International Journal of Future Generation Communication and Networking
Vol. 7, No. 6 (2014), pp. 181-192
http://dx.doi.org/10.14257/ijfgcn.2014.7.6.17

CARC: A Reliable Routing Mechanism for Cognitive Ad Hoc Networks

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Abstract

In cognitive radio Ad Hoc networks, the events of node failure and link failure maybe happen frequently, especially the primary users will access the authorized channel whenever possible. In order to maintain the connection between cognitive users and resume their communication as soon as possible when the current route is invalid, a reliable routing mechanism CARC is proposed, which employs primary and candidate route to communicate under differential cases. Meanwhile, how to choose candidate route, maintain or rebuild route are also elaborated. Numerical simulations show that the proposed CARC protocol has a higher performance compared with other typical protocols.

Keywords: *Cognitive radio Ad Hoc networks, Primary route, Candidate route*

1. Introduction

Cognitive radio Ad Hoc networks, abbreviated as CRAHNs, is a kind of distributed networks combined with cognitive radio technology and Ad Hoc networks, which is proposed to alleviate the crowded ISM spectrum used by CRAHNs terminals as well as other wireless communication systems [1]. CRAHNs terminals, *i.e.*, cognitive users or second users (SUs) could opportunistically access the authorized channel to communicate with other SUs without interfering the primary users (PUs) by means of spectrum sensing technologies. Due to the uncertainty of PUs accessing authorized channels, the communication connection between SUs will be failed frequently and how to achieve reliable routing capability is our focus under such dynamic surroundings.

One typical scheme to enhance route reliability is through warding off the collision regions or links with PUs [2-4]. In [2], a route protocol named SEARCH is proposed based on the spectrum sensing technologies, which selects the communication paths and channels that have a lower collision probability with PUs. In [3], two kinds of route mechanisms are designed, one is used to assure the PUs communication without interference, and the other is to avoid collision with PUs in advance. In [4], a backup route mechanism is proposed to avoid PUs' activities.

Another reliable route scheme is achieved by means of allocating and switching channels [5-10]. In [5], a distributed stability algorithm (DSA) is proposed to search paths and allocate channels based on PUs' activities, which could achieve a high stability of SUs' communication in some restricted conditions. In [6], an optimized channel allocation approach for maximizing the link capacity is proposed based on the

ISSN: 2233-7857 IJFGCN

technology of cross-layer design. In [7], a computation approach for optimal route with minimum interference and hops is proposed based on the Directed Digraph Model. In [8], the problem of finding an optimal route is modeled as a stochastic process, in which the time duration of the authorized channel occupied by PU is analyzed in detail. [9] and [10] propose a similar route mechanism from an aspect of proactive channel allocation.

In most traditional route mechanisms, the collision with PUs in CRAHNs is impossible to avoid thoroughly. In case of collision, how to resume SUs' connection and communication still remains unsolved. In addition, how to rebuild the route in some extreme conditions is still an open issue. Unlike the conventional research works, we propose a reliable communication route protocol in CRAHNs (CARC) on the basis of multi-path route, which employs primary route to communicate when there is no link failure or node failure, and otherwise the candidate primary can be used to resume the communication.

The remainder of this paper is organized as follows. In section 2, we introduce the system model for CRAHNs route. In section 3, our proposed protocol CARC is described in detail. We evaluate the performance of CARC via experiment in Section 4, which is followed by the conclusion.

2. The System Model

The typical scenario of the multi-hop CRAHNs is shown in 0, in which more than one PUs and SUs are coexisted in a common network region, and the communication between two SUs is by way of other relay SUs with a multi-hop manner. Here we employ the typical ON-OFF mechanism to denotes PU's activities, *i.e.*, the state 'ON' stands for the authorized channel being occupied by some PU and the 'OFF' for its vacancy. Suppose K denotes the set of authorized channels, and T_{ON}^{k} $(k \in K)$ is the duration of the PU's activities, which is an exponential distribution with parameter λ_k. In other words, the duration from a PU's arrival to departure at some channel is exponential distribution. Correspondingly, the T_{OFF}^{k} $(k \in K)$ for a PU without accessing the authorized channel is also exponential distribution with parameter μ_k, thus the expected durations for 'ON' and 'OFF' stages are $1/\lambda_k$ and $1/\mu_k$.

2.1. The Multi-path Route Mechanism

As discussed in above sections, CRAHNs are confronted of serious link failure and node failure issues. To handle those problems, the multi-path routing strategy is employed in this system model and a candidate routing mechanism is proposed correspondingly. Meanwhile, two kinds of route mechanisms are required, one is the primary route that is served for SUs communication when there is no link failure or node failure, and the other one is candidate route that is used to compensate the primary one's failure.

In each source-destination pair, the primary route and candidate route are both required to store in the source node. Once the RREQ packets arrive at the destination, all the possibly paths from the specific source could be attained simultaneously. On this basis, the reliable retention time (RRT) of the route included of primary and candidate route, can be calculated as the minimum link RRT value along the route paths. Thus, the route with the maximum RRT will be chosen as the primary route, and then the candidate route can be determined according to the relativity between candidate and primary route which has been described in next section. Generally, multi-path routes are categorized into the following three classes.

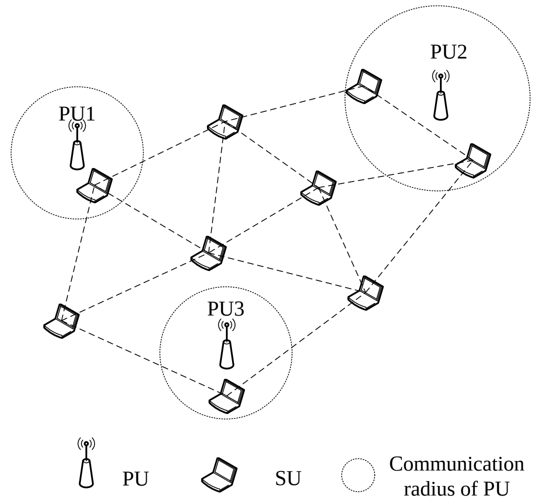

Figure 1. A Typical Scenario of CRAHNs

- **Multi-path routes without any link or node intersection**. There is no any common node among those multi-path routes besides of the source and destination nodes, such as paths SAD, SBD and SCD in 0.
- **Multi-path routes without link intersection**. There is no any common link among those multi-path routes. However it is possible that there may be some common nodes among the paths, such as paths SBD and SABCD in 0.
- **Multi-path routes with link intersection**. There are some common links among those multi-path routes, and there also exist some common nodes among them, such as paths SAD and SABD in Figure 2. Compared with the above multi-path routes, this kind of route is quite easy to find, but short of failure-tolerance capabilities.

Based on the characters of those above multi-path routes, we employ the hybrid multi-path route which could include of all three kinds of routes. As a result, the scope of searching routes can be extended effectively.

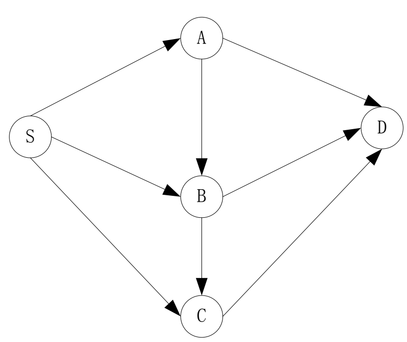

Figure 2. Illustration of Multi-path Route Classification

2.2. The Determination of Candidate Route

Because the link reliable time (LRT) can be calculated out based on the arrived RREQ packets, the primary route will be determined correspondingly. The value LRT of link j can be calculated as in (1):

$$LRT_j = \frac{1}{num_j} \cdot \sum_{0<k\le num_j} CRT_j^{(k)} \tag{1}$$

where num_j is the available channel amount, and $CRT_j^{(k)}$ is the reliable time of channel *k* in link *j*. In case of primary route failure, it is required to find a candidate route to assure the communication according to the relativity between primary route and other routes. Here, the notation n_i stands for the node overlap extent between path *i* and primary route, which can be calculated as (2):

$$n_i = 1 - \frac{N_c^{(i)}}{N_p} \tag{2}$$

where $N_c^{(i)}$ is the amount of nodes that the path *i* and the primary route have in common, and N_p is the account of nodes in primary route. In the same way, the notation l_i is used to reflect the link overlap extent between path *i* and the primary route, which can be calculated as in (3):

$$l_i = 1 - \frac{L_c^{(i)}}{L_p} \tag{3}$$

where $L_c^{(i)}$ is the amount of links that the path i and the primary route have in common, and L_p is the account of links in primary route, i.e., the total hops of primary route from source to destination. When we make a candidate route selection among all possible paths, both n_i and l_i should be taken into account simultaneously due to the hybrid routing mechanism employed in our model, such as (4):

$$\alpha_i = \phi \cdot n_i + (1-\phi) \cdot l_i, 0 \le \phi \le 1 \tag{4}$$

where α_i is the irrelevant extent between the path *i* and the primary route, and ϕ is the weight which is adaptable to the network surroundings. For example, if the events of node failure happen frequently, weight ϕ should have a comparable high value, otherwise its value should be lowered correspondingly. In addition, the RRT of candidate route should be taken into account, so we defined the parameter β as in (5):

$$\beta = \frac{RRT_i}{RRT_i + RRT_{pri}} \tag{5}$$

where RRT_i and RRT_{pri} are the reliable time of path i and primary route respectively. Therefore, the candidate route selection can be determined according to the value of η as in (6), and the path with the maximum of η will be chosen as the candidate route.

$$\eta = \alpha \cdot \beta = [\phi \cdot n_i + (1-\phi) \cdot l_i] \cdot \beta \tag{6}$$

3. CARC Route Protocol

The CARC route protocol is designed on the basis of AODV, and the channel information has been added into the format of control packet, which is used for selecting an optimal primary route as well as candidate route. Just as the conventional AODV, the proposed protocol is also consisted of three parts: route discovery, route response and route maintenance.

3.1. Route Discovery

In cognitive Ad Hoc, the PU's arrival is one of main reasons that can cause the link failure of SUs, thus the PU's activities must be considered into the protocol design. In CARC, two routing tables should be maintained in each SU: primary table and candidate table, which can be identified by the route flag. The common fields in each table are consisted of destination, available channel set and their CRT values, the fixed channel, next-hot node, available channel set and their CRT values in next-hop node, the fixed channel in next-hop node, TTL and route flag.

In the process of route discovery, the on-demand route manner is employed. When the source node begins to communicate with the destination but there is no any reachable path in the route table, the source node will broadcast the RREQ packet to its neighbors. Once the RREQ packet is received by its neighbor nodes, it will be inspected and one of the following cases will be happen.

Case 1. Check the field of hop. If the number in this field, *i.e.*, the amount of hops experienced by this packet exceeds the allowable maximum value, this packet will be discarded immediately.

Case 2. Check the set of available channels in the current node. If there is no any intersection between it and the available channel set in previous-hop node, this RREQ packet should be discarded. In other words, the two node cannot communicate with each other.

Case 3. Check the relay node IP addresses and make sure whether the current node IP is in the relay IP set or not. If yes, it is obvious that this RREQ packet has been arrived at the current node in earlier time and should be discarded this time to prevent the route loops.

Case 4. Check whether the received RREQ packet is the destination node. If it is, the primary route and the candidate route are calculated based on the information carried by the RREQ. And then the route response packet is generated and transmitted along the reversal path. Otherwise, the current node should be the relay node and then the information related with the current node is added into this packet. At last this updated packet is forwarded until the RREQ packet reaching the destination node.

3.2. Route Response

In the process of route discovery, a destination node maybe receives more than one RREQ packet from the same source. Under this case, the destination dose not have to response every RREQ packet other than that the primary and candidate route are decided by this packets. What we dose will alleviate the network workload effectively. At the destination node, a timer will be started when it receives the first RREQ from one source. After a predefined interval, *i.e.*, the timer being over, those RREQ packets from the same source will not be accepted by this destination. Based on those collected RREQ packets, the primary and candidate route will be calculated respectively.

As discussed above, the destination address, source address, the fixed channels of relay nodes, available channel set and their CRT values are included in the RREP packets, which could be easy the path construction including primary and candidate route from relay nodes to the destination. At the destination, the orderly relay node in the RREQ will be placed in the response packet with their reversal order and transmitted to the source along the reversal path. In consideration of the dynamic channel character, available channel set in each SU is variable correspondingly, so the route information has to be updated periodically.

3.3. Route Maintenance and Rebuilding

In cognitive Ad Hoc networks, the changing of network topology will possibly cause some nodes, links failure, or link quality decreased dramatically. Especially the PU's arrival maybe result in the interruption of some connections between SUs, and thus the data communication cannot be completed with high reliability and stability. Therefore, how to handle those problems will be crucial, which is also the key point in route maintenance and rebuilding. When a route path is failed, the related nodes should take the following actions to ensure the communication quality and the flowchart is shown in 0.

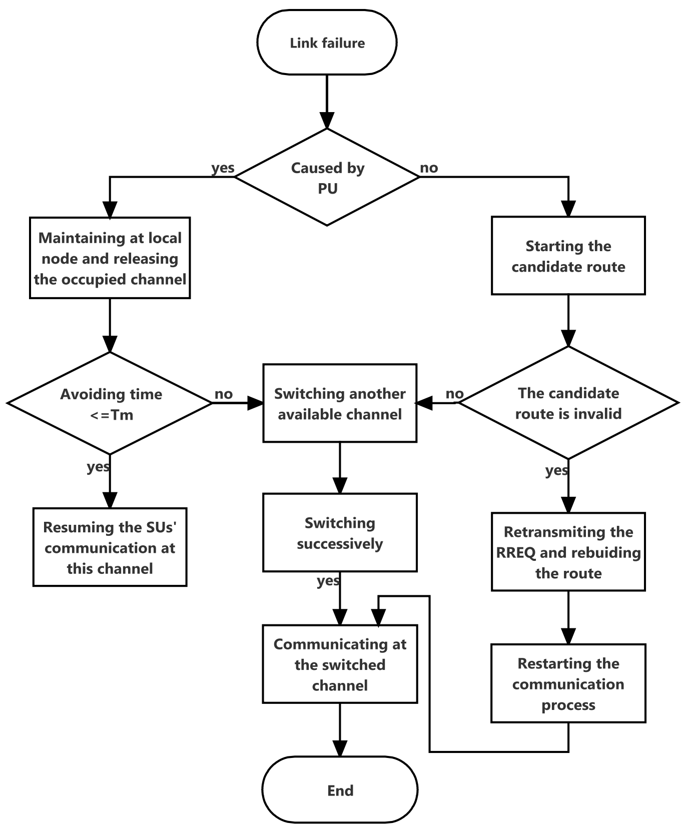

Figure 3. The Flowchart of Route Maintenance

There are main four steps for route maintenance and rebuilding.

Step1. It is required to check whether the failure channel is occupied by the PU. If it is, the SU's communication will be suspended, start the timer, wait the channel released by the PU and then go into the second step. Otherwise, this channel is not occupied by any PU, *i.e.*, the link failure is not caused by the PU's arrival. Under this case, go into the fourth step directly.

Step 2. If the PU releases the channel before the timer over, the SUs will resume their communication using this free channel. If the timer is over, *i.e.*, the suspending interval exceeds the maximum avoiding time T_m, go into the third step.

Step 3. Stop the procedure of waiting for channel release, and switch to other channels. First, check whether the fixed channel of next-hop is in the available channel set of itself. If it is, switch to the fixed channel of next-hop; if not, choose the channel k with the maximum CRT value in the available intersection set between itself and its next-hop node, and then both of nodes switch its communication interface to channel k. If the intersection set is null, go into step 4 directly.

Step 4. Notice the source node to start candidate route, and retransmit the packet. In extreme cases, if the candidate route is invalid, this source node must retransmit RREQ packet and rebuild a valid primary route and candidate route in the next route round.

4. Simulation Analysis and Comparison

In order to verify the performance of the proposed CARC protocol compared with JSORP [11] and SEARCH [2], the simulation experiments are conducted with simulation tools ns2. In our experiments, 50 nodes are randomly placed in a 1000*1000 m2 region, and 35 authorized channels are existed in the simulation process. The duration of the authorized channel occupied by PU is obliged to a exponential distribution with a parameter λ, and the remaining duration is also a exponential distribution with parameter μ, where λ and μ are generated in [0.5, 1.0] randomly. The maximum of interference avoiding time Tm is 1.4s and the maximum connections between SUs are set 35. The parameter φ is set 0.6 and the simulation process lasts 300s. The amounts of PU are varying from 5 to 35, i.e., its amount takes value of 5, 10, 15, 20, 25, 30, and 35. The velocity of SU takes value of 1m/s, 4m/s, 8m/s, 12m/s, 16m/s, 18m/s and 21m/s.

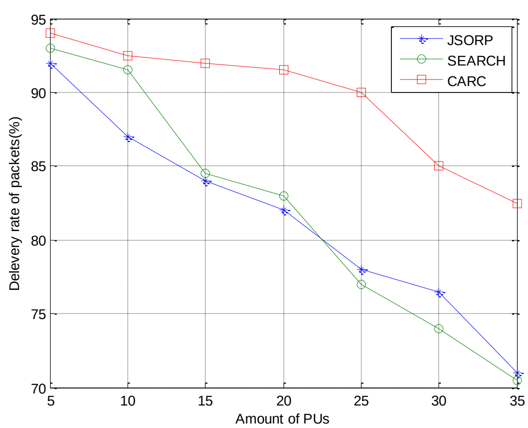

Figure 4. The delivery rate of SU's packets with different amounts of Pus

0 and 0 show the delivery rates of three kind protocols with different PUs amount as well as connections amount. With the amount increasing of PUs or connections, the delivery rates of JSORP and SEARCH protocols are decreased rapidly, but the proposed

CARC descends slowly. The reason is that the PUs activities are taken into account when the CARC protocol is designed, but this factor has been omitted by the other two protocols.

0 and 0 show the average route costs of three protocols with different amount of PUs as well as different velocities of SUs, which is described as the ratio of total control packets and data packets. The overall trends of those protocols are ascending with increasing of PUs number or SUs velocity, but the proposed CARC protocol has a higher performance because the candidate route could alleviate the network workload and route cost when the communication disconnection events happen frequently.

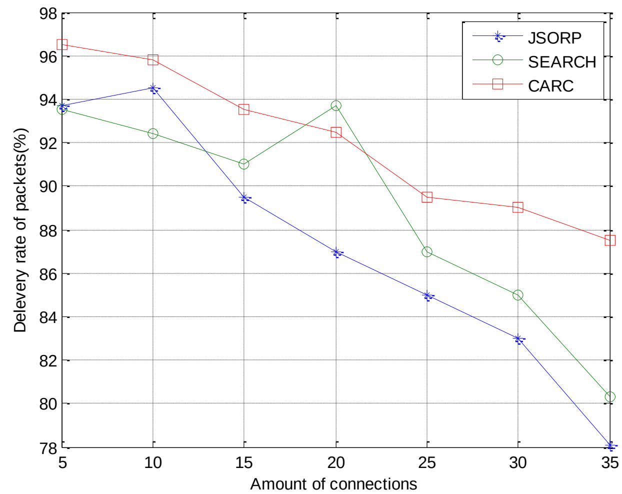

Figure 5. The Delivery Rate of SU's Packets with Different Amounts of Connections

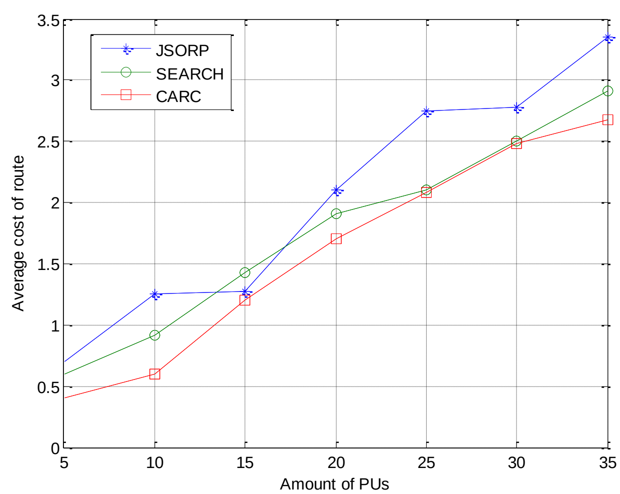

Figure 6. Average Cost of Route with Different PUs Amounts

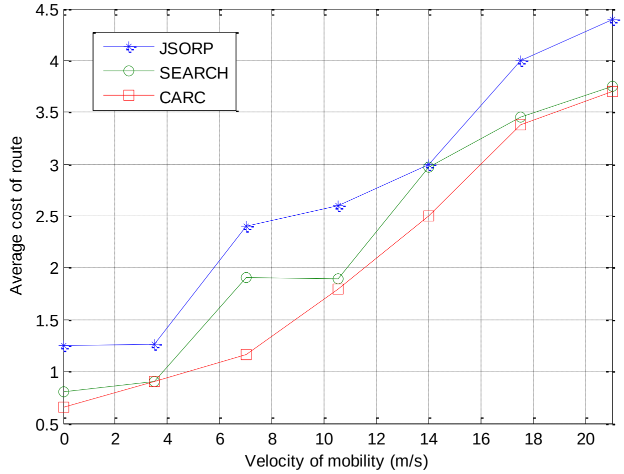

Figure 7. Average Cost of Route with Different SUs Mobile Velocities

The link maintenance capabilities can be shown in 0 and 0. With the amount of PUs increasing gradually, the protocol CARC has a good performance in maintaining link connection due to its primary route as well as candidate route maintenance mechanism. However, the JSOP protocol is short of strategy coping for PUs activities, and SEARCH cannot provide a reliable route maintenance mechanism either.

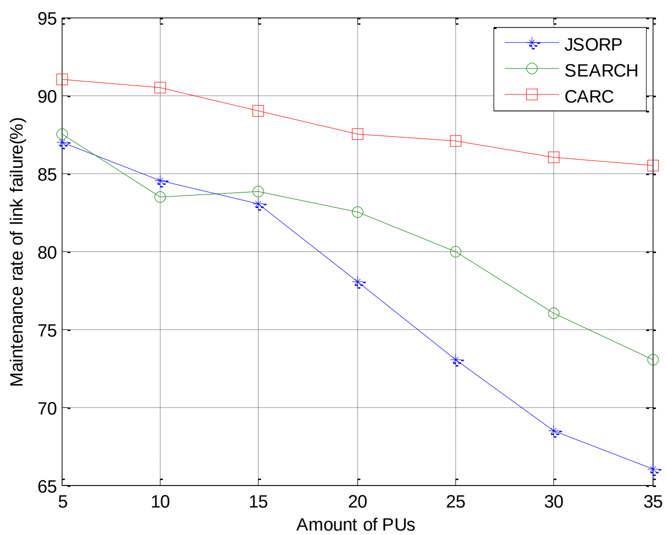

Figure 8. Maintenance Rate of Link Failure with Different Amounts of PUs

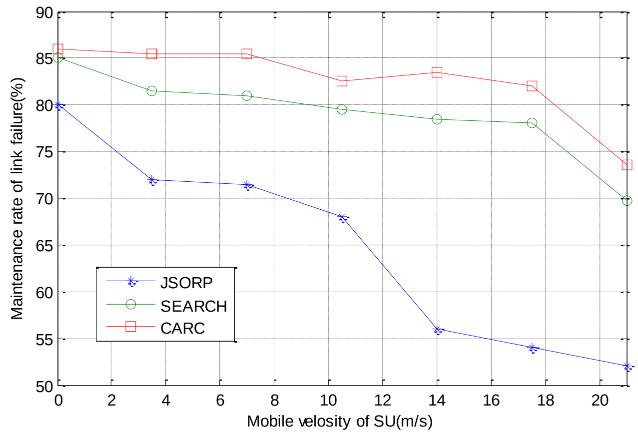

Figure 9. Maintenance Rate of Link Failure with Different Velocities of SUs

5. Conclusion

In this paper, we propose a reliable route protocol in cognitive Ad Hoc protocols CARC. Compared with other typical route protocols, the proposed CARC can enhance the reliability of route from the aspects of route discovery and maintenance, which can not only increases the packet delivery rate efficiently, but also decrease the route cost to some extent. On the other hand, our protocol will bear some overhead on the network nodes that maybe has a restricted computation capacity or energy, thus we will continuously explore this kind of route protocol in consideration of energy consumption in further work.

Acknowledgements

This work was supported in part by Science and Technology Research Projects of Department of Education in Heilongjiang Province under Grant 12521135.

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