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Performance Enhancement for Routing in Cognitive Radio Mobile Ad Hoc Networks using Topology Control

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Abstract- Cognitive Radio (CR) is an adaptive, intelligent radio and network technology that can automatically detect available channels in a wireless spectrum and change transmission parameters enabling more communications to run concurrently and also improve radio operating behavior. We are going to discuss topology control and routing issues in CR-MANETs and propose a distributed prediction-based cognitive topology control (PCTC) scheme to provision cognition capability to routing in CR-MANETs. PCTC is a middleware residing between CR model and routing makes use of cognitive link availability prediction based on that it captures the dynamic changes of topological and constructs an efficient and reliable topology which improves the end to end Network performance such as throughput and Delay. A simulation result also ensures the effectiveness of the proposed scheme.

Index Terms- Cognitive radio (CR), link-availability prediction, mobile ad hoc network (MANET), routing, topology control.

I. Introduction

Cognitive Radio is an enabling technology that allows cognitive users (CUs, i.e., unlicensed users or secondary users) to operate on the vacant parts of the spectrum allocated to primary users (PUs, i.e., licensed users). CR is widely considered as a promising technology that deals with the spectrum shortage problem caused by the current inflexible spectrum-allocation policy. CR technology will have significant impact on upper layer performance in wireless networks, particularly in mobile ad hoc networks (MANETs), which enable wireless devices to dynamically establish networks without necessarily using a fixed infrastructure.

Although some efforts have been done to the medium access control (MAC) layer issues [1], [2], routing is still one of the particularly important networking issues in CR-MANETs. The routing in CR-MANETs (called cognitive routing hereafter) should have the following unique characteristics.

1) *PU interference awareness*: Cognitive routing should choose a path that the interference to PUs is below the required threshold.

2) *Link-availability prediction*: It is mentioned in [8] that a CR network should be forward looking, rather than reactive. since spectrum sensing may take a long time and be delayed [3]–[4], a reactive CR network will degrade performance. Therefore, cognitive routing should not only be aware of PUs but should be concern with link-available periods

3) *Adaptive acting*: Cognitive routing should be adaptive to choosing a path based on the prediction to increase end-to-end throughput and decrease end-to-end delay.

There are a large number of routing protocols proposed in classical MANETs, such as destination-sequenced distance vector routing [5], dynamic source routing (DSR) [6], and adhoc on-demand distance vector (AODV) routing [7]. However, it is difficult to apply them directly to CR-MANETs due to the distinct characteristics described above, it is better to provision the cognition capability to routing via a middleware-like mechanism. Specifically, we propose a novel scheme, called prediction based cognitive topology control (PCTC), to provision cognition capability to routing protocols in CR-MANETs.

It can capture the topology dynamically based on link prediction to provide efficient and opportunistic link management and routing. The cognitive link-prediction model considers both user mobility and interference to PUs. It predicts both link duration and the probability that this duration may really last to the end of this period. Based on the cognitive prediction, we further describe how to construct a more reliable topology and reduce rerouting. It requires only local neighbor information, and network connectivity is preserved in a distributed manner. Simulation results show that PCTC results in a simpler topology and has longer link durations than that without topology control. Routing protocols also perform better in the resulting topology.

II. TOPOLOGY CONTROL AND ROUTING IN COGNITIVE RADIO MOBILE AD HOC NETWORKS.

The dynamic spectrum availability and the importance of limiting the interference to PUs differentiate the CR-MANET from classical MANETs. Two factors affect spectrum availability.

1.The first one is capability limitation of some CUs. Since CUs are considered to be low priority and secondary users of the spectrum allocated to PUs, CUs should sense the spectrum to detect PU activities by itself, or cooperatively. Due to the capability limitation of some CUs and a large number of possible spectrum bands, spectrum sensing may take a long time [3]–[4].

2. The second factor that affects spectrum availability is CU mobility. In classical MANETs, routes formed by multiple hops may experience frequent disconnections caused by node mobility.

This problem may be detected when the next-hop node in the path does not reply to messages and the retry limit is exceeded. However, this problem is difficult to solve in CR-MANETs since a node may not be able to transmit if the spectrum becomes unavailable when a node moves into the interference boundary of an active PU. Therefore, correctly inferring mobility conditions in designing effective topology control and routing scheme [9].

In this sense, we concentrate on how the spectrum availability due to CU mobility affects the network performance in CR-MANETs. We use a simple scenario in Fig. 1 to illustrate the effects of CU mobility on routing in CR-MANETs. There are one PU and four CUs in this scenario. The source node is CU1, and CU4 is the destination node. As we can see in Fig. 1, CU3 is moving toward the PU, while CU2 is moving away from the PU. The traditional routing in classical MANETs will select paths under a shortest path criterion. Link CU1 → CU3 may be selected in the route. However, as CU3 moves close to the PU, link CU1 → CU3 cannot be used due to the interference from CU3 to the PU.

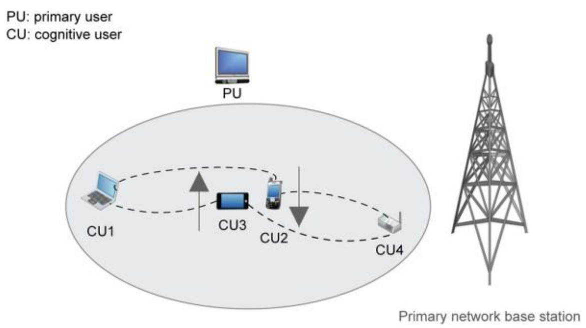

Fig 1. Motivation scenario. Cognitive routing selects CU2 in its path other than CU3 for the sake of reducing rerouting frequency when considering interference avoidance to PU. The arrows indicate the movement directions of CU2 and CU3, respectively.

The relaunching route request will be triggered to find another route. Link CU1 → CU2 does not have this problem, since CU2 is moving away from the PU, and the interference from CU2 to the PU is below the threshold. The rerouting problem would not happen if link CU1 → CU2 instead of CU1 → CU3 were selected. From this example, we can see that mobility prediction can help improve the performance of routing in CR-MANETs. It is desirable that cognitive routing should prefer the links with long durations to prolong the path survival time and improve the path stability.

Existing routing protocols in classical MANETs lack this cognition capability. Therefore, to provision cognition to routing, we adopt a middleware-like technology, i.e., topology control, in CR-MANETs. In our framework, topology control is treated as a cross-layer module connecting the routing layer and the CR module.

III. COGNITIVE LINK- AVAILABILITY PREDICTION

A large number of prediction models are available for link availability prediction [10]–[11].The basic principle of the prediction framework is to provide a predicted time period *Tp* that the link between two nodes will stay available. In addition, another important parameter, which is denoted by *L*(*Tp*), can be obtained from this framework to estimate the probability that this link may really last to the end of *Tp* by considering possible changes in velocities. In CR-MANETs, [*Tp*, *L*(*Tp*)] is not sufficient to predict link duration, because the links between CUs are affected by CU mobility as well as by the interference to Pus.

In this situation, a link with a high quality may be regarded as unavailable if a node in that link is moving close to a PU. As a result, to avoid interference, the distance between a CU and a PU should be monitored. This paper proposes another pair of [ˆ *Tp*, *L*(ˆ *Tp*)] to predict the link availability before nodes moves into the interference boundary of PUs. Similar to *Tp*, ˆ *Tp* is the predicted time until a CU moves into the interference area of a PU, and *L*(ˆ *Tp*) is its corresponding probability. The final link availability is revealed by the combination of [*Tp*, *L*(*Tp*)] and [ˆ *Tp*, *L*(ˆ *Tp*)] to enable cognitive link prediction.

A. [ˆ *Tp*, *L*(ˆ *Tp*)] *Estimation*

Then, the available period T_P if counted from *t*2, is Obviously, the preciseness of ˆ *Tp* depends on the measurement {Formula}- (1).

$$Tp = \frac{\sqrt{\beta^2 + 4\alpha\rho^2 - 4\alpha\gamma - \beta}}{2\alpha} - t_2$$

There are some methods to obtain distance information. Similar to [*Tp*, *L*(*Tp*)] estimation, we also have to provide a probability *L*(*Tp*) to *Tp* {Formula}-(2)

$$L(T_p) = 1^{\lambda Tp 1^{-\lambda T}} + \varsigma(1 - 1^{-\lambda Tp})$$

B. Link-Availability Prediction

A link is considered available if the two nodes associated with this link are within the transmission range of each other and if they are both out of the interference region of any PU in CR-MANETs. The former is a common condition in MANETs, while the latter is the specific requirement in CRMANETs. Consequently, link availability should be determined by [*Tp*, *L*(*Tp*)] and [ˆ *Tp*, *L*(ˆ *Tp*)] together. Jiang *et al.* [21], [24] use *Tp* × *L*(*Tp*) as a routing metric to assist routing protocols in selecting reliable paths. However, it is far from sufficient for CR-MANETs. For instance, if a link with *Tp* × *L*(*Tp*) = 8 s, but ˆ *Tp* × *L*(ˆ *Tp*) = 5 s, it cannot stay available for 8 s since it will move into the interference region of PUs, which suppresses its transmissions.

IV. COGNITIVE TOPOLOGY CONTROL AND ROUTING

A. Distributed Topology Construction

The dynamic changes due to CU mobility or the interference to PUs, which will result in frequent rerouting, waste large amounts of scarce network resources and achieve low end-to-end performance. In PCTC, a new link reliability metric is defined

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for topology construction. We first introduce a rerouting penalty denoted by δ.

This penalty is a period that is incurred by rerouting and reduces link availability to ($Ta - \delta$) in the sequel. Actually, the path duration is not the main concern of an end-to-end transmission. Instead, by nature, it is expected to deliver as many packets as possible before a path failure happens. From this point of view, the only consideration of link available duration *Ta* is not enough since a link with long duration may have a poor quality resulting in low data rate.

In the long run, it needs fewer re routings if the selected path consists of links with longer *Ta* and higher quality.To quantify this measurement, we set the link weights to *{Formula}- (6) AND (7)*

$$\omega = \gamma * (T_a - \delta)$$
$$W = \min W_i, i \in L$$

where the link data rate *r* captures its link quality. Herein, the rerouting penalty δ is converted into a capacity loss $r \times \delta$ during the available period. The link weight then presents the traffic carrying ability of this link.

& L is the set including all the links along the path. We can see that the definitions of link and path weights reflect its true data-transmission ability.

It is desirable to transmit more data traffic before link failure. Similar to other topology control algorithms, the topology-construction process in this paper consists of three steps: neighbor collection, path search, and neighbor selection. The distributed localized Dijkstra topology control (LDTC) algorithm, which aims at constructing an energy-efficient topology, has some beneficial properties, particularly the 1-spanner property, which preserves the global minimum energy paths in a distributed manner. LDTC runs the Dijkstra algorithm over a neighborhood graph. Therefore, it requires only local information exchanges. In this paper, the distributed cognitive PCTC algorithm enhances LDTC to preserve the end-to-end reliable paths for CR-MANETs.

As a distributed algorithm, each node runs the following procedures as an initial node.

1) *Neighbor collection:*

a) Collect all of its neighbors, and calculate the edge weights according to (6).

2) *Path search:*

a) Set the path weights to infinity for the initial node and to zero for neighbors. Mark all the neighbors as unvisited and the initial node as the current one.

b) Calculate the path weights according to

(7) from the initial node to unvisited neighbors via the current node. If they are larger than the previously recorded ones, update the path weights to them.

c) Mark the current node as visited, and set the unvisited node with largest path weight as the current node. Then, repeat from b) until all the neighbors are visited.

3) *Neighbor selection:*

a) All of the most reliable paths from the initial node to its neighbors are now found. The resulting topology is the output by preserving all the first-hop neighbors of the initial node along these paths.

B. Topology Reconfiguration

Wireless links are changing dynamically due to node mobility, fading, barrier, interference, etc. In this section, we study how to do topology reconfiguration due to the dynamically changing wireless links in CR-MANETs. Topology reconfiguration can also be used to deal with inaccurate link availability predictions since prediction errors are inevitable.

In CR-MANETs, therefore, an intuitive method for topology reconfiguration is to run the topology control algorithm frequently to keep pace with the dynamical links. However, this frequent topology control requires an enormous amount of computational loads and is quite power consuming. To respond promptly to topology changes, it is desirable to be able to deal with some asynchronization occurrences, such as link appearance, disappearance, and link weight change

1) When a new node wants to joint the network, it first predicts all links to its neighbors based on the cognitive link-duration prediction scheme presented in Section III. These predictions are then broadcast to neighbors in its range. For any node that has been in the network, it is not necessary to rerun the topology algorithm to reconfigure the topology.

What a reconfiguration needs to do is to find a reliable path to the new node from the existing topology. After running PCTC, the initial has obtained the reliable paths to all its original neighbors. Then, the topology reconfiguration extends these paths by adding the newly appearing links to the newcomer.
The one with maximum weight is selected, and the first-hop neighbor in the path is preserved. The new node may compose more reliable paths to the existing nodes. Therefore, reconfiguration extends the reliable path of the newcomer

C***. Cognitive Routing on the Resulting Topology***

Routing is defined to select paths in a network to send data traffic. A challenge in CR-MANETs is to provision cognition capability to routing protocols. With PCTC, existing routing protocols can be easily adopted in CR-MANETs with cognition capability. Based on the cognitive link-prediction scheme presented in Section III, routing on the PCTC resulting topology is aware of PUs and is forward looking to link duration.

Further, PCTC makes routing adaptive to a mobile environment, in which routing favors reliable paths in the network. Take the popular routing protocols, such as DSR and AODV, as examples. They usually send routing request packets (RREQs) to find a path for a source and a destination. When an RREQ reaches an intermediate node, it may be dropped if the transmitter does not exist in the neighborhood relationship generated by the PCTC algorithm. Otherwise, this RREQ is disposed by the intermediate node and rebroadcast.

As a result, the links in the vicinity of PUs or with poor quality and short available duration are avoided. The first RREQ is replied to in terms of a routing metric of the first found path to confirm the found path. Actually, PCTC optimizes neighborhood relationship among nodes and assigns each path a weight with regard to reliability. With PCTC, we can improve the performance of other routing metrics such as shortest path or quality-of-service routings.

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D. Message Overhead Analysis

PCTC in this paper requires the knowledge of local connectivity. Consequently, message exchanges with neighbors are indispensable. Each node periodically broadcasts a message including its neighbor list and the corresponding predicted link durations. On receiving these messages, each node is able to construct a local connected graph for PCTC. On the other hand, as discussed in Section IV-D, the routing on the PCTC resulting topology reduces the number of RREQs in the route establishment phase.

V. SIMULATION RESULTS AND DISCUSSIONS

In this section, the proposed scheme is evaluated via computer simulations. In the simulation environment, nodes are randomly moving in a 2-D space according to the random-walk based mobility model, where a node moves with a direction uniformly and a speed uniformly from 0 to *v*max with exponentially distributed epochs. IEEE 802.11 is adopted for the MAC layer. The maximum transmission range of each node is 300 m, and the transmission rate is 2 Mb/s.

Routing over the PCTC topology is then adaptive in CR-MANETs. The following two routing strategies are adopted to evaluate the performance of the topology control algorithm further in the simulations.

1) *Shortest path (SP)*: Each flow is transmitted along the path with the minimum number of hops.

2) *Reliable path with regard to Ta* (*RPTa*): This is the proposed scheme in this paper. It selects the path with maximum path duration

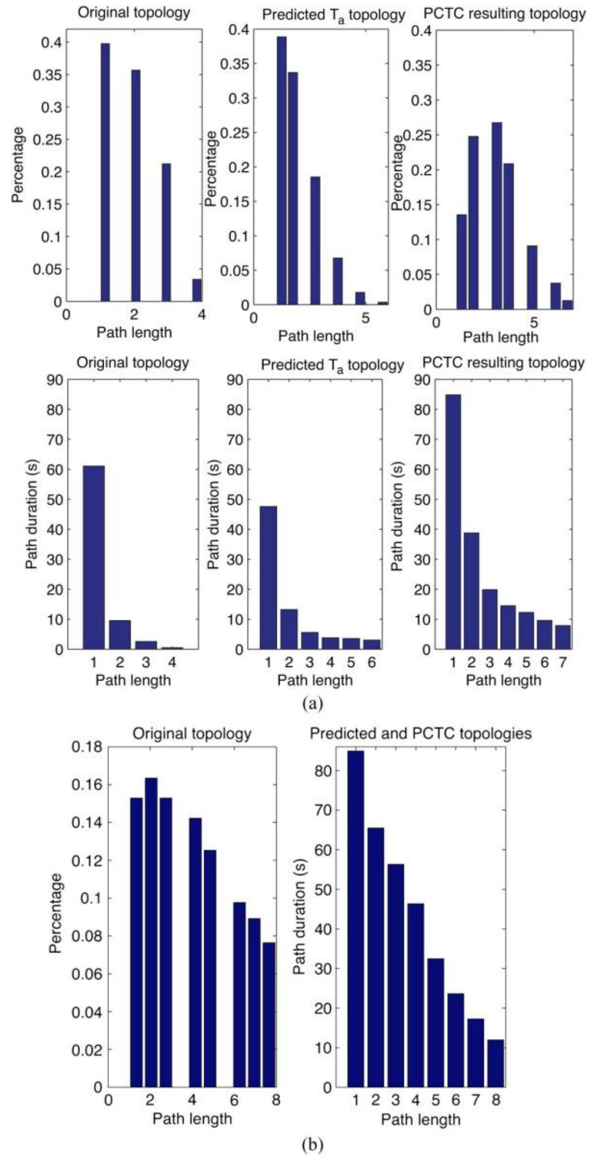

Fig 6.Routing over Different Topologies

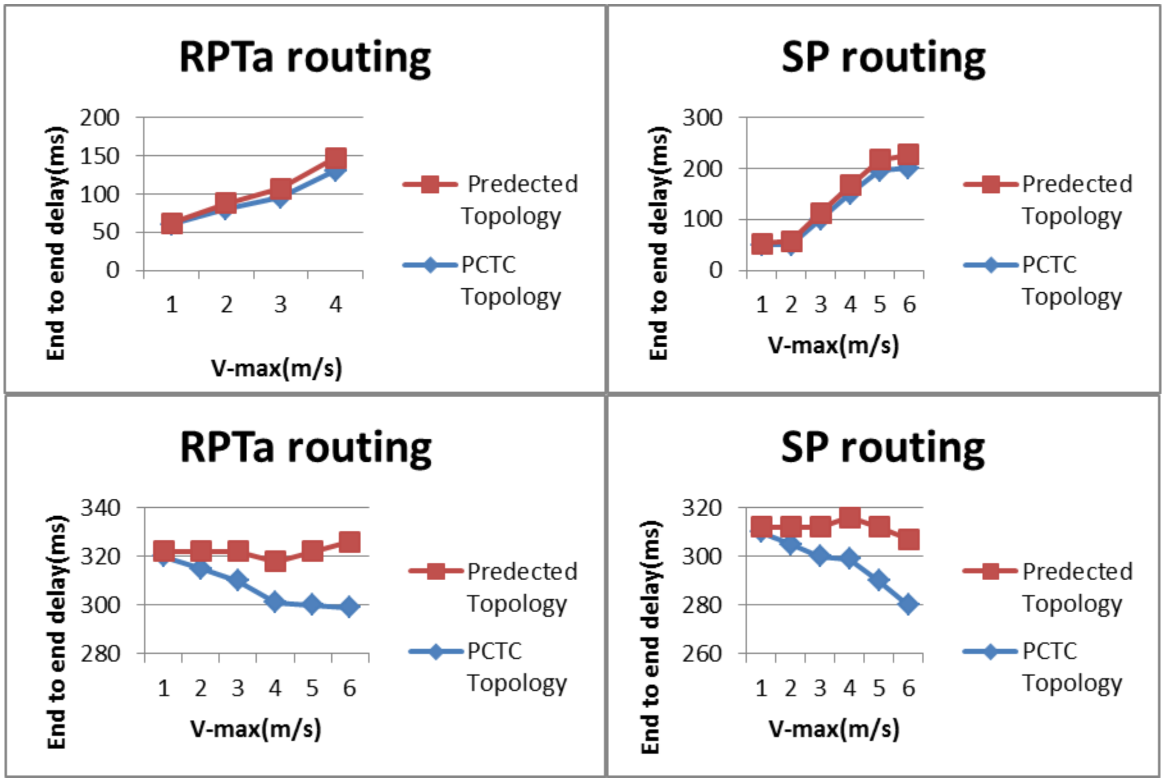

Fig. 7. End-to-end performance studies

Fig. 6(a) shows the results of SP routing. We can see that SP routing under the original topology, which is not aware of PUs, has the smallest hop counts while performing the worst in terms of path duration. The PCTC resulting topology has longer path length compared with the predicted topology.

End-to-end performance is a critical objective for routing protocols. Fig. 7 demonstrates the two main performance metrics, i.e., 1) end-to-end throughput and 2) delay, of routing on the predicted topology and cognitive routing on the PCTC resulting topology. For RPT*a* routing, although the same path is selected on the predicted topology and PCTC topologyThis is because less node degree in PCTC topology may alleviate the contention in the shared wireless medium and results in less medium access time. As for SP routing, although there are paths with more hop counts, the end-to end throughput under the resulting topology is higher than that under *Ta* topology. The end-to-end delay is also shorter. The reason is that the paths under the resulting topology last longer, resulting in fewer link breakages and less rerouting frequency.

VI. CONCLUSION AND FUTURE WORK

CR technology will have significant impact on upper layer performance in CR-MANETs. In this paper, we have proposed a framework to provision cognition capability to the routing protocols in CR-MANETs, which are aware of the interference to PUs, forward looking to link-available duration, and adaptive to the mobility environment. A novel distributed PCTC scheme was presented. Link-available duration prediction takes into account both the interference to PUs and the mobility of CUs. We have evaluated the routing performance over the resulting topology by computer simulations. It was shown that with the proposed middleware-like topology control residing between the routing layer and CR module, the resulting network topology is simpler, and links last longer.

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