It is a fixed infrastructure component. Similar to primary base station with cognitive capabilities.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

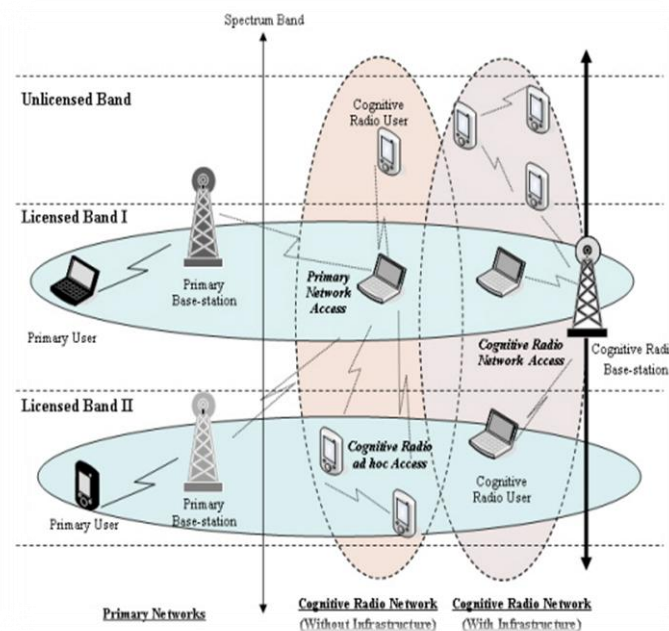


Figure 3. CRN Architecture [3]

On-demand routing protocols applicable for cognitive radio ad hoc networks (CRAHNs) are classified and reviewed, and then challenges and open issues are discussed. The protocols are based on ad hoc on demand distance vector (AODV) protocol. Because of the challenging nature of CRAHNs, there are some unique issues encountered while designing a routing protocol. Routing protocols can be classified as shown in below figure 4.

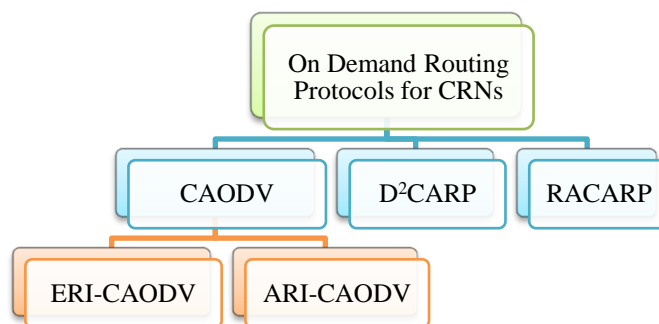


Figure 4. Classification of Routing Protocols for CRNs

On demand routing protocols are continuously maintain the routes within the network. Which trigger the route discovery process only when a data transfer is required by a source node. All nodes update their tables to preserve compatibility by exchanging routing information between the participating nodes. When the topology of the network changes, the nodes distribute update messages across the networks.

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 4, Issue 12, December 2015

II. RELATED WORK

Several On demand routing protocols are introduced for finding the best path and effect of packet loss in cognitive radio ad-hoc networks such as Cognitive ad-hoc On-demand Distance Vector Routing (CAODV) [5], Dual diversity cognitive ad hoc routing protocol (D2CARP)[6], and Robustness Aware Cognitive Ad-hoc Routing Protocol (RACARP) [7].

Cognitive Ad-hoc On Demand Distance Vector Routing (CAODV)

Cognitive Ad-hoc On-demand Distance Vector [5] performs PU activity of individual path and spectrum diversity. It provides end to end connectivity in CRNs.

Two different types of CAODV

1. intEr-Route dIversity(ERI-CAODV): CU is able to discover different routes evolving through different channels.
2. intrA-Route dIversity(ARI-CAODV): CU is able to discover only one routes evolving through all available channels.

Route discovery for intEr-Route dIversity

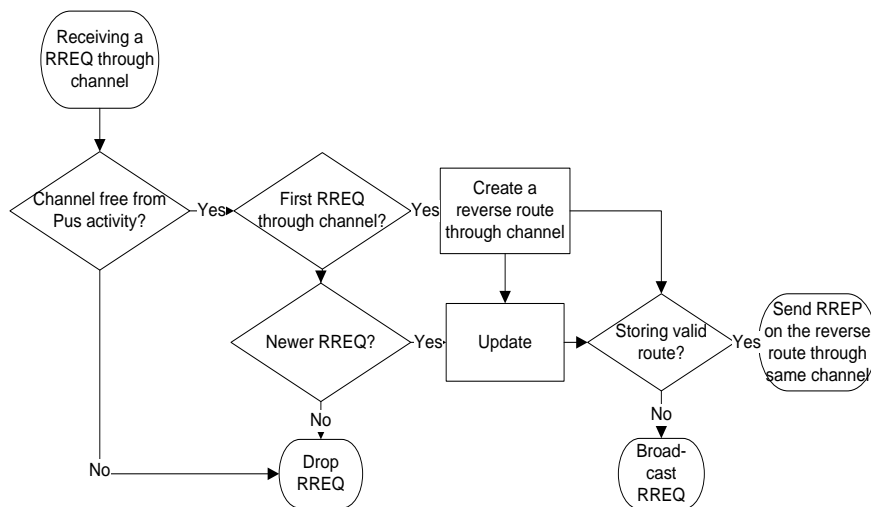


Figure 5.Route Request Flow Chart for ERI-CAODV [5]

In figure 5, When an intermediate CU receives a route request (RREQ) packet through an idle channel then it set up a reverse route toward the source through the same channel. After CU supply a valid route for the desired destination, then CU sends a unicast route reply (RREP) packet back to the sender through the same channel. Otherwise, it re-broadcasts the received route request through the same channel. On newer route request or better reverse route form same source to destination on same channel it is process by same CU and stored in the routing table. Otherwise it is discarded.

In route reply (RREP) phase, when an intermediate CU receives the first route reply through an idle channel, it generates a forward route within the same channel toward the destination. CU sends a copy of the RREP with the reverse path has been set in the routing table.

Route discovery for intrA-Route dIversity

In route request (RREQ) phase when CU receives route request through idle channel than it generate the reverse route through same channel and it broadcasts a copy of RREQ packet through all available channel. An intermediate CU creates some links toward the next hop by sending a route request (RREQ) through each idle channel.

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In route reply(RREP) phase when an intermediate CU receives the first route reply within idle channel than , it generate forward route within same channel and it forwards a copy of the RREP packet within each channel for which a reverse path has been set in the routing table. Remaining route request on different channel will be re-broadcasted only if it refers to better or newer reverse route. Otherwise it is discarded.

Dual Diversity Cognitive Ad-hoc Routing Protocol (D²CARP)

Dual diversity cognitive ad hoc routing protocol [6] performs PU activity with joint path and spectrum diversity.Hop count is used for path decision.

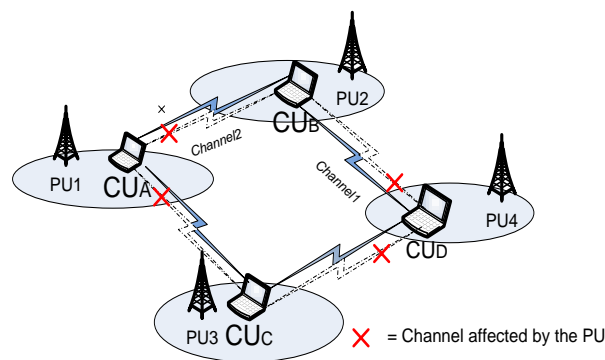


Figure 6. Joint Path and Spectrum Diversity [6]

In figure 6, where PU activity can affect a routing process. Here, CUA and CUD are lightly affected by primary users (PUs) and on channel 1 and channel 2, respectively, and CUA can communicate with CUD. Using the optimal path by link CUA → CUB (on channel 1) and CUB → CUD (on channel 2) when PU2 is not active or the sub-optimal path by link CUA → CUC (on channel 1) and CUC → CUD (on channel 2) when PU3 is not active.

Route discovery

In RREQ phase, when destination node receives the first RREQ, then it creates a reverse path toward the sender node through the idle channel and it broadcasts a copy of the RREQ packet through each idle channel. If destination node receives a further RREQ from the same neighbour node, but on a different channel, then it creates a reverse route only through idle channel. Through the multiple idle channels destination node is able to create reverse routes. Additionally, if destination node receives a new or better RREQ, then it updates the reverse route through the channel.

D²CARP selects best path according to the first hop node (FHN), which is a field of RREQ packet. On receives RREQ from a source then the receiving node's ID is stored in FHN. If multipath condition occurs then node creates a reverse route through channel, otherwise it drops the packet. The same process is carried out in RREP phase also from destination to source.

The multi-path conditions necessary are

1. The receiving node must be the destination.
2. The selected path must not share any intermediate node with previous established paths.
3. Minimum hop count for particular source to destination is considered for RREQ packet.

Robustness Aware Cognitive Ad-hoc Routing Protocol (RACARP)

RACARP [7] is performing PU activity of joint and spectrum diversity. The expected path delay (EPD) routing metric is used for path decision in the RACARP.

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The EPD routing metric used link delay and effect of packet loss during route setup stage.

$$EPD(P) = \sum_{Link \ l \in P} ELD(l) \dots (1)$$

EPD (p) represents the expected time it takes a packet to travel along a path p from a node to another node. Where p is a path and $ELD(l)$ is Expected link delay.

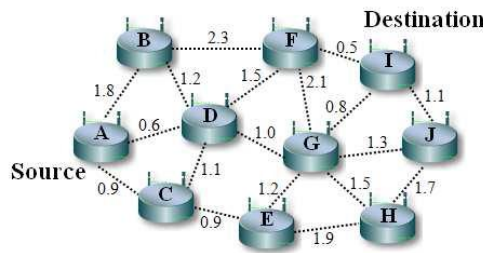


Figure 7.Path Diversity [7]

In Figure 7, where node A is source and Node I is destination. Node A can communication with node I through the minimum hop count ,i.e. A-D-F-I or A-D-G-I .These transmission path are equal number of hops but their path qualities are different. The minimum EPD value can calculated for data transmission. The path A-D-G-I with lowest EPD metric is used for path decision in RACARP protocol.

Exploitation of joint path and spectrum diversity

To provide multi path and multi channel routes, the RACARP protocol utilizes the joint path and spectrum diversity in routing process. In figure 8(a), where SU1 is a source node and SU2 is destination node. Using route discovery process base on minimum EPD value. The path is SU1 → ch1 → SU2 → ch2 → SU4.

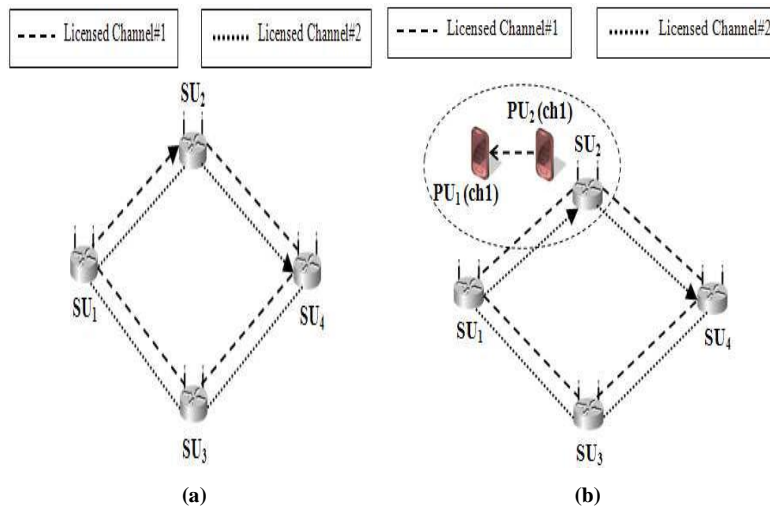


Figure 8.Path and spectrum diversity (a) No PU Activity is Detected [7] (b) PU Activity over Channel 1 is Detected [7]

In Figure 8(b), Secondary (SU) notifies PU activity on channel 1 then SU2 move into licensed region. SU1 uses available channel 2 for data packet transmission without altering path. New transmission path is SU1 → ch2 → SU2 → ch2 → SU4.

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Route Discovery

When a source node needs to transmit a data packet towards another node for which the routing information is unknown, it broadcasts an N-RREQ packet for the destination node to its neighbours through all its available channels. An intermediate node which receives the first N-RREQ packet creates a routing table entry for a route towards the source node, called a reverse route, and records the channel, through which the packet has been transmitted, in its routing table. Afterwards, it re-broadcasts the packet via all its vacant channels. If an extra NRREQ packet with the same sequence number received from the same node but on different channel, it creates another routing table entry of reverse route for that channel without rebroadcasting the packet. In such a way, the multichannel reverse routes are established. The record of reverse route will be updated only if it receives an additional N-RREQ packet with a higher sequence number or the same sequence number but lower EPD value.

Multi path reverse routes are created in following conditions

1. RREQ's First-Hop Node ID in the N-RREQ packet is different from First-Hop Node ID of reverse route entries in its routing table.
2. The ID of the node from which the N-RREQ packet has been received is different from Next-Hop Node's ID of reverse route entries in its routing table.
3. EPD value in the N-RREQ packet is less than or equal to the minimum EPD value of previously established reverse route entries in its routing table

III. COMPARATIVE ANALYSIS

Table 1, shows the comparison of different routing protocols. RACARP protocol is providing less packet loss and fast route recovery with compared to CAODV and D²CARP protocols.

Table 1 Comparison of On Demand Routing Protocols for CRNs [5][6][7]

Protocols	CAODV	D ² CARP	RACARP
Route discovery	Intermediate node	Broadcasting RREQ message by neighbours	Broadcasting RREQ message by neighbours, acknowledgment.
Routing decisions	MAC, physical, network layers	MAC, physical, network layers	MAC, physical, network layers
Best path selection	Shortest path	Hop count	Expected path Delay(EPD)
PU activity check interval	-	-	Every 5s
Advantages	Avoid interferences to PU during forwarding and formation, end to end connectivity.	The availability of multiple channels to improve the overall performance.	Fast route recovery in presence of PU activities during data delivery.
Disadvantages	High resource consumption	High resource consumption	More complex

IV. CONCLUSION

Cognitive radio ad hoc networks can be used to solve the difficulty of spectrum usage for inefficiency spectrum in wireless networks. Cognitive radio allows sharing of licensed spectrum band in opportunistic and avoid interference

International Journal of Innovative Research in Science, Engineering and Technology

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other licensed user. From comparative analysis of On-demand routing protocols for CRAHNs is used such as Cognitive ad-hoc On-demand Distance Vector Routing (CAODV), Dual diversity cognitive ad hoc routing protocol (D²CARP) and Robustness Aware Cognitive Ad-hoc Routing Protocol (RACARP). CAODV is best for end to end connectivity between source nodes to destination node for data. D²CARP protocol provides joint path and spectrum diversity which is used to decrease overhead and improve end to end delay. RACARP protocol is provide less packet loss and fast route recovery compared to CAODV and D²CARP protocols and select best path based on the expected path delay (EPD) metrics. Overall, for the same cognitive radio ad hoc networks, RACARP provides best performance in terms of higher average throughput and end to end delay.

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BIOGRAPHY



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