International Association of Scientific Innovation and Research (IASIR)
(An Association Unifying the Sciences, Engineering, and Applied Research)

ISSN (Print): 2279-0047
ISSN (Online): 2279-0055

International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS)

www.iasir.net

Link Prediction-Based Topology Control and Adaptive Routing for Cognitive Radio Mobile Ad-Hoc Networks

Kanchan Hadawale[1], Sunita Barve[2], Parag Kulkarni[3]
Computer Department, MIT Academy of Engineering, Pune University[1]
Research Scholar, Bharati Vidyapeeth Deemed University[2]
EKLaT Research[3]
Pune, Maharashatra, India

***Abstract**: Cognitive Radio (CR is a promising technology which deals with using vacant spectrum of licensed frequency band opportunistically. In CR Network, route construction must not affect the transmission of Primary User activity. In CR technology challenge of maintaining optimal routes arises due to PU activity and mobility of spectrum resources i.e. CR users. Maintaining optimal routes in Ad-hoc CR network increases the overall network throughput and decreases end-to-end delay. This end-to-end network performance can be increased by providing cognition capability to routing in Cognitive Radio Mobile Ad-Hoc Network. We propose routing scheme with link-availability prediction and topology control. Link-availability prediction considers primary user activities and user mobility. Topology control constructs dynamic and reliable topology based on link prediction. This routing scheme reduces energy consumption, rerouting and thus enhances overall network performance and ensures least delay.*

***Keywords**: Cognitive Radio Network (CRN); Cognition capability; Link prediction; Topology control*

I. Introduction

Cognitive Radio (CR) technology is one of the promising technologies that allow unlicensed users to access licensed spectrum bands opportunistically in a dynamic and non- interfering manner. Federal Communication Commission (FCC) highlights that many licensed spectrum bands are used only in specific geographical areas and over limited period of time average utilization of spectrum band varies between 15% and 85%. Cognitive radio technology is thus introduced to solve the problem of spectrum usage inefficiency.

In CRN, most research is done on MAC layer issues such as opportunistic spectrum access and spectrum utilization. Whereas CR technology has more impact on upper layer performance issues in wireless network, specifically in Mobile Ad-Hoc Networks (MANETs). In routing issue, data should be routed via stable and reliable path to avoid rerouting and thus congestion in network. This degrades the performance of network such as throughput and delay. As compared to classical routing, routing in CRN is more unstable as it is affected not only by mobility of Cognitive User's (CU) but also by Primary User (PU) activities. Thus routing in CR-MANETs should have the following characteristics to ensure stable and reliable paths.

i. **PU activity awareness**: In CRN, path selection should be in such a way that it should not interfere to PU activity i.e. PU interference should be below the required threshold.
ii. **Link-availability**: To avoid PU interference, cognitive routing should also be reactive. It should be aware of link-available periods.
iii. **Adaptive behavior**: Cognitive routing should be adaptive to selected path based on some prediction to avoid rerouting frequency and to increase end-to-end throughput and to decrease end-to-end delay.

There exists large numbers of routing protocols for MANETs which cannot be applied directly to CR-MANETs because of its distinct characteristics of CR-MANETs. So here we proposed technique that provides cognition capability for routing through middleware mechanism like topology control. Topology control is used in almost all wireless networks to reduce energy consumption and interference. With topology control network connectivity is achieved through link information provided by MAC and physical layers. Thus topology control works as middleware that connects routing and lower layers. In CR-MANETs, topology control takes care of PU activities and spectrum-availability. In proposed scheme, prediction based topology control is considered to provide cognition capability for routing. This technique captures topology dynamically based on the link information provided by lower layers to provide opportunistic link management and routing in CR-MANETs. Link-prediction model is proposed to deal with cognitive user mobility and PU activities. This model predicts the link-availability duration as well as probability that duration remains till the end of this period. Based on this predicted links, reliable topology is constructed to reduce rerouting. For link prediction, local neighbor information is collected and network connectivity is preserved in distributed manner.

II. Related Work

A. Link Stability Routing Solutions

Link availability in cognitive network is different from traditional wireless network. Link availability in cognitive network varies with time and space. Thus stable links is one of the routing solutions which can be achieved through following routing schemes.

1) Enhanced Path Recovery Functionalities

In [2], authors proposed SPEctrum-Aware Routing (SPEAR) protocol to get link flexibility with spectrum heterogeneity. Spectrum availability depends on location and presence of primary user activities. SPEAR considers following concepts for link stability,

a) To deal with spectrum heterogeneity, spectrum discovery is integrated with route discovery.
b) By minimizing inter-flow interference, channel assignments are coordinated on per-flow basis.
c) To achieve spectrum diversity and to reduce intra-flow interference, local spectrum heterogeneity is considered.

SPEAR set-up route by broadcasting and AODV-style route discovery is used to get each node's channel quality and availability information. Each Route Request (RREQ) contains node IDs, nodes spectrum availability and link quality. All these parameters are combined at destination to select optimal route. SPEAR discovers multiple paths with redundant paths that are sent to destination for best path selection. Selected route is reserved at destination by using RREP messages. In [3], collaboration between route selection and spectrum decision is considered. In this paper, authors proposed Spectrum Tree based On Demand routing Protocol (STOD-RA) which includes,

a) Route metric based on PUs activities and SUs QoS requirements.
b) Spectrum-tree structure of each available channel
c) Spectrum Tree based On Demand Routing Algorithm

Routing metric combines both link stability and spectrum availability. It predicts spectrum availability time from history of PU activities.

2) Targetting Route Stability

In [4], link stability is associated to path connectivity through mathematical model. Degree of connectivity is considered while measuring paths, also PU behavior is also considered. Authors introduce novel metric to assign weight to routes which also captures path stability and availability over time. In this paper routing scheme is named as "Gymkhana", which forwards information along paths to avoid unstable and low connectivity network zones. Gymkhana uses distributed protocol to collect information of candidate paths from source to destination. Gymkhana contributes following work in cognitive routing,

a) Provision of re-elaboration of algebraic connectivity in cognitive context.
b) Formulation of path connectivity and path length used in cognitive routing protocol.

In [5], route stability is defined In terms of route maintenance cost and protocol is designed. Route maintenance cost represents efforts required for maintaining end-to-end connectivity in cognitive routing. It includes operations like link switching and channel switching on presence of primary user activity. In link switching link routes must be replaced by the links that are not affected by PU. In channel switching same link can be maintained but spectrum portion must be changed. Authors propose MILP formulation to minimize route maintenance cost with link capacity and flow balance constraints. Centralized algorithm is designed to compute minimum maintenance cost routes in cognitive routing.

3) Routing with Mobile SUs

In [6], SEARCH routing protocol is designed on geo- graphic forwarding principle. In cognitive radio network, route is constructed at network layer must not affect primary user's transmission and thus must be aware of spectrum availability. The frequency changing PU activity and mobility of CR user make the problem of maintaining optimal routes in Ad-Hoc cognitive radio network challenging. SEARCH mainly works on following two concepts,

a) PU activity awareness: In CR network, route must be constructed to avoid region affected by active PU. When PU activity affect region, SEARCH provides hybrid solution, it first uses greedy geographic routing on each channel to reach destination by identifying and circumventing PU activity region. The path information from different channels is combined at destination in series of optimization steps to decide on optimal end-to end route in a computationally efficient way.

b) CR user mobility: Cognitive user mobility results into frequent route disconnections. Thus for each node, through periodic beacons, updates its one-hop neighbor about it current location. SEARCH ensures performance as well as less interference in cognitive radio network.

B. Solutions with Link-Availability Prediction Model

In [7], to reduce rerouting, path availability and reliability metric is concerned in routing of MANETs. For that prediction based link-availability estimation and path reliability estimation is used as routing metric. The basic idea of this estimation is nodes first predict that a continuous time period (Tp) that the link-availability remains from t0 with assumption that velocity both nodes of that link will be constant during Tp. Then the probability estimation L(Tp), that this link remains until t_0 + Tp, with possible changes in velocities of nodes during t_0 to t_0 + Tp. Thus with these link-availability estimation they get two approaches, “unaffected Tp” with constant velocities and “affected Tp” with changes in velocities. This estimation improves the tendency of link availability to develop path selection metrics to improve network performance.

In [8], authors proposed enhancement to the prediction based link availability estimation. Since, in original estimation L (Tp) all possible changes in velocities during Tp do not take into account. It only considers first change in velocity during time period Tp and link availability for these changes is estimated by ϵ. This is given as,

$$\mathrm{L\ (Tp)} \approx \left[\frac{1}{2\lambda Tp}\right] + \grave{o} + e^{(-2\lambda Tp)}\left(\rho\lambda Tp - \left[\frac{1}{2\lambda Tp}\right] - \grave{o}\right)$$

Where, p = probability of two nodes of a link to get close to each other. For link prediction Tp, node can measure the link duration that remains till the end of Tp and link-availability measured as Lm (Tp) = (Tr) / (Tp)

1) Spectrum Sensing: Spectrum sensing allows cognitive user to detect spectrum holes by detecting primary users that are receiving data within its communication range. Spectrum sensing techniques are classified as follows, transmitter detection, cooperative detection, interference-based detection.
2) Spectrum Management: To meet QoS requirements of application cognitive radio should select best available spectrum band among all available spectrum bands. This is achieved through following spectrum management functions, Spectrum Analysis, Spectrum Decision.
3) Spectrum Mobility: Spectrum mobility occurs when primary user requires its licensed band. Such type of handoff is referred as spectrum handoff. Spectrum mobility ensures that transition of network protocol from one mode of operation to another is made smoothly and without degrading network performance.
4) Spectrum Sharing: Provides spectrum scheduling among all existing users. Spectrum sharing process is divided into following 5 steps, spectrum sensing, spectrum allocation, spectrum access, transmitter-receiver handshake and spectrum mobility.

This paper presents current challenges of routing in Cognitive Radio Network (CRN) and different solutions with different routing metrics. We first explain differences between classical routing in wireless network and routing in cognitive radio network. Then we provide brief overview of spectrum management for cognitive radio network. We explain existing work and challenges in cognitive radio network. And finally different methodologies for different routing metrics are explained as solutions for different challenges of CRN.

III. System Model

Cognitive Radio Network (CRN) routing is different from classical wireless routing in terms of dynamic spectrum availability and PU activity interference. Spectrum availability is affected by following two factors,

a) PU activities: As CUs are considered as secondary user due to low priority in accessing the spectrum band allocated to PU. CU should be aware of PU activities while sensing the spectrum. Spectrum sensing can be done either non-cooperatively i.e. individually each CU conducts radio detection and takes decision by itself or cooperatively where spectrum sensing is done by group of CUs in collaboration.

b) CU mobility: Due to node mobility frequent disconnection occurs in established route. Route disconnection is detected when next-hope node in route does not reply to message and retry limit is exceeded. In CR-MANETs, due to node mobility in PU activity region spectrum also becomes unavailable.

To solve the spectrum availability problem, above two factors should be consider for designing efficient topology control and routing schemes. In proposed system, focus is on spectrum availability affected by CU mobility. That means cognitive routing should select the links with long path survival time to improve path stability. This cognition capability is achieved through middleware technology such as topology control. Topology control works with cross-layer module that connects routing layer and CR module. In proposed scheme topology control is integrated with link-availability prediction. The proposed system is divided into 3 stages,

Fig. 1 Proposed system architecture

A. Link-Availability Predictions

A reasonable link-availability prediction model is used for proposed system. The basic principle is to provide predicted time period Tp for link-availability between two nodes. L(Tp) parameter is used to estimate probability that this link may remain till the end of Tp by considering changes in velocities. It also estimates L(Tp) for a node that does not move at a constant velocity. In CRMANETs along with CU mobility PU activity region is considered for link prediction. To avoid PU interference distance between CU and PU is calculated. For link-availability before node moves into PU activity region, another pair of parameters [Tp,L(Tp)] is calculated. $\widehat{Tp}$ is predicted time till CU is outside the PU activity region and L($\widehat{Tp}$) is its corresponding probability. Final link prediction we get by combining [Tp, L(Tp)] and [$\widehat{Tp}$, L($\widehat{Tp}$)].

1) [$\widehat{Tp}$, L ($\widehat{Tp}$)] Estimation

As we consider that the velocities of nodes stay constant during random long period of times, so it is easy to get $\delta^2 d^2/\delta^2 T^2=0$.

Where, d = distance between two nodes T = time interval

Then d can be calculated as,

$$d^2 = \alpha T^2 + \beta T + \gamma \qquad (1)$$

Where, α, β and γ = constant

α, β and γ can be calculated by three points of measurements (t_0, d_0), (t_1 , d_1) and (t_2 , d_2). Sample time is $t_i = t_0 + T_i$ and d_i is measured distance between two nodes. Without loss of generality, Let $t_0 = 0$ then α, β and γ can be sorted as,

$\alpha = [(d_1^2\, t_2 - d_2^2\, t_1) - d_0^2(t_2 - t_1)] / [t_1 t_2 (t_1 - t_2)]$

$\beta = [(d_1^2\, t_2^2 - d_2^2\, t_1^2) - d_0^2\, (t_2^2 - t_1^2)] / [t_1 t_2 (t_1 - t_2)]$

$\gamma = d_0^2$

When two nodes are in each other's transmission range and their velocities are constant and different from each other than there is also possibility that they will travel out of this range then Tp can be considered for equation 1. Some nodes always remain outside the PU activity region then there is no solution $\widehat{Tp}$ for equation 1. Once CU is detected in PU activity region by CR module then we don't need to predict link availability thus, $\widehat{Tp}$ is set to 0. This system consider situation where nodes are out of PU activity region.

Let, ρ = interference radius

$\Delta = \beta^2 + 4\alpha\rho^2 - 4\alpha\gamma$

To get one solution for equation 1 of $\widehat{Tp}$ we have $\Delta >= 0$. Consider $\widehat{Tp} >= 0$, the available time period Tp if counted from t_2 is,

$$\widehat{Tp} = \begin{cases} \dfrac{\sqrt{\beta^2+4\alpha\rho^2-4\alpha\gamma}}{2\alpha} - t_2 & \text{if } \Delta >= \beta^2 \\ \infty \end{cases} \qquad (2)$$

Preciseness depends on ρ, we can be derived by propagation model and measured received signal strength by time-of arrivals based distance measurement for indoor environment and GPS system for outdoor environment. Similarly probability L ($\widehat{Tp}$) to $\widehat{Tp}$ can be derived as,

$$L\,(\widehat{Tp}) \approx e^{-\lambda \hat{T}_p e^{-\lambda\tau}} + \zeta(1 - e^{-\lambda \hat{T}_p}) \qquad (3)$$

Where, τ and ζ are obtained by measurements. Then the pair [$\widehat{Tp}$, L ($\widehat{Tp}$)] can predict link duration corresponding to PU interference.

1) Link-Availability Prediction

Link is considered to be available if two nodes associated with link are within transmission range of each other and both are out of interference region of any PU. We consider Tp * L (Tp) routing metric to assist routing protocols in reliable path selection. But if Tp * L (Tp) > $\widehat{Tp}$ * L ($\widehat{Tp}$) then it suppress transmission. Thus, link available duration Ta should be set to,

$$T_a = \min_{i=1,2,\, j\in\{\mathrm{PUs}\}} \left\{ T_p * \mathrm{L}(\mathrm{T}_p), \hat{\mathrm{T}}_{pi}^{j} * L(\hat{\mathrm{T}}_{pi}^{j}) \right\} \tag{4}$$

Where, i = associated with 2 ends of link
{PUs} = all PUs in network
i, j = indicates boundary of link i.e. if any end moves in PU activity region then link becomes unavailable.
Thus, Ta is cognitive feature enabled which considers node mobility and PU activity region.

B. Distributed Topology Construction

Based on link prediction, topology control and routing scheme is proposed. In wireless network, topology control is introduced to save energy consumption. In CR-MANETs due to CU mobility and PU activity region causes frequent rerouting and thus results into low end-to-end network performance. Thus to solve this problem more reliable topology is constructed in CR-MANETs.

New link reliability metric is defined for topology control. In CR-MANETs rerouting penalty denoted by δ is the period that occurred by rerouting is one of the metric. Rerouting penalty reduces link availability to (Ta - δ). In CR-MANETs it is requires fewer rerouting if selected path consists links of longer Ta and higher quality. Link weight can be estimated as, $w = r * (Ta - \delta)$
Where, r = link data rate, δ = rerouting penalty
Here δ is converted into capacity loss r* δ during available period. Traffic carrying ability of link is represented by link weight. Path weight can be defined as,
$W = \min w_i \quad i \in L$
Where, L = all links along the path
In proposed scheme, focus is on to transmit more data traffic before link failure. Topology construction is three step process: Neighbor collection, path search and neighbor selection. For CR-MANETs to preserve end-to-end reliable paths, distributed cognitive algorithm uses enhancement of Localized Dijkstra Topology Control (LDTC) algorithm. With this distributed algorithm, each node performs following functions as an initial node.

a) Neighbor Collection:
Exchange local information within all its neighbors and calculate edge weight as, $w = r * (Ta - \delta)$

b) Path Search:
For initial node set path weight to infinity and to zero for neighbors. Mark initial node as current one and all neighbors as unvisited.
Calculate path weight by using following equation, from initial node to unvisited nodes. According to change in path weights update the records.
$W = \min w_i \quad i \in L$
Then mark the current node as visited, and set the unvisited node with largest path weight as the current node. Until all nodes get visited repeat from step b).

c) Neighbor Selection:
Once all reliable paths from initial node are found, select first hop neighbors from initial node along these paths.

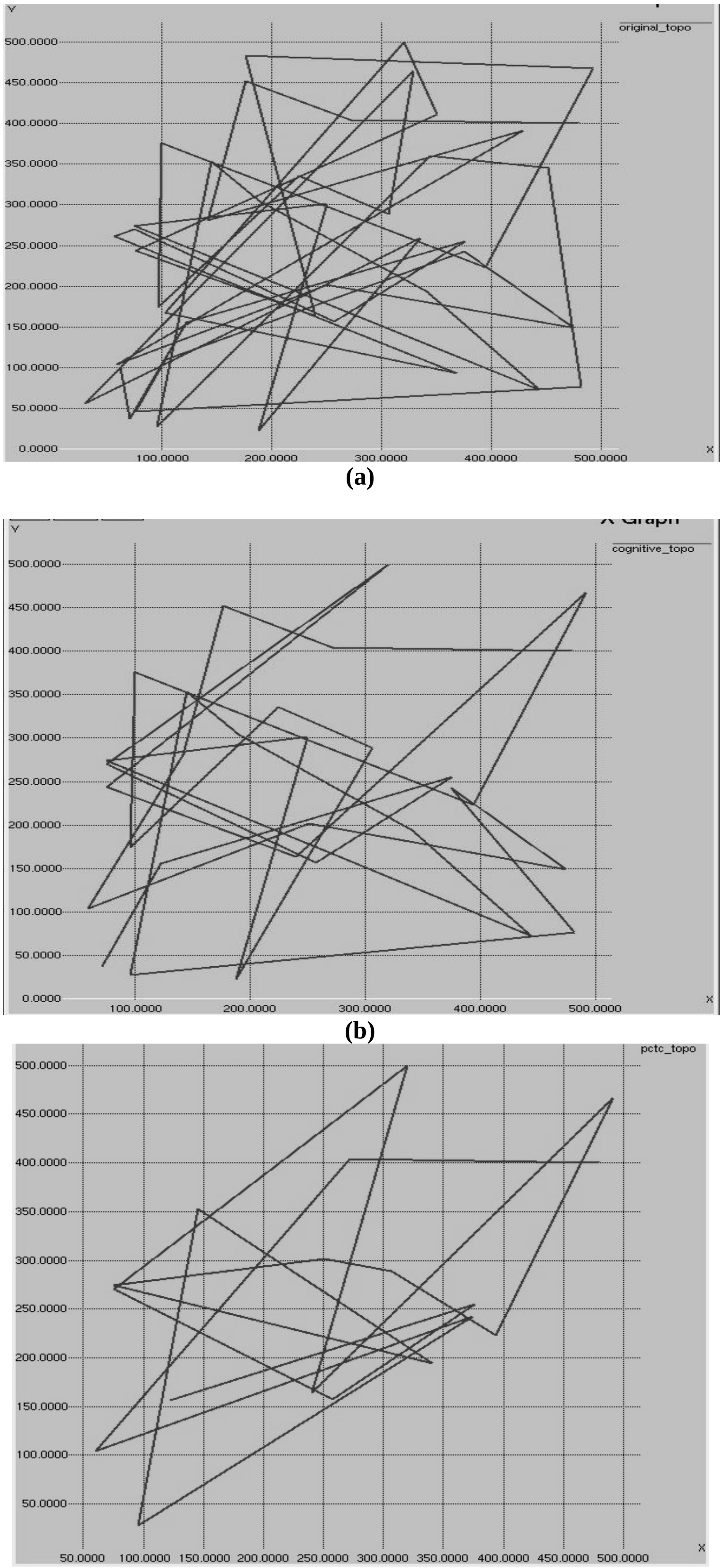
C. Routing on Resulting Topology

With link prediction, routing in CR-MANET considers both CU mobility and PU activity region. It makes routing adaptive to mobile environments by considering reliable paths. For example, with DSR and AODV routing protocols, node sends RREQ packets to find path from source to destination. When RREQ reaches an intermediate node, it may drop if transmitter does not exist in neighborhood relationship. Otherwise this RREQ is disposed by intermediate node and rebroadcast. Thus as a result, links in PU activity region or poor quality are avoided. With predicted link durations, performance of topology control can be evaluated.

IV. Simulation Results

The proposed scheme is evaluated using computer network simulator tool. In this random wireless environment nodes are moving randomly in a 2-D space. IEEE 802.11 is used for MAC layer. The performance evaluation of PCTC is plotted in Fig.2. Simulation results are in area 600×500m2 with 45 mobile CUs. The original topology shows that the link between 2 nodes exists whenever they are in each other's transmission range. In original topology PU awareness is not considered. Whereas, in Fig.2 (b) and Fig.2 (c) shows that with cognitive link duration Ta, links around PU are avoided for communication. Thus the resulting topology makes reliable paths available for communication.

We run simulation 50 times. Fig. 3 (a) shows proposed topology has small average node degree and small maximum node degree as compared to without topology control mechanism. The small node degree simplifies route-discovery process by reducing no. of RREQs and at same time it also reduces contention in shared wireless medium. Fig. 3 (b) shows topology control algorithm also results into longer link-durations. Thus the proposed topology provides cognition capability to avoid interference to PUs activities, which in turn provides adaptive routing over proposed topology in CR-MANETs.

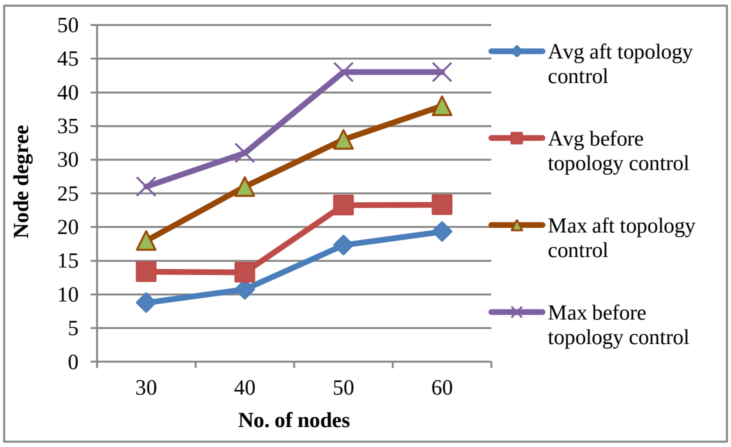


(a)

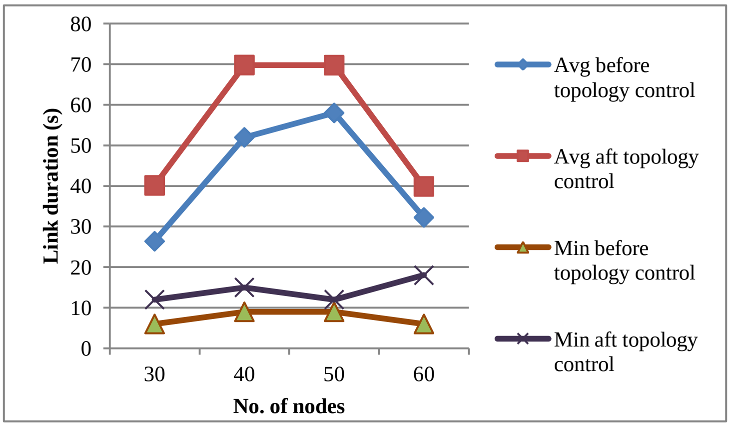
(b)

(c)

Fig. 2 Topology comparison (a) Original Topology (b) Topology with cognitive link-prediction (c) Prediction Control Adaptive Topology Control resulting topology.



(a)



(b)

Fig. 3 Properties of resulting prediction based topology (a) Node degree (b) Link duration

V. Conclusion

Thus proposed system provides cognition capability to routing protocols in CR-MANETs which takes care of PU activities as well as CU mobility. With last longer links, reliable topology is constructed which makes protocol adaptive to mobility environment. With resulting topology, rerouting is reduced which increases overall end-to-end performance.

References

[1] I.F. Akyildiz, W.-Y. Lee, M.C. Vuran, S. Mohanty, “Next generation/dynamic spectrum access/cognitive radio wireless networks: a survey”, Computer Networks 50 (13) (2006) 2127–2159. doi: 10.1016/j.comnet.2006.05.001.

[2] A. Sampath, L. Yang, L. Cao, H. Zheng, “High throughput spectrum-aware routing for cognitive radio based ad-hoc networks”, in: 3th International Conference on Cognitive Radio Oriented Wireless Networks and Communications, Crwown-Com 2008

[3] G.-M. Zhu, I. Akyildiz, G.-S. Kuo, “STOD-RP: a spectrum-tree based ondemand routing protocol for multi-hop cognitive radio networks”, in: IEEE Global Telecommunications Conference, GLOBECOM 2008.

[4] A. Abbagnale, F. Cuomo, “Gymkhana: a connectivity- based routing scheme for cognitive radio ad hoc networks”, in: IEEE Conference on Computer Communications, INFOCOM 2010, pp. 1U5, doi:10.1109/ INFCOMW.2010.5466618.

[5] I. Filippini, E. Ekici, M. Cesana, “Minimum maintenance cost routing in cognitive radio networks, in: Mobile Adhoc and Sensor Systems”,2009, MASS Š09. IEEE 6th International Conference on, 2009, pp. 284U293, doi: 10.1109/MOBHOC. 2009.5336987

[6] K. Chowdhury, M. Felice, “Search: a routing protocol for mobile cognitive radio ad-hoc networks”, Computer Communications 32(18) (2009) 1983-1997

[7] K. Yang and Y. Tsai, “Link stability prediction for mobile ad hoc networks in shadowed environments, T in Proc. IEEE GLOBECOM, San Francisco, CA, Nov. 2006, pp. 1U5

[8] S. Jiang, “An enhanced prediction-based link availability estimation for MANETs,T IEEE Trans. Commun., vol. 52, no. 2, pp. 183U186, Feb. 2004.

[9] Quansheng Guan,Shengming Jiang,“Prediction Based Topology Control and Routing in Cognitive Radio Mobile Ad hoc Networks”, November 2010

[10] M. Cesana et al.,“Routing in cognitive radio networks: Challenges and solutions”, Ad Hoc Netw.(2010), doi:10.1016/j.adhoc.2010.06.009