*IOSR Journal of Computer Engineering (IOSR-JCE)*
*e-ISSN: 2278-0661,p-ISSN: 2278-8727, Volume 19, Issue 3, Ver. V (May - June 2017), PP 16-22*
*www.iosrjournals.org*

# Effect of PUs Mobility in CRAHNs using an Activity and Mobility Based Routing Protocol

Faisal Awad Mahgoub [1], Hussein A. Elsayed [2], Salwa El Ramly [3], IEEE Senior
*Electronics & Communication Eng. Dept., Ain Shams University, Cairo, Egypt*

***Abstract*** *: Cognitive Radio (CR) is capable to identify the unused spectrum in order to allow Cognitive users (CUs) to occupy it without interfering the primary users (PUs). Routing in Cognitive Radio Ad-Hoc Networks (CRAHNs) is a very challenging task due to diversity in the available channels. In this paper, Mobility and Activity Based Routing Protocol (MABRP), is proposed. In the proposed protocol, CUs discover next hops based on the collected spectrum and mobility information. In addition, using cooperative communication mechanisms to reveal new routing opportunities, enhance route qualities, and enable true coexistence of primary and secondary networks is investigated. The performance of MABRP and Cognitive Ad-hoc On-demand Distance Vector (CAODV) are evaluated on the basis of packet delivery ratio (PDR), end-to-end delay, routing overhead, and hop count in two different scenarios: mobile PUs scenario, and static PUs scenario. The availability of a routing channel dynamically varies in time due to the changes of the PUs relative positions. The performance evaluation is carried out using NS2 simulator. The simulation results proved that MABRP achieves better performance in terms of average PDR, with a slight increase in overhead and end-to-end delay in low PUs activity compared to CAODV routing protocol.*

***Keywords:*** *Cognitive Radio, CRAHNs, CAODV, MABRP, Routing Protocols.*

## I. Introduction

Cognitive Radio networks (CRNs) are considered the enabling technology of the Dynamic Spectrum Access (DSA) paradigm which is envisaged to solve the current spectrum scarcity problem, thus facilitating the accommodation of new wireless services as well as providing an effective solution to the ever increasing user's demand [1-3]. CRNs are two types according to their architecture: infrastructure based networks and ad-hoc based networks. Ad-hoc based networks are also called Cognitive Radio Ad-Hoc Networks (CRAHNs). Users of infrastructure based CRNs connect with each other via an infrastructure, like access point. Unlikely in CRAHNs, CUs connect with each other in an ad-hoc manner i.e., there is no access point present. In CRAHNs, the available spectrum also known as Spectrum Opportunity (SOP) is divided into multiple channels. CUs try to access those channels which are currently not occupied by any PU.

The main concept of Cognitive Radio Ad- Hoc Network (CRAHN) [4] is that, in a wireless ad hoc network, the CUs are allowed to access the temporally unused licensed spectrum bands for data communications without harmful interference to the PUs. With unique characteristics of CRAHNs, the traditional ad- hoc routing protocols are not suitable to apply in the networks and new several challenges [5-6] must be taken into account. Similar to the ad-hoc networks, CRAHN is a temporary network where the CUs are mobile and PUs are static and/or mobile. Due to the unpredictable nature of ad-hoc network, reactive routing performs better than other approaches in this network [7]. Moreover, the activity of PUs is unpredictable; they are active in an On-Off manner. By analyzing these issues, we can consider that reactive routing approach will also be the suitable choice for CRAHNs. Furthermore, most of the routing solutions for CRAHNs in literature are provided through reactive approach [8].

The rest of the paper is organized as follows. In section II, we review the related work, while section III presents the proposed protocol. The implementation of the Common Control Channel (CCC) on MABRP is presented in Section IV. In section V we discuss Link expiration time calculation, while section VI provides the network architecture model and the related assumptions. Section VII describes the NS-2 simulator and Cognitive radio cognitive network (CRCN) patch used in simulation. The simulation results and performance evaluation are presented in Section VIII. Finally, concluding remarks are drawn in Section IX.

## II. Related Work

The Multi-hop Single-transceiver Cognitive Radio network routing Protocol (MSCRP) was proposed in [9]. This routing scheme addresses some challenges, which are dynamicity of channel availability, lack of a fixed common control channel (CCC) and minimization of the channel switching delay and back-off delay. A mechanism is designed to interchange control information of routing protocol among CUs without a common control channel. This mechanism is embedded in the routing framework. It maximizes the throughput of each flow through achieving a balanced tradeoff between the channel switching delay and back-off delay. The SpEctrum Aware Routing for Cognitive ad-Hoc networks (SEARCH) [10] is based on geographic forwarding principles. According to the proposed protocol routing and channel selection decisions are performed by avoiding PU active regions. The key functionality in the proposed scheme is to evaluate when the coverage region of the PU should be circumvented, and when changing the channel is the preferred option.

The Cognitive Ad-hoc On-demand Distance Vector (CAODV) is a reactive routing protocol based on the Ad-hoc On-demand Distance Vector (AODV) protocol and is designed for operation in mobile CRAHNs to improve the reliability of the spectrum sensing in CAODV, the cooperative approaches can be used at the physical layer. The CUs should be able to exploit the spectrum diversity without causing excessive overhead for route formation [11]. Zhu, Akyildiz, and Kuo [12] proposed the Spectrum Tree based On Demand Routing Protocol (STOD-RP) in order to simplify channel and route selection. This routing scheme addresses some challenges, such as the dynamicity of channel availability, lack of fixed CCC and integration of route discovery with channel decision. A more recent work proposed a method called joint path and spectrum diversity in cognitive radio ad hoc networks, named Dual Diversity Cognitive Ad-hoc Routing Protocol (D2CARP). In the D2CARP, the authors proposed a joint exploitation of a path and spectrum diversity for effective use of spectrum in cognitive radio ad-hoc networks. By jointly exploiting both diversities, CUs can move dynamically to different paths and spectrum bands for communicating with each other in the presence of PU activity [13]. The mobility-assisted routing algorithm with spectrum awareness (MARSA) [14] was proposed to select relays based on both the probability that a node meets the destination and the chance of the existence of at least one available channel when they meet. MARSA, which was mainly motivated by analyzing the real-world phenomenon and trace data of human mobility habits, is based on the deduced rule that the approximately regular PU behaviors result in the approximate regularity of the mobility of the spectrum that could be available for CUs.

In [15], the authors proposed an adaptive delay tolerant routing protocol (ADTRP) for cognitive radio mobile ad-hoc networks to find a stable sequence of instances of the mobile graph and the communication topology of interest such that the number of transitions from one instance of the topology to another in the sequence is the global minimum. The average lifetime of the mobile graphs in the stable sequence found by the ADTRP algorithm would serve as an upper bound (benchmark) for any communication topology that spans all the CUs found by any centralized or distributed algorithm. In [16], an optimal routing metric for cognitive radio ad-hoc networks, referred to as OPERA, is proposed. OPERA is designed to achieve optimality and accuracy. OPERA exploits the route diversity provided by the intermediate nodes to measure the actual end-to-end delay, by taking explicitly into account the unique characteristics of cognitive radio networks. In [17], the authors introduced a Fault-Tolerant Cognitive Ad hoc Routing Protocol (FTCARP) as a fast and efficient route recovery in the presence of path failures during data delivery in CRAHNs. In FTCARP, a backup path is immediately utilized in case a path failure occurs over a primary transmission route.

In [18[, a new direction of jointly exploiting path and spectrum diversity is explained for efficient use of spectrum in CRAHNs. By jointly exploiting both the diversities, CUs can switch dynamically to different paths and spectrum bands for communicating with each other in the presence of space and frequency-varying PU activity. S. Chinnasamy and R. Vadivel [19] proposed an Energy Efficient Spectrum Aware Channel Sensing Routing Protocol (EESACSRP) to minimize energy cost for channel sensing so as to prolong lifetime of the network. In [20], Routing Protocol for Cognitive Radio Ad Hoc Network (ROPCORN) and Weight Cumulative Expected Transmission Time (WCETT) routing protocols used to address the efficient route selection between the source and destination in a Cognitive Radio Ad-Hoc Network (CRAHN). In [21], a multipath activity based routing protocol for cognitive radio network (MACNRP) is proposed. The proposed protocol utilizes channel availability and creates multiple node-disjoint routes between the source and destination nodes. The proposed protocol is compared with D2CARP and FTCRP protocols.

## III. Mobility And Activity Based Routing Protocol (MABRP)

Compared with classical ad-hoc networks, a routing path in CRAHNs is particularly unstable. Routing path formed over multiple links may experience disconnections caused not only by the mobility of CUs but also by the activity and mobility of PUs as well. A link is considered available if the two CUs associated with this link are within the transmission range of each other and the spectrum used on this link is also available. It is desirable that CR routing should favor links with higher link availability so as to improve the path stability. Link availability in MABRP is considered through calculating the Link Expiration Time (LET) which is proposed to be used for forward looking in link selection.

A CU calculates its LET value on the basis of its link status with its previous hop node, as will be explained in section V. Naturally, the source does not have a valid LET value as it does not have any previous hop node. Therefore, when the route discovery mechanism is initiated by the source CU node, the source CU node broadcasts an RREQ (Route Request) packet with a high value of LET. In general, after receiving an

RREQ, an intermediate CU node calculates its distance from the previous hop CU node and the distance between PU node as well as the time that two CUs are expected to have an active route between them without a disconnection ($LET_1$), and the time before a CU moves into the PU activity region ($LET_2$) respectively. After that, the intermediate CU retains the minimum of these two LET values and re-broadcasts the RREQ packet by inserting the minimum LET value in its RREQ packet header. This process continues until an RREQ packet reaches its destination. This routing metric always gives emphasis to the best LET value path. However, if two or more paths have the same LET value, then the path with the lower hop count is chosen. Thus, if the destination node receives an RREQ packet from a different path with a better LET value, then it regenerates the RREP (Route Reply) packet and sends it to the source node. After receiving the RREP, the source node updates its routing table and starts sending data.

## IV. Common Control Channel (CCC) And MABRP

A CCC in CR networks is a medium allocated in a portion of spectrum commonly available to two or more CUs for control message exchange. The CCC allocation can be temporary or permanent in a licensed or unlicensed band to facilitate various CR network operations such as transmitter-receiver handshake, neighbor discovery, channel access negotiation, topology change and routing information updates, and cooperation among CUs [10]. In MABRP, CUs show their existence by broadcasting control messages on the CCC for neighboring users in the proximity to maintain the contact and network connectivity. Moreover, CUs can cooperate and share their spectrum sensing data with each other by using the CCC to improve the detection of PUs. More importantly, CUs need to inform each other about PU activity and mobility changes, spectrum availability, and network topology in order to improve the CR throughput and spectrum efficiency. Thus, it is essential to investigate the CCC reliability issues and provide novel CCC solutions to address these new challenges in MABRP.

## V. Link Expire Time (LET) Calculations

When a certain amount of data is required to be transmitted using a CRAHN, some data is lost due to the handoffs and/or link breakages due to PUs activity or mobility. To avoid this loss of data, a reliable link should be formed; this link must survive the time taken for transmitting the data size as given at a definite rate of data flow supplied by the CRAHN.

In this section, a description of MABRP based LET routing metric is presented. The LET for the two scenarios: the dynamic PUs case where both PUs and CUs are mobile and the static PUs case where only CUs are mobile.

### A) Dynamic PUs Scenario:

Fig. 1 shows two mobile CUs I and J with their radio ranges, r. The current locations of I and J are I ($x_{i1}$, $y_{i1}$) and J ($x_{j1}$, $y_{j1}$), respectively. I and J are moving with velocities $v_i$ and $v_j$, and angles $\Phi_i$ and $\Phi_j$, respectively. Their future locations are I ($x_{i2}$, $y_{i2}$) and J ($x_{j2}$, $y_{j2}$) after some time duration, t. We are assuming that nodes I and J are not changing directions within this time duration t. Then, the amount of time two CUs will stay connected, is predicted by the formula given by (1).

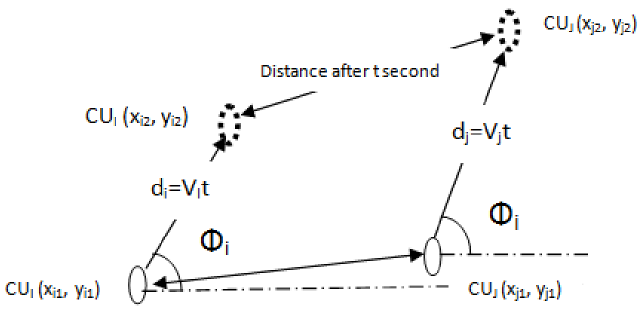


**Fig.1:** Two CUs Movement diagram after t seconds

$$LET_1 = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2} \qquad (1)$$

where $a = v_i\cos\Phi_i - v_j\cos\Phi_j$ , $b = x_i - x_j$ , $c = v_i\sin\Phi_i - v_j\sin\Phi_j$ , $d = y_i - y_j$.
where r: CU transmission range.

Similar to Fig. 1, to avoid PU interference, the distance between CU and PU is also calculated (distance between $CU_i$ and $PU_j$). Before a node moves into the PU activity region, a second parameter $LET_{2d}$ is calculated as given in (2), when the distance between CU and PU equal to PU transmission range.

$$LET_{2d} = \frac{-(ab+cd)+\sqrt{(a^2+c^2)D^2-(ad-bc)^2}}{a^2+c^2} \qquad (2)$$

where $a = v_i \cos\Phi_i - v_j \cos\Phi_j$ , $b = x_i - x_j$ , $c = v_i \sin\Phi_i - v_j \sin\Phi_j$ , $d = y_i - y_j$ .
where D: PU transmission range.

The link prediction is obtained by combining $LET_1$ and $LET_{2d}$.

**B) Static PUs Scenario:**

In this scenario we assume that all the PUs are static and all CUs are dynamic as in scenario A. The $LET_1$ between two moving CUs can be calculated as shown in (1) and the $LET_{2s}$ between moving CU (I) and static PU (J) is predicted by the formula given by (3).

$$LET_{2s} = \frac{-(ab+ck)+\sqrt{(a^2+c^2)d^2-(ak-bc)^2}}{a^2+c^2} \qquad (3)$$

where $a = v_i \cos\Phi_i$, $b = x_i - x_j$, $c = v_i \sin\Phi_i$ , $k = y_i - y_j$ .
where d is the PU transmission range.

The link prediction is obtained by combining $LET_1$ and $LET_{2s}$.

In the two scenarios, the Supply Time (ST), would be the minimum of both the link times $LET_1$ and $LET_2$.

$$ST = \min [LET_1, LET_2].$$

where $LET_2$ is $LET_{2d}$ for scenario A and $LET_{2s}$ for scenario B.

## VI. Network Architecture Model

In Fig. 2 we consider a CRAHN consisting of n CUs and m PUs. The PUs coexist in an overlapping region with the CUs, share K licensed data channels (DCs). We assume that each PU holds licenses for specific spectrum channels and can only utilize their assigned channels. The channel k is busy when its licensed holder arrives and accesses it while the channels can be used by CUs when PUs are not present. We assume that there is also a CCC available for all CUs to cooperate in spectrum sensing and to know all the information about the PUs.

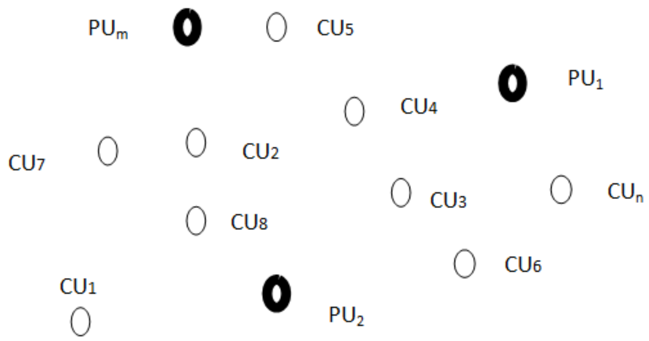


**Fig.2**: Network Architecture Model

## VII. NS-2 Simulator And Cognitive Radio Cognitive Network (CRCN) Patch

Simulations are carried out using Network Stimulator- 2 (NS-2) version 2.31[22] having additional patch of Cognitive support CRCN (Cognitive Radio Cognitive Network) [23]. CRCN stimulator is a software based network stimulator for cognitive network stimulations. It depends on open-source NS-2, CRCN stimulator which aids in performance evaluations for the specific dynamic spectrum resource allocation, power control algorithms and the adaptive Cognitive Radio CR) networking protocols which contain the CR MAC and the CR Routing protocols. CRCN works on NS-2 to develop realistic traffic and topology patterns. For every node in CRCN an adaptive and changeable multi-radio multi-channel PHY layer is available by tailoring the spectrum parameters like the transmission power, propagation etc.

## VIII. Simulation And Performance Evaluation

In this section, the performance of the MABRP and CAODV protocols are simulated by NS-2.31 [22] based on the CRCN integrated simulator [23] to evaluate the network performance. During simulation, PUs and CUs are distributed randomly across an area size of 1000x1000 $m^2$ with 60 moveable CUs and (2, 4, 6, 8, 10, 12, 14) PUs nodes. The nodes of each network are able to communicate with each other in the same network using the IEEE 802.11 MAC layer protocol. The number of licensed channels is set to 10, and the propagation model is the Two-Ray Ground one. In dynamic PUs Scenario, CUs were made to move at two different velocity types, low velocity (LV) and high velocity (HV) and PUs were made to move at different velocity types as shown in Table 1.

**Table 1:** Simulation mobility ranges

| CUs and PUs mobility type | CUs and PUs velocity |
|---|---|
| Dynamic PUs Scenario | PUs velocity range( 1 m/s - 4 m/s) |
| Low Average Velocity(LV) | 80% CUs velocity range( 0.5 m/s - 3 m/s) |
| | 20% CUs velocity range( 8 m/s - 10 m/s) |
| High Average Velocity(LV) | 80% CUs velocity range( 8 m/s - 10 m/s) |
| | 20% CUs velocity range( 0.5 m/s - 3 m/s) |

The simulation time is set to 500 seconds. Each simulation is repeated ten times and then the average values of the results are taken to ensure integrity. The four indicative performance metrics are considered in measuring and comparing the performance of the MABRP with CAODV. Those metrics are PDR, average end to end delay, routing overhead, and hop count. PDR is the ratio between the number of received packets by the destination and the total number of packets sent by the source at the end of each simulation. The average end to end delay is defined as the span of time required by a packet to reach from source to destination. It includes all possible delays that occur while buffering during route discovery latency, queuing at the interface queue. The hop count refers to the number of intermediate CUs (like routers) through which data must pass between source and destination. The routing overhead is defined as the number of routing packets "transmitted" per data packet "delivered" at the destination. The performance of routing protocol MABRP and CAODV are evaluated by multiple random topologies where CUs are placed in an area of 1000x1000$m^2$. Table 2 summarizes the simulation parameters.

**Table 2**: Simulation parameters

| Parameter | Values |
|---|---|
| CUs number | 60 |
| PUs number | (2,4,6,8,10,12,14) |
| CU transmission range | 120 m |
| PU transmission range | 300 m |
| Radio-propagation model | Two-Ray Ground |
| Area ( M*M) | 1000*1000 |
| Traffic type | CBR |
| Packet size | 512 bytes |

In the first scenario (dynamic PUs), the simulation results compare the performance of MABRP with that of COADV, as we are dealing with the effect of mobility in a CR network; we have chosen speed (meter/second) of the CUs and PUs mobility as a variable while measuring the performance of the protocols. We have compared our MABRP with the original CAODV for the four performance parameters. From Fig. 3-a, it can be seen that the PDR decreases as the number of PUs increases. This is due to the increase of the activity (PU is in ON state) of PUs, which reduces the number of available frequency channels for CUs. Also, it can be noted that MABRP protocol is better than CAODV in all the scenarios; this is due to the use of reliable paths with low probability of PUs activity. MABRP produces around 69–40 % PDR, while CAODV produces around 60-34%. With high CUs mobility, MABRP produces around 57–32 % PDR while CAODV produces around 53-25 %. This result proves that the implementation of MABRP algorithm improved the routing mechanism of CAODV by reducing the loss of data packets. Fig. 3-b shows the relation between the average end-to-end delays versus the PUs. The delay tends to increase as the number of PUs increases especially in low and moderate PUs activities and tends to decrease in high PUs activities. This behavior can be explained directly by investigating the number of hops which decreases as PUs activities increase, also it is observed that the number of CUs node reachable decreases as the number of PUs increases (around 83% when the number of PUs equal to 2, 71% when the number of PUs equal 6, 58% when the number of PUs 10, and about 49% when the PUs number reaches to 14). These behaviors are reasonable due to the increase of probability of collision between the PUs and CUs connections. The results of overhead versus number of PUs are shown in Fig. 3- c. It is clear that the CAODV protocol has a higher overhead than MABRP protocol. This is due to the fact that the CAODV uses extra control packets during the route maintenance phases, especially at high PUs activity. Fig. 3-d shows that the average hop count decreased from moderate to low levels especially at high PUs activity because the packets delivered are mainly those sent when the CUs destinations are very close to the sources, as confirmed by the average value of the hop count metric, roughly 3.

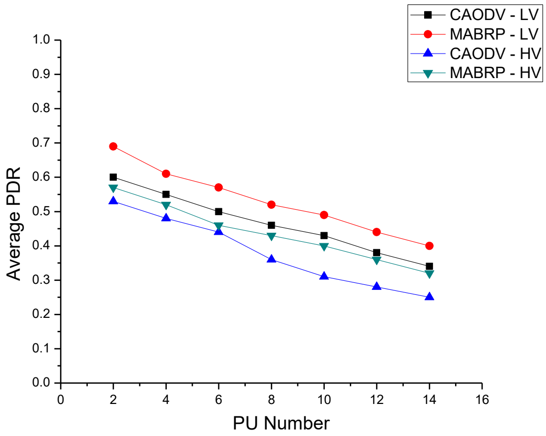


Fig. 3-a: PDR vs. PUs number

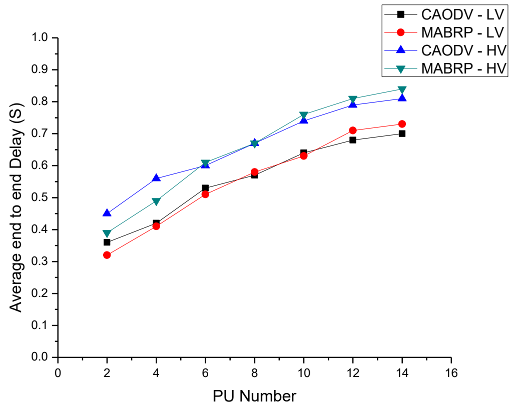


Fig. 3-b: Delay vs. PUs number

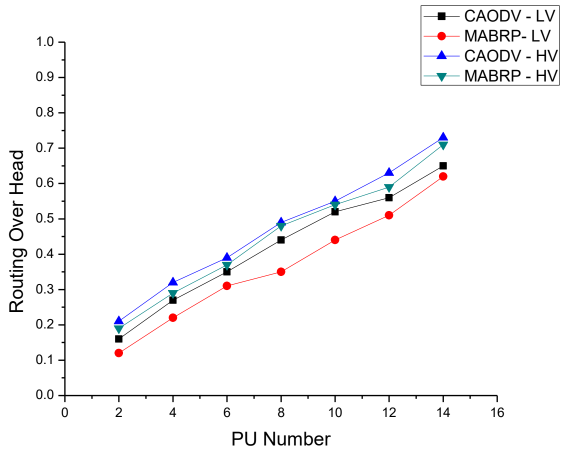


Fig. 3-c: Routing over head vs. PUs number

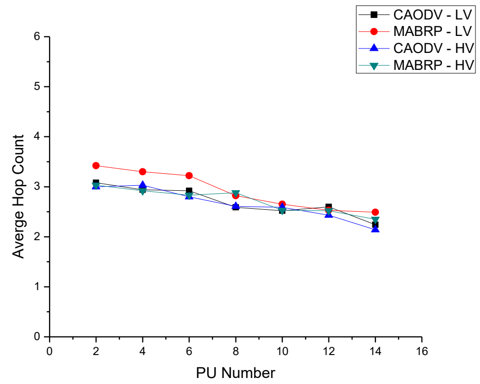


Fig. 3-d: Hop count vs. PUs number

In the second scenario (static PUs), the results compare the performance of MABRP with that of COADV, as was mentioned in the first scenario, the number of link failures is increasing with the increase of the number of PUs. So, packet delivery ratio is decreasing in both MABRP and CAODV as illustrated in Fig. 4-a, but the values of PDR is better than the first scenario (MABRP produces around 87–55 % PDR, while CAODV produces around 80-47%. At high CUs mobility, MABRP produces around 78–45 % PDR while CAODV produces around 70-39 %), because the link failure in static PUs is affected only by CUs mobility and PUs activity while in first scenario the PDR is affected also by the mobility of PUs. Figs. 4-b and 4-c show that the end-end delay and routing over head are increasing with increasing PUs number, while the hop count decreases as depicted in Fig. 4-d.

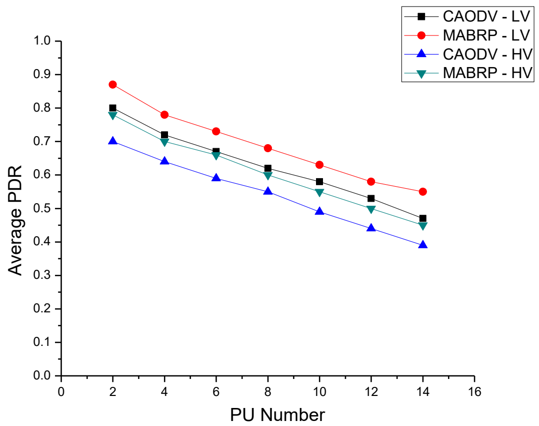


Fig 4-a: PDR vs. PUs number

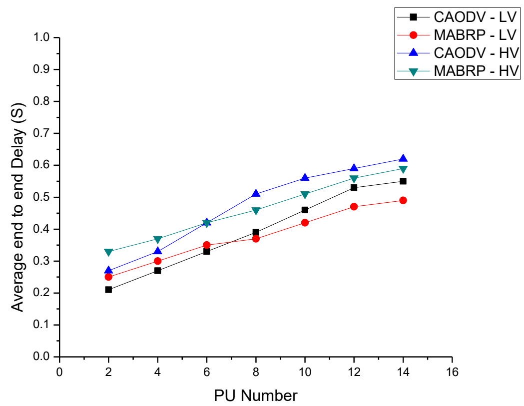


Fig. 4-b: Delay vs. PUs number

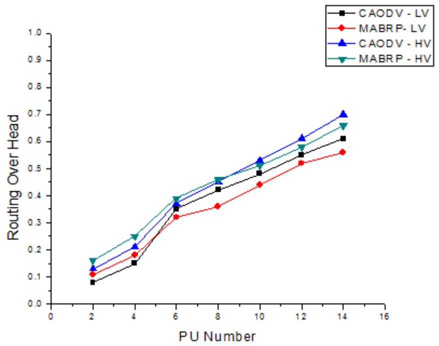

Fig. 4-c: Routing over head vs. PUs number

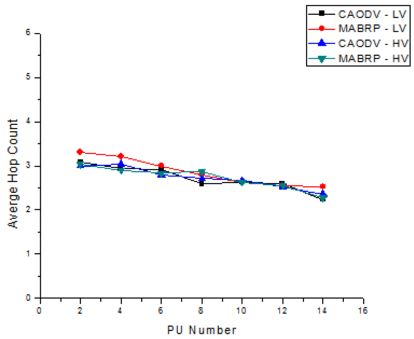

Fig. 4-d: Hop count vs. PUs number

## IX. Conclusion

This paper described the details of operation of the MABRP under two different scenarios, dynamic PUs and static PUs. MABRP protocol succeeds to establish reliable path between the source and destination CUs with PUs and CUs activity and mobility. In MABRP a new approach to reduce packet loss due to inevitable link failures in CRNs is presented. Through simulations, we showed that, the MABRP protocol increases the PDR with little routing over head and delay especially in low PUs activity. Also, the proposed protocol reduced the number of failed paths in case of PUs mobility compared to CAODV.

## References


[1]. Haykin, S.: Cognitive Radio: Brain-Empowered Wireless Communications. IEEE Journal on Selected Areas in Communications, 23(2), 2005, 201–220.

[2]. IF Akyildiz, WY Lee, MC Vuran, M Shantidev, "Next generation/ dynamic spectrum access/cognitive radio wireless networks: a survey". Computer Networks, 50(13), 2006, 2127-2159.

[3]. Mitola, J.: Cognitive Radio Architecture Evolution. Proceedings of the IEEE, 97(4), 2009, 626–641.

[4]. Akyildiz, I.F., Lee, W.-Y., Chowdhury, K.R.: CRAHNs: Cognitive Radio Ad Hoc Networks, Ad Hoc Networks, 7(5), 2009, 810–836.

[5]. Cesana, M., Cuomo, F., Ekici, E.: Routing in Cognitive Radio Networks: Challenges and Solutions. Ad Hoc Networks, 9(3), 2011, 228–248.

[6]. Sengupta, S., Subbalakshmi, K.P.: Open Research Issues in Multi-hop Cognitive Radio Networks, IEEE Communications Magazine, 51(4), 2013, 168–176.

[7]. Md. Afatur Rahman, Farhat Anwar, J. Naeem, and M.S.M. Abedin, A simulation based performance comparison of routing protocol on Mobile Ad-hoc Network (proactive, reactive and hybrid). International Conference on Computer and Communication, (ICCCE 2010), Kuala Lumpur, Malaysia, 11-13 May, 2010.

[8]. S.M. Kamruzzaman, E. Kim, and D.G. Jeong, Spectrum and energy aware routing protocol for cognitive radio ad hoc networks. In Proceedings of IEEE International Conference on Communications (ICC), Kyoto, Japan, 2011, 1-5.

[9]. H. Ma, L. Zheng, X. Ma, and Y. Luo, Spectrum aware routing for multi-hop cognitive radio networks with a single transceiver. In Proceedings of 3rd international conference on cognitive radio oriented wireless networks and communications (CROWNCOM), Singapore, 2008, 1-6.

[10]. K.R. Chowdhury and M.D. Felice, "SEARCH: A routing protocol for mobile cognitive radio ad-hoc networks," Elsevier Computer Communications, 32(18), Dec. 2009, 1983-1997.

[11]. Angela Sara Cacciapuoti, Cosimo Calcagno, Marcello Caleffi, and Luigi Paura, "CAODV: Routing in Mobile Ad-hoc Cognitive Radio Networks," ieeexplore.ieee.org, wireless days 2010 IFIP.

[12]. G.M. Zhu, I.F. Akyildiz, and G.S. Kuo, STOD-RP: A spectrum tree based on-demand routing protocol for multi-hop cognitive radio networks. In Proceedings of global telecommunications conference (GLOBECOM), New Orleans, LA, 2008, 1-5.

[13]. M. Rahman, M. Caleffi, and L. Paura, "Joint path and spectrum diversity in cognitive radio ad-hoc networks," EURASIP Journal on Wireless Communications and Networking, 1(2012), 2012, 1–9, doi: 10.1186/1687-1499-2012-235.

[14]. Huang J., Wang S., Cheng X., Liu M., Li Z., Chen B. Mobility-assisted routing in intermittently connected mobile cognitive radio networks. IEEE Trans. Parall. Distrib. Syst., 25(ISSUE 11), 2014, 2956–2968.

[15]. L. Indhumathi, and R. Vadivel, "Adaptive Delay Tolerant Routing Protocol (ADTRP) for Cognitive Radio Mobile Ad Hoc Networks," International Journal Computer Applications (0975–8887), 128(6), 2015, 1-6.

[16]. M. Caleffi, I.F. Akyildiz, and L. Paura, "OPERA: Optimal Routing Metric for Cognitive Radio Ad Hoc Networks," IEEE Transactions on Wireless Communications, 1(8), 2012, 2884-2894.

[17]. Zamree Che-aron, Aisha Hassan Abdalla, Khaizuran Abdullah and Md. Arafatur Rahman "FTCARP: A Fault-Tolerant Routing Protocol for Cognitive Radio Ad Hoc Networks" KSII Transactions on Internet and Information Systems, 8(2), 2014, 371-388.

[18]. Priyank Mishra and Vimlesh Kumar "A Survey on Routing Protocol for Dynamic Activity of Primary User," International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT), Chennai, India, 2016.

[19]. S. Chinnasamy and R. Vadivel, " Energy Efficient Spectrum Aware Channel Sensing Routing Protocol for Cognitive Radio Mobile Ad-Hoc Networks", International Journal of Computer Applications (0975 – 8887), 157(3), January 2017, 31-36.

[20]. Yashoda Krishna Lenka, "Performance Analysis of ROPCORN and WCETT Routing Protocols in Cognitive Radio Ad-Hoc Network (CRAHN)," International Journal of Advanced Research in Computer and Communication Engineering, 5(Issue 11), November 2016, 68-72.

[21]. Shereen Omar, Osama El Ghandour, and Ahmed M. Abd El-Haleem, "Multipath Activity Based Routing Protocol for Mobile Cognitive Radio Ad Hoc Networks," Wireless Communications and Mobile Computing, vol. 2017, Article ID 5380525, January 2017, 12 pages, doi.org/10.1155/2017/5380525.

[22]. "CRCN simulator" http://stuweb.ee.mtu.edu/~ljialian/, 2009.

[23]. "The Network Simulator NS-2," http://www.isi.edu/ nsnam/ns/, 1996