An Opportunistic Routing Protocol for Mobile Cognitive Radio Ad hoc networks

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Abstract- Cognitive radio, an upcoming technology gives the solution for the scarcity of spectrum where the transmitter acts as a sensible device which behaves as per the surrounding environment. A group of devices, which follows this technology, forms a temporary network called mobile cognitive radio ad hoc networks. The widely known ad hoc networks are always in moving fashion and there is no need for central abstraction in collecting the data. In such networks, formation of route(s) to the destination becomes a leading problem. In Cognitive Radio ad hoc Networks (CRAHNs) a challenging problem is to design the routing metric and also to reduce the packet drop. This problem arrives due to the usage of traditional routing in CRAHNs. Opportunistic routing - a new routing paradigm has been used as an alternate for maximizing the packet delivery ratio. The paper discusses about the routing protocol called CRCN CORMEN discusses about packet delivery ratio, reduces delay in a cooperative way among the nodes, when compared to the traditional Cooperative communications. The proposed protocol is evaluated and compared through NS2 simulation. The result indicates a high performance due to opportunistic routing and the evaluation is shown through by using xgraph.

Keywords – Cognitive radio ad hoc networks; Opportunistic routing; Cooperative communication; routing; packet delivery ratio;

I. Introduction

To solve the problems of using the traditional wireless networks in cognitive radios a cutting edge technology has been formed, called cognitive network. The cognitive network is different from cognitive radio as the network consists of all layers in the Open System Interconnection model other than layer 1 and layer 2 of cognitive radio. Earlier cognitive network [1] is defined as the network that has cognitive process which can recognize the network condition, plan to make decisions, act on particular conditions, understand from its actions and observe the end to end goal. However this definition does not provide full detail knowledge of the network explicitly. The definition can be rewritten as “Cognitive network [2] is to be viewed as a network of communication that is improved by a knowledge plane that extends across layers horizontally and through technologies vertically”. Thus the Cognitive radio network is a composite heterogeneous wireless network that includes continuous dynamics and discrete events.

Cognitive networks (CRN) can be explained in detailed [3] as it is the network which utilizes both the wireless station and radio spectrum resources in an opportunistic manner depending on the resources that is available. Cognitive radio (CR) is the fundamental technology to utilize the unused spectrums available. It has been identified as the important fifth generation wireless networks. The Transceiver developed using cognitive radio uses the spectrum channel opportunistically and form the Opportunistic cognitive network. In CRN networks, two users are available. One is the primary user (PU) and other is the secondary user (SU). The SUs occupies the unlicensed spectrum without disturbing PUs, a licensed spectrum user. To identify the available spectrum either the PU informs about the spectrum usage to SU or the cognitive user (CU)(otherwise called as SU) by itself has to discover the free spectrum spaces by means of direct sensing of licensed bands [3]. All the SUs can communicate among themselves in an ad hoc fashion. In addition to this, designing a network for such users is very difficult in the wireless networks.

To overcome the existing problem of spectrum leasing given in [4], an alternate solution for wireless networks where a common model is used for sensing and to avoid receiver interference is given in [5]. Interference at the receiver is also discussed in [6] and [7] using the frequency reuse concept. It is well known that such leasing of standard spectrum are always priced [8] thereby influencing an idea called cooperative communication. The needed qualities of service requirements are made to satisfy in exchanging the cooperation of secondary users [8] using the part of leased primary users are accepted. Opportunistic routing means, only one node will be receiving the message, sent from the source. That node may be close to the destination or might know about the closest node to the destination. This routing is preferred in order to avoid redundant information passing in the networks.

By the process of opportunistic routing the above said cooperation between primary user and secondary user, the multi-hop transmission can be accomplished [9]. By making use of the channel range given by the ease of use of possible multi-hops these process goals at maximizing the throughput in multi-hop networks. Based on the feedback generated from the decoder [9], [10], the next hop is selected thereby focusing the channel conditions for the required packet. If the channel condition seems to be poor or it cannot withstand till the transmission from end to end then another appropriate hop is chosen for transferring the packets [10].

Practically, in a Cognitive Radio Ad hoc Network with multi radio system it is necessary to make the routing factors at the top of the opportunistic links. Since the lacking of complete understanding of this link is failed, end to end transmission is also not reliable. Moreover, the availability of local node also changes from time to time and hop by hop. To overcome this, dynamic routing algorithm is proposed with the Cognitive Radio Ad hoc Networks. By performing joint routing, scheduling, and transmit power control the routing algorithm aims to increase the packet delivery ratio [9].

Here in this paper, Cooperative Opportunistic Routing protocol for Cognitive radio MANET (CRCN CORMEN) protocol, under multi-hop wireless networks are investigated in depth. When compared to the conventional wireless networks by combining the opportunistic routing and the opportunistic spectrum access, it is proved that an improvement in the quality of wireless communication has been found [16]. The main aim of this paper is to decrease the packet drop rate of secondary users and to reduce the average delay that occurs during the generation of packets,as well as at the destination side. The evaluation is done in opportunistic process. Similar to CORMAN, CRCN CORMEN protocol too acquires concepts like Batch_Size, Size of the Forwarder List, Packet_Number, Forwarder_Number, Batch_Array, and subset of packets called fragment. To show the increase in performance and analysis, network simulator (NS2) is used.

The rest of the paper is presented as follows. In section II the related work of this approach is given in detail. System implementation model is described elaborately in section III. In section IV we described the performance of our work through simulation and finally the paper concludes in section V.

II. LITERATURE REVIEW

Over past years many techniques related to the work are presented and the main work related to the proposed scheme is considered. Based on cooperation and opportunistic routing a mechanism [11] of leasing of spectrum is planned for the purpose of coexistence between the primary and secondary network. Based on the availability of certain primary nodes the source and destination of primary network is communicated. By using the process of opportunistic routing for each transmission the succeeding node is selected through the feedback of decoder of the previous transmission. At the time of leasing of spectrum the secondary node is used as the next hop for the primary network and thus maintains the quality factors. This results in throughput gain and energy expenditure in primary network for different tradeoffs. *David Chiarotto, et al* done the analysis by using Markov chain tools.

Lei Ding, et al in their paper describes that the main challenge in cognitive radio network is the throughput maximization [12]. The local nodes change their topology for time period and also changes from hop to hop. To overcome this problem cross layer opportunistic spectrum access and dynamic routing algorithm is proposed. Through this process the throughput maximization is better aimed. During the transmission of packets from the source to destination this routing algorithm allocates resources to increase the links capacity so that the packets reach the destination without any interference problem and also it guarantees bounded bit error rate to the receiver. The other goal of this algorithm is to increase the stability of the links there by giving priority to the links that long lasts during transmission. This process is distributed and efficient and this model is evaluated and observed to be low delay, maximum throughput and better allocation of bandwidth.

Another challenging problem in cognitive radio networks is the designing of the routing path appropriately. *Osamah S. Badarneh, et al* in their paper concludes that the connectivity of the network and routing is significant based on the spectrum channel availability time and the transmission time required in a multi hop cognitive radio network. If the transmission time is higher than the required channels availability time then this spectrum handoff results in the degradation of cognitive radio network performance. If such case happens then termination of cognitive radio transmission through primary user results in the decrease of throughput. To overcome this drawback a novel routing method is introduced [13] that can consider both the availability time and the transmission time as its requirement. Due to this process from the source to destination maximum probability of success is achieved. The better performance of their algorithm can be viewed clearly from their simulation result.

Di Li et al describes that the connectivity and the reliability of ad hoc cognitive radio networks [14] remains as a challenge with the availability of channel those changes are with space and time among cognitive nodes. To support synchronized switching of channel and to simplify the routing in ad hoc cognitive radio network an approach to overcome the above drawback is performed by clustering the nearby cognitive radio nodes that enables cooperative spectrum sensing. Even though the primary node that lies in the cluster may get disappeared which results in the loss of connectivity during transmission. By using planned way of cluster formation this problem can be diminished to some extent. To improve the inter cluster connectivity and intra cluster connectivity and thereby strengthening the reliability of the clusters here in this work two algorithm namely distributed and light weight algorithm have been discussed. A comparison with the relative work numerical evaluation shows better improvement targeted by both the algorithm on the reliability.

Yongkang Liu et al investigates the cognitive routing coupled with spectrum sensing and sharing in a multi-channel multi-hop cognitive radio network. To improve the performance of transmission under each step, to recognize the network spectrum dynamics [15] in cognitive radio network an opportunistic cognitive routing protocol is proposed from which the users can make use of the geographic information and can identify the local nodes access possibility. The secondary user on the basis of location information and channel usage information selects the next hop in a distributed manner and its transmission is adapted to the dynamic spectrum access possibility in its neighborhood. To evaluate the potential relay gain and to capture the exceptional properties of cognitive radio networks of each candidate, an additional novel metric is introduced. To reduce the complex search of the optimal solution for channel and relay, a heuristic algorithm is proposed. Simulation results are given to demonstrate that the proposed work well adapts to the spectrum dynamics and outperforms existing routing protocols in CRN.

Zehua Wang et al describes about a protocol called CORMAN which works based on the Cooperative Communications among the mobile nodes in ad hoc networks [16]. By using a source routing protocol, transmits the data packet to the destination. This protocol works well in the Mobile ad hoc networks. The work given in [17] is an extended version of Cognitive AODV protocol. CAODV follows the traditional routing mechanism in the cognitive radio networks. E-CAODV [17] functions in the same way similar to CAODV, with the difference that the PUs is used for transmitting the data packets, to help the SUs and there is no link failure for spectrum for the SUs. The PUs works in a Cooperative manner.

Ranjana Pathak et al introduces an integrated pattern is given in [19] which combine both the opportunistic protocol in the traditional routing protocol for wireless mesh networks. Accumulation of packets occurs at the source when there is no exact route to the destination. In situation, an alternative path has to be found by forwarding the request packet to a node, which may be close to the destination. The simulation results shows that the proposed protocol achieves better performance than the traditional routing protocol.

III. IMPLEMENTATION OF CRCN CORMEN PROTOCOL

A multi hop Cognitive Radio Network with a set of primary users and secondary users are considered [16]. A cognitive source and a destination node are used for our proposed work. Packets can be transferred through relay nodes from the source to destination node. These relay nodes are available in the form of cooperative nodes. These nodes transfer the required packets from source to destination without interference problem and also perform reliable transmission. In our model main focus lies on the selection of reliable nodes that can transfer packet without loss of data. This is performed by the previous analysis of node status. Our system is designed in a way so that even if number of packets gets increased the general result of overloading can be prevented through effective channel allocation. In our system to achieve high performance, by diminishing the interference problem and linkable problem the following models are used to implement.

They are,

- Source routing
- Information Sharing
- Cognitive radio network

Here the proactive source routing is implemented initially then large scale live updates are successfully processed separately. Finally the above two stages are implemented in the cognitive radio networks to achieve our targeted aim. This is explained briefly in the following section.

A. SOURCE ROUTING

In this method of source routing, this is proactive where the routing table is constructed based on the path of transmission. The routing table consists of the information about the number of nodes and the average number of neighboring nodes. The routing table formed is based on the analysis of the transmission path and the nodes that participate in the transmission. For particular source and destination reliable path is identified through the data stored in the routing table based on the previous transmissions. From the data obtained through the table further transmission is occurred. For the proposed work, the routing protocol used is: Dynamic Source Routing (DSR) [18]. DSR protocol maintains a routing table for their forwarding purpose.

B. INFORMATION SHARING

Through information sharing i.e sharing the updates about the routes, the reliability and safety transmission of packet can be ensured. Based on the feedback obtained from the above routing protocol [18] transmission of nodes is monitored. If in a particular section certain nodes seem to be unreliable that is it gives poor transmission or packet loss then that node will be replaced with the node that can withstand longer with better results. Through this approach these active nodes are largely updated periodically so that it results in better transmission of packets. The priority is given to the node that transmits many numbers of packets with reliability and the updation is done for every transmission.

C. COGNITIVE RADIO NETWORK

Cognitive radio (CR) is a type of wireless network in which a transceiver can smartly identify the communication channels which are in use and which are not, and instantaneously travel into vacant channels by avoiding occupied ones. This efficiently makes use of available radio frequency (RF) spectrum by minimizing interference to other users. The above mentioned stages will work well in the common traditional adhoc networks, CORMAN[16]. Both these stages are used in our proposed work of mobile cognitive radio ad hoc by the routing process which is carried out on the basis of the feedback from previous transfer process and it is derived from the table created by information sharing stage where reliable nodes are updated instantly. Due to this process performance of the system increases when compared to previous CORMAN system which follows few concepts like batch size, forwarder list size, packet number, forwarder number, etc. The performance of the proposed system (CRCN CORMEN) is explained in the forthcoming sections. A sample CRAHN setting is given in the Fig. 1.

The proposed work consists of 38 nodes, which are in random nature. The working of CRCN CORMEN protocol can be better explained with the help of the following nodes Node 1,4, 11,9,15,22. All the six nodes are SUs and form the CRAHN network. The first three nodes are source nodes whereas the remaining three nodes are destination nodes. The control packets sent from the source reaches the destination in a cooperative way.

Eg. In the Fig.1, Node 11 is the source and Node 22 is the destination. The Node 3 is considered as the closest node to the destination, so it forwards the control packet to it neighbor, Node 33. Now, node 33, which has moved so near to Node 22, retransmits the message sent by the source node 11. Thus these four nodes follow cooperative communication among themselves.

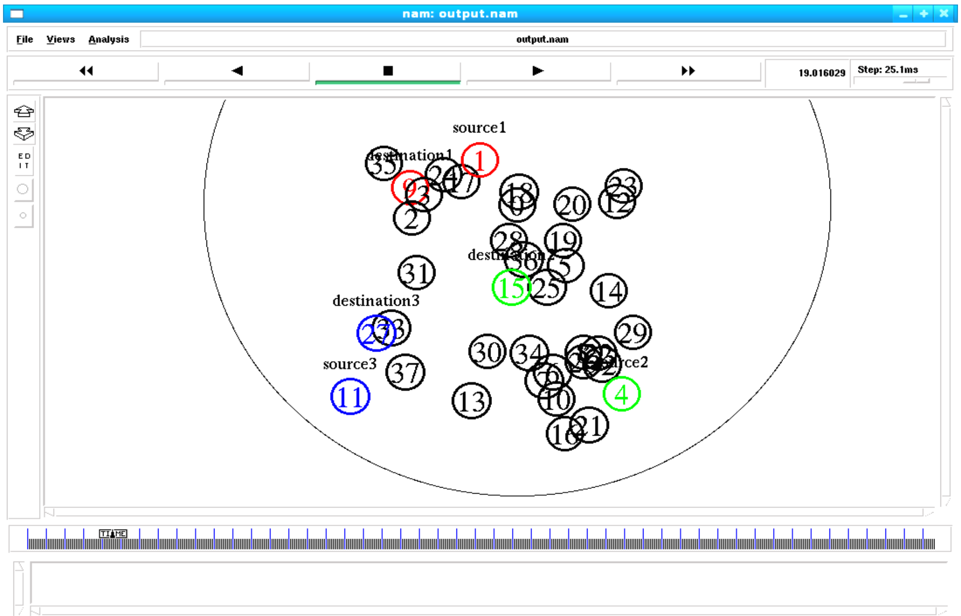

Fig. 1 CRAHN Scenario for the proposed work

In the proposed work, a group of nodes are considered and called as forwarder nodes. Each forwarder node will be assigned with a forwarder number [16]. The forwarder nodes are named as f1,f2,f3,etc. In Fig.1 Node 33 and 37 are forwarder nodes. For retransmitting the message, few nodes are considered, namely retransmitting node and these nodes are named as r1,r2,r3 etc. A retransmitter node, retransmits the message, if it satisfy certain specification: (i) Node r must be nearby to a forwarder path, (ii) the distance between the forwarder nodes should be not equal and (iii) the ‘r’ node must uses the RSSI (Received Signal Strength Indicator) value inorder to ensure the quality of its retransmission. The node ‘r’ should carry the missed out packets of the preceding nodes. In order to know about the packet passage in the network, a parity ‘p’ is used. This parity will be lies between the values of 0 to 2(L-1), i.e p(0≤ p≤ 2(L-1), L is the number of nodes in the forwarder list.

IV. Performance Evaluation

The performance of the system is evaluated based on the transformation of packets using few parameters like packet delivery ratio (PDR), speed, number of nodes, number of request packets, delay, etc. Based on the speed and movement of number of nodes for effective transformation of every distance of five meter determines the performance of the system. If the number of packets to be transfer increases then it results in overload generally. This rate of getting overloaded is examined with both MANET and CRCN CORMEN separately and then both are compared for evaluating better performance among them.

One of the methods is to calculate the ratio between the numbers of packets send to the number of packets received. The difference if calculated is minimum then performance will be higher. The other method is calculating the routing overhead. Routing overhead is done on the basis of the time taken to transmit the packet. In our system this is illustrated using graph. The performance of the CORMEN and CRCNCORMEN is is simulated using NS2 (version 2.34), the proposed protocol is evaluated and graph is plotted. This proves the better performance of the proposed protocol. To have a better clarity, CORMAN protocol is mentioned as CORMEN in the work. The experimental settings for the ns2 simulator are given in the following table, Table1.

Table 1. Experimental Settings used in the proposed work

Parameter	Value
Simulation Time	20 min(1200 sec)
Simulation Area Size	1000 * 1000 m
No of Nodes	38
Traffic used	CBR
Mobility Model	Random Way model
Packet size	512 bytes
Packet Interval	0.01
Queue Length	220
MAC Layer supported	802.11

In the first graph, Fig. 2, it deals with the speed of the packets and required number of request packets. It is plotted having X- axis with measure of speed and Y with the request packets. Initially for the transfer of 1000 packets the speed for CORMEN is nearly half to the speed of CRCN, it gradually maintains the performance and finally when the number of packets arise to 4000 the performance speed of CORMEN is 10 percent less than the speed of CRCN CORMEN.

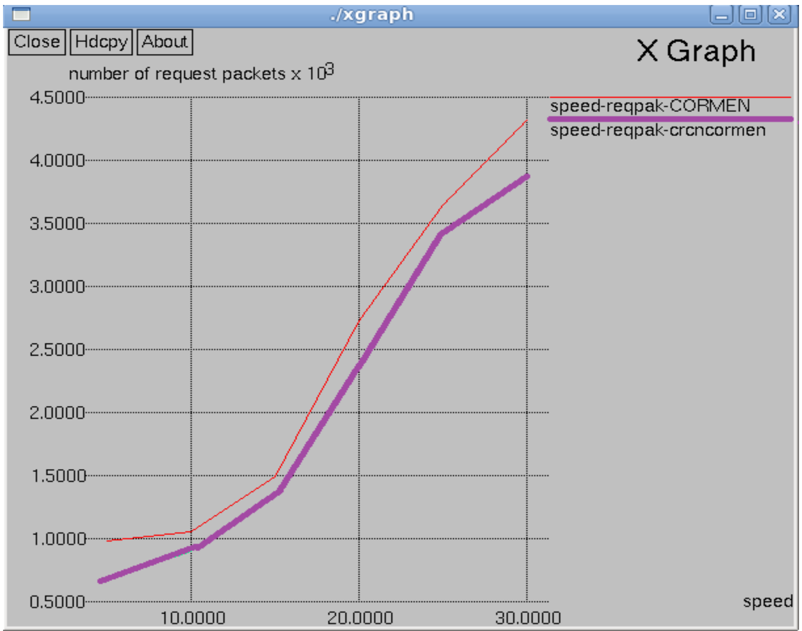

Fig 2. Speed Vs No. of Request packets

Graph 2 deals with the relation between the speed and the packet delivery ratio. It is plotted having X-axis with measure of speed and Y with the packet delivery ratio in percentage. When the speed is lower, ratio percentage is 100 for CRCN CORMEN whereas CORMEN do not achieve 100 percent ratio. When the speed slowly increased, packet delivery ratio decreases to the maximum percent in CORMEN and for the CRCN

CORMEN it is higher to it. The least delivery ratio of packet for CRCN CORMEN is 81 but for CORMEN it is reduced to 78 percent with the speed of 30. This graph evaluates the result that the performance of the CRCN CORMEN is much better when compared to CORMEN. This can be seen in Fig.3.

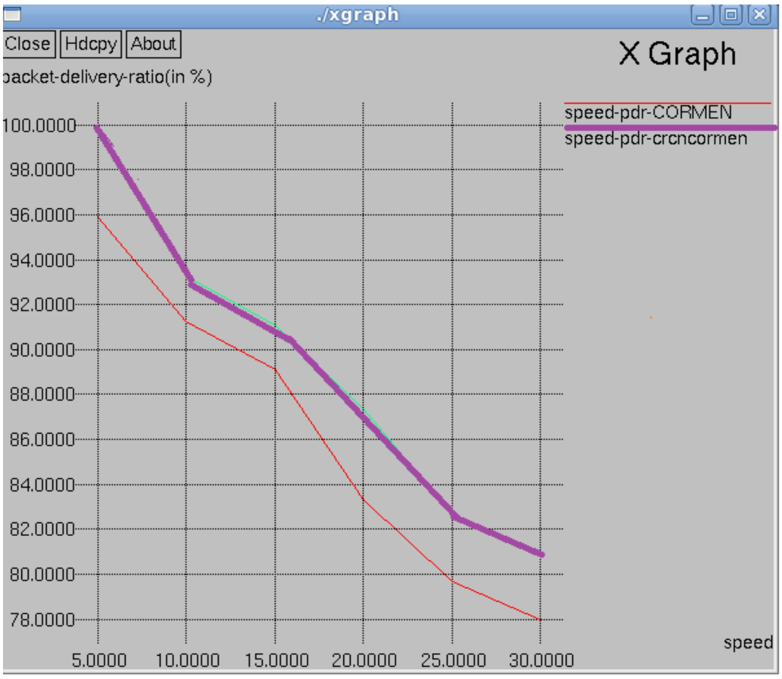

Fig 3. Speed Vs Packet Delivery ratio

Graph 3, Fig.4, deals with the number of nodes in X-axis and average delay in delivery of packets by seconds in Y-axis. When the number of nodes is low the CRCN CORMEN has more delay than CORMEN but as the number of node increases this situation becomes vice versa. For example from the graph for the number of 150 nodes CRCN CORMEN has the average delay of 95 seconds but CORMEN has delay of 98 seconds.

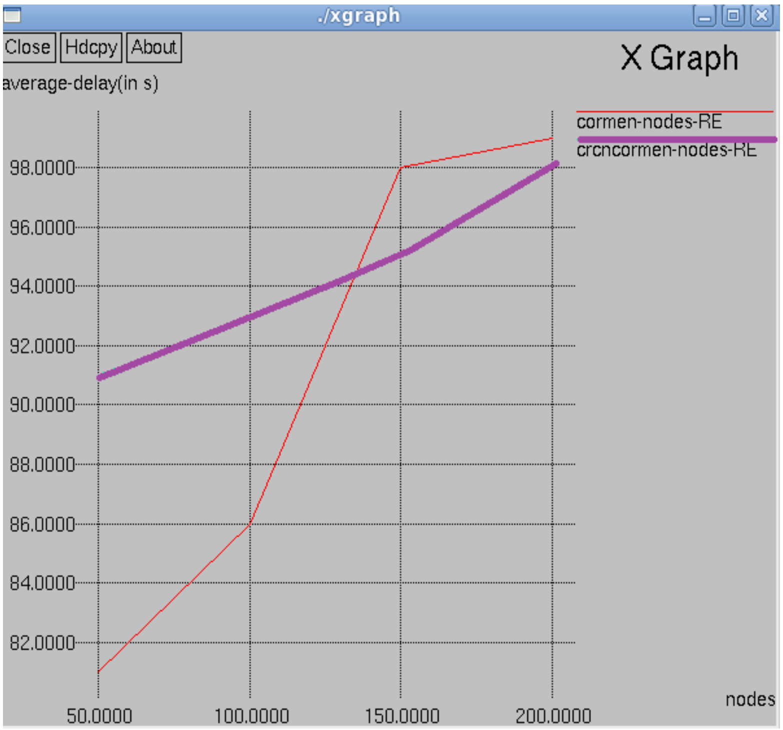

Fig 4. No. of Nodes Vs Average delay among the packets

In Graph 4 deals with the number of nodes in X-axis and average delay in delivery of packets by seconds in Y-axis. When the number of nodes is small the CRCN CORMEN has 0.3 seconds delay and CORMEN has 0.5 seconds delay. From the graph for the number of 100 nodes CRCN CORMEN has the average delay of 1.0 seconds but CORMEN has delay of 1.25 seconds. On increasing number of nodes for about 200 the CRCN CORMEN average delay is 1.8 seconds and for CORMEN it is 4.8 seconds. This shows, Fig 5, that there is an increase of 3 times in the speed of time of CRCN CORMEN when compared to CORMEN.

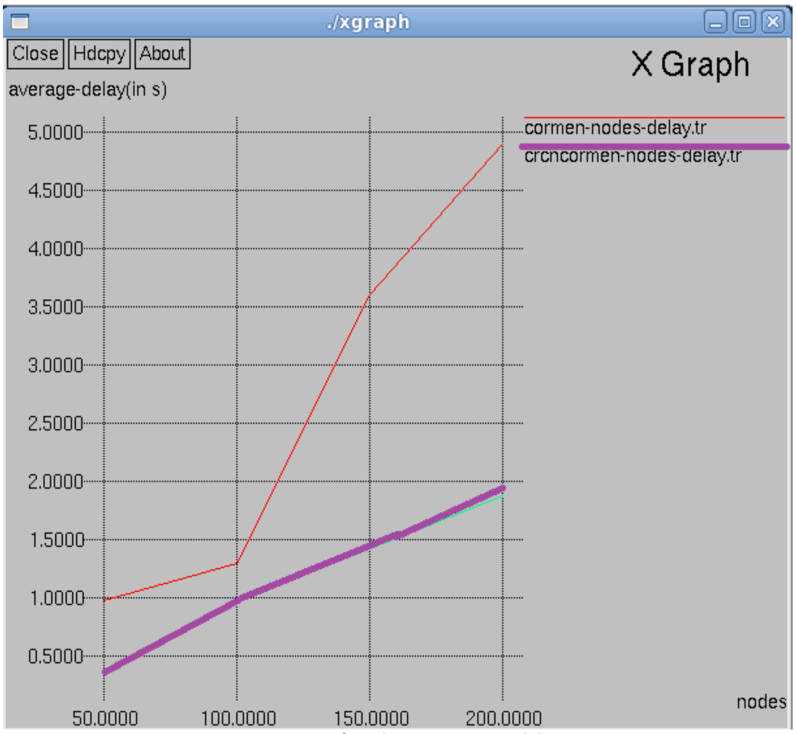

Fig 5. No. of Nodes Vs Average delay

In the following Graph 5 deals with number of nodes in X – axis and packet delivery ratio in Y – axis. From the graph CORMEN has the packet delivery ratio for nodes 50 is 88 percent and for the increasing number of nodes, the percentage reaches 94. But for CRCN CORMEN the number of nodes 50 starts at 94 percent and for every increase of nodes, the PDR increases to a maximum of 99 percent, can be referred in Fig 6.

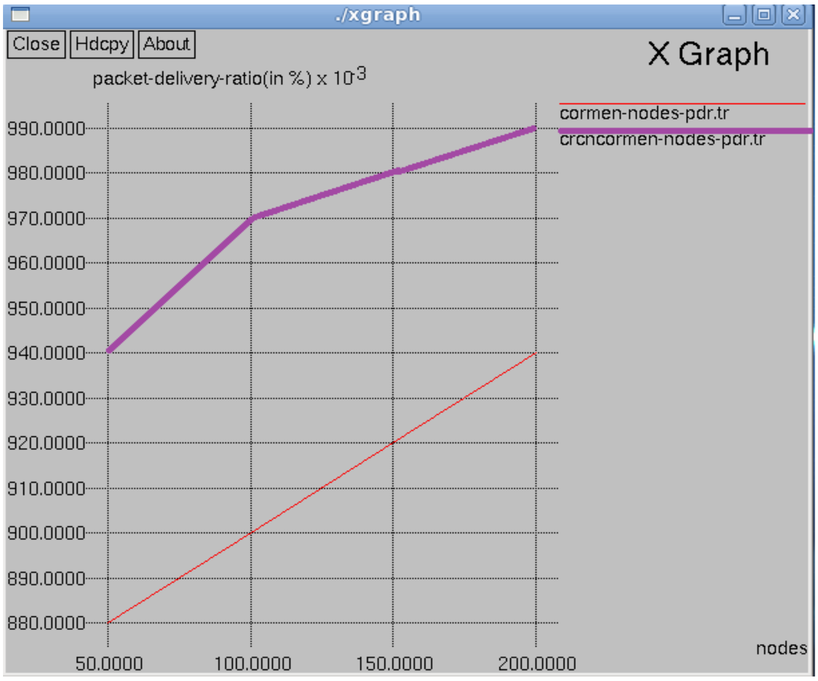

Fig 6. No. of Nodes Vs Packet delivery ratio

In the Graph 6, speed for the nodes is given in the X axis and the delay is in the Y axis. It is shown clearly that in the beginning, CORMEN delay starts at the rate of 1.17 seconds and CRCN CORMEN, the delay is very less. Once the speed is increased, both the protocol gradually increases the delay. CORMEN ends with a delay more than 2.3 seconds whereas CRCN CORMEN ends at > 2.1 sec and can be seen in the Fig. 7.

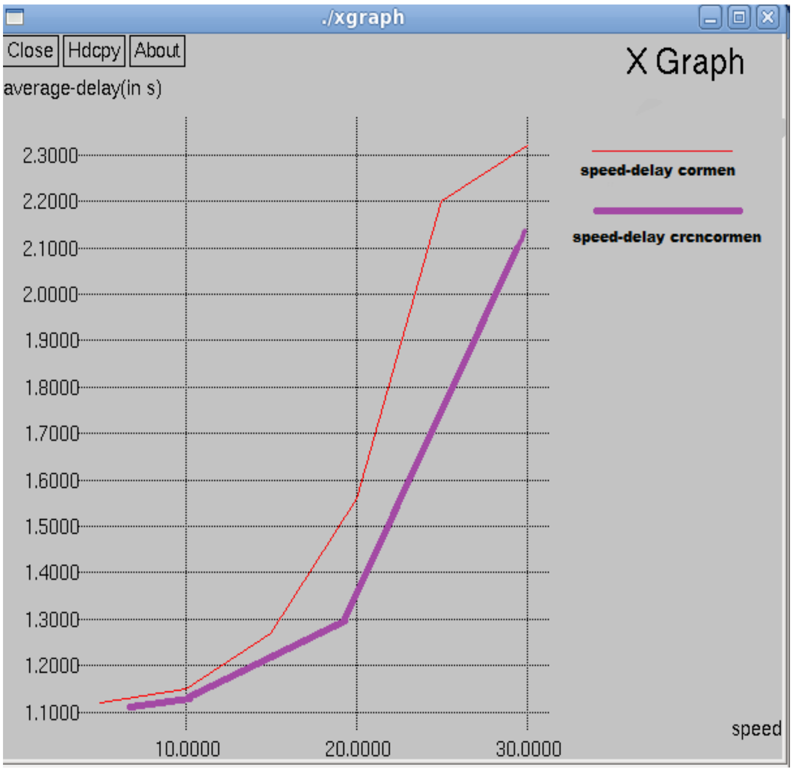

Fig 7. Speed Vs. Average delay

All these graphs depicts that the performance of CRCN CORMEN is always better than the performance of CORMEN. This proves that the Cognitive radio ad hoc network system results better in performance when compared to previous other systems.

V. Conclusion

In this paper discussion about the routing problems that exists in the protocol CORMAN, is dealt and applied for Cognitive radio ad hoc networks resulting in CRCN CORMEN protocol where the nodes work in a cooperative manner among the neighboring nodes for transformation of packets from the source to destination. By using CRCN CORMEN the average delay and packet delivery ratio is low and it is not up to the level. The CRCN CORMEN deals with the five parameters like packet delivery ratio (PDR), speed, number of nodes, number of request packets, and delay all are required for the transmission. The graph is plotted based on the simulation of CRCN CORMEN network for transfer of packets between primary and secondary users. All the graph acts as the proof for the better performance in the Cognitive radio networks. The Simulation for CORMEN and CRCN CORMEN has been shown and it results in better performance of CRCN CORMEN by having less average delay and high packet delivery ratio.

In the future, the work can be improved further by using different coordination scheme at different layers.

REFERENCES

[1] Ryan W. Thomas, Luis A. DaSilva, and Allen B. MacKenzie, "Cognitive networks," IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN) 2005, pp. 352 –360, Nov. 2005.
[2] Carolina Fortuna and Mihael Mohorcic, "Trends in the development of communication networks: Cognitive networks," Computer Networks, vol. 53, no. 9, pp. 1354–1376, June 2009.
[3] Liang Song and Dimitrios Hatzinakos, "Cognitive networking of large scale wireless systems," Int. J. Commun. Netw. Distrib. Syst., vol. 2, no. 4, pp. 452–475, June 2009.
[4] O. Simeone, I. Stanojev, S. Savazzi, Y. Bar-Ness, U. Spagnolini, and R. Pickholtz, "Spectrum Leasing to Cooperating Secondary Ad Hoc Networks," IEEE J. Select. Areas Communication , vol. 26, no. 1, Jan. 2008.
[5] I. Stanojev, O. Simeone, U. Spagnolini, Y. Bar-Ness, and R. Pickholtz, "Cooperative ARQ via auction-based spectrum leasing," IEEE Trans. Communication, vol. 58, no. 6, Jun. 2010.
[6] M. Cesana, F. Cuomo, and E. Ekici, "Routing in cognitive radio networks: Challenges and solutions," Elsevier Ad Hoc Networks, 2010, doi:10.1016/j.adhoc.2010.06.009.
[7] A. Sahai, N. Hoven, M. Mishra and R. Tandra, "Fundamental tradeoffs in robust spectrum sensing for opportunistic frequency reuse," Univ. Calif., Berkeley, CA, Tech. Rep., Tech. Rep., 2006.
[8] J. M. Peha, "Approaches to spectrum sharing," IEEE Communication Mag., vol. 43, no. 2, pp. 10–12, Feb. 2005.
[9] S. Biswas and R. Morris, "Opportunistic Routing in Multi-Hop Wireless Networks," ACM SIGCOMM Comput. Commun. Rev., Jan. 2004.
[10] M. Zorzi and R. Rao, "Geographic random forwarding (GeRaF) for ad hoc and sensor networks: multihop performance," IEEE Trans. Mobile Comput., vol. 2, no. 4, pp. 337–348, Oct. 2003.

[11] Davide Chiarotto, Osvaldo Simeone andMichele Zorzi "Spectrum Leasing via Cooperative Opportunistic Routing", IEEE Transactions on Wireless Communications, Vol. 10, Issue 9, pp 2960-2970, Sept 2011.

[12] Lei Ding, Tommaso Melodia, " Cross-Layer Routing and Dynamic Spectrum Allocation in Cognitive RadioAd HocNetworks", IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 59, NO. 4, MAY2010

[13] Osamah S. Badarneh and Haythem Bany Salameh "Opportunistic Routing in Cognitive Radio Networks: Exploiting Spectrum Availability and Rich Channel Diversity", IEEE Global Telecommunications Conference, December 2011, pp. 1 – 5.

[14] Di Li and James Gross, "Robust Clustering of Ad-hoc Cognitive Radio Networks under Opportunistic Spectrum Access", Ultra High-Speed Mobile Information and Communication (UMIC), German Research Foundation grant DFG EXC 89,2011

[15] Yongkang Liu, Lin X. Cai, " Spectrum-Aware Opportunistic Routing in Multi-Hop Cognitive Radio Networks", IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 30, NO. 10, NOVEMBER 2012

[16] Zehua Wang, Yuanzhu Chen, Cheng Li, "CORMAN: A Novel Cooperative Opportunistic Routing Scheme in Mobile Ad Hoc Networks", IEEE Journal on Selected areas in Communications, Vol 30, No.2, pp 289 – 296, February 2012.

[17] Nitul Dutta, Hiren Kumar Dev Sarma, "A Routing Protocol for Cognitive Networks in presence of Co-operative Primary user", IEEE International Conference on Advances in Computing, Communications and Informatics, October 2013, pp. 143 – 148.

[18] D Johnson, Y Hu, D Maltz, "The dynamic source routing protocol (DSR) for mobile ad hoc networks for Ipv4. (IETF RFC 4728, 2007). http://www.ietf.org/ rfc/rfc4728.txt. Accessed 24 January 2011

[19] Ranjana Pathak, Peizhao Hu, Jadwiga Indulska, Marius Portmann and Wee Lum Tan, "Towards efficient opportunistic communications: a hybrid approach", IEEE International workshop on the impact of Human Mobility in Pervasive Systems and Applications, March 2013, pp 255 – 260.