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Hybrid Proactive-Reactive Routing (HPRR) For Cognitive Radio Networks

S. S. Kulkarni
Electronics and Telecommunication Department Sinhgad College of Engineering Pune, India
kulk.shri@gmail.com

S. D. Lokhande
Electronics and Telecommunication Department Sinhgad College of Engineering Pune, India
sdlokhande.scoe@sinhgad.edu

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Abstract

Today, with the increasing popularity of Internet of Things (IoT), there is a huge demand of the wireless devices and is creating the problem of spectrum scarcity. On the other hand, spectrum utilization statistics says that the spectrum usage is inefficient causing white spaces; the unutilized portions of the spectrum. Dynamic spectrum usage with Cognitive Radio (CR) devices is the solution of these problems. But the variations in availability of spectrum pose many challenges in designing the protocols at all the layers of the protocol suite. Also, at network layer routing is much difficult. In this paper, a new routing scheme called Hybrid Proactive Reactive Routing (HPRR) for CR Networks (CRNs) has been introduced. It is implemented using clustering. The proposed algorithm is hybrid, as it considers the combination of proactive and reactive mechanisms. The algorithm is proactive by considering that it constructs a routing table by exchanging routing information, but if destination node goes beyond some specific number of hops then it keep the routing information with some in between node until and unless the destination node receives it. Here, far destination node receives it through route request and reply messages. Simulation results of HPRR show enhanced performance in terms of network characteristics like average end to end delay, average throughput and routing overheads. The performance of HPRR is compared against other two routing schemes in CRNs namely Adhoc On-demand Distance Vector (AODV) and Cluster based Cognitive Radio Routing Protocol with Link stability (C2R2M-LS).

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I. INTRODUCTION

The term "Internet of Things" (IoT) enables the connection of various things i. e. physical devices with the internet. Therefore not only computers or smart phones are connected to the internet but many other things like vehicles, cameras, toys, medical instruments, home appliances, industrial systems etc have also become active members of it. Thus, it is now a network of numerous heterogeneous devices in terms of types and sizes where all can communicate and share information.

IoT capable devices are interconnected through wired and wireless communication technologies. However, flexibility and ease of use make wireless communication has become a popular solution. Around 50 billion devices all over the world are expected to be connected on IoT by 2025 [1]. The whole world is moving towards the always connected situation from

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individuals to gadgets. Thus IoT is going to put tremendous burden on the wireless spectrum. This leads to the challenge of enhancing the network capacity. The network capacity can be increased with the help of designs using multiple channels. Multi-channel communication is the characteristic of the Cognitive Radio Networks (CRNs). It is the recommended that smart IoT objects should have cognitive capabilities so that the limited spectrum will be able to cater the demand of its usage.

Licensed and unlicensed are the two categories of wireless spectrum out of which the unlicensed spectrum in ISM (Industrial, Scientific and Medicine) is very small and is always crowded. Telecom companies take part in the auction process carried out by the governmental agencies and get license for the spectrum after paying for it. Thus the licensed spectrum gets distributed amongst various telecom companies which become license holders and then provide services to the end users. These users are called licensed users. This policy is called as fixed spectrum assignment policy.

As per detailed studies carried out by Federal Communications Commission (FCC), spectrum utilization fluctuates from 15% to 85% measured at various instants of time and various locations i.e. the spectrum is underutilized [2]. Thus, on one side researchers are working on increasing the capacity of the network while on the other side the spectrum is not fully utilized. Spectrum utilization can also be increased with the help of Cognitive Radio (CR) device that can change its characteristic parameters used for data transmission to work with different frequency bands. CR is a smart device which senses the spectrum holes (unused sections of the spectrum) and uses them opportunistically i.e. whenever licensed user becomes active, CR switches to some other spectrum hole. In CRNs, the devices using the assigned licensed frequency bands are called as Primary Users (PUs) and the devices using the frequency bands not assigned to them (cognitive users) are called as Secondary Users (SUs).

With the use of continuous changing spectral characteristics, research in CRNs has primarily been carried out in the physical and data link layers of protocol stack. In this paper, a new routing scheme called Hybrid Proactive Reactive Routing (HPRR) is proposed which address the above mentioned limitation. Working of HPRR is divided into three parts. In first part it goes for finding a reliable link for communication of SUs. In second part it goes for deciding Trustworthy Routing Relays (TRRs) which reduce the amount of routing information. And in the third part control messages are exchanged to find the one-hop and two-hop neighbors. As the name suggests HPRR is combination of both proactive and reactive approaches and gains advantages of both. Therefore it shows improved performance over two routing protocols in CRNs namely Cluster based Cognitive Radio Routing Mechanism with Link Stability (C2R2M-LS) and Adhoc On demand Distance Vector (AODV).

The rest of the paper is organized as follows. Survey of related research work is discussed in section II. System model, assumptions and notations used are given in section III. In section IV, detailed description of the novel routing mechanism HPRR is provided. Performance assessment of HPRR and comparison with AODV and C2R2M-LS is presented in section V. Section VI concludes the paper.

II. RELATED WORKS

A cross-layer design based routing method is introduced by Rojin Tizvar et al. [3]. It is for the CR Wireless Sensor Networks (CRWSN). This technique is collision aware and is energy efficient. It jointly considers route and spectrum selection. In first phase it goes for next hop

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selection and during second phase it carries out channel selection. It gives priority to the PU while selecting the spectrum. It reduces collisions by distributing equal number of frequency channels amongst adjacent nodes which results in reduction of retransmissions and energy consumption. It also reduces the packet delay in terms of hop cost.

Ghalib A. Shah et al. [4] have proposed a routing scheme for CRSN known as Spectrum aware Cluster based Energy Efficient Multimedia (SCEEM) routing. Issues like spectrum and energy are addressed in this scheme. In selection of route, number of nodes required is less by using clusters, which also enhances the quality of service (QoS). One member of the cluster is chosen as Cluster Head (CH) on the basis of energy and relative spectrum awareness so that non-adjacent available spectrum bands are grouped. It is also planned to provide constant transmission opportunity. Joint energy spectrum rank is found by each node and a node with high rank is elected as CH, who controls the use of spectrum and routing of data. Multimedia quality distortion is reduced by forming optimum number of clusters. Carrier Sense Multiple Access (CSMA) and Time Division Multiple Access (TDMA) methods are combined to generate hybrid medium access using clustering. But it is at cost of increased routing overheads.

Chih-Chieh Tang et al. [5] have introduced a reactive routing in Cognitive Radio Ad Hoc Networks (CRAHNs). It is a spectrum aware routing technique which uses a link recovery mechanism based on clustering. In this scheme, only the failure links are recovered locally without affecting the original routes. To cache the data packets it uses buffers at the time of link recovery. After formation of clusters of SUs, each member node uses the same channel for the data transmission which is assigned to them by CH. This scheme shows increased throughput even in the network with more congestion. But link recovery mechanism pose additional burden in terms of routing overheads

Anna Vizziello et al. [6] proposed CR routing based on location of nodes known as LCR. It is based on RSSI localization algorithm. This technique also is PU activity aware as it considers position of PU and minimizes harmful interference to them. Routing is carried out into two phases first intra cluster and then inter cluster. It considers the existence of heterogeneous PUs. It jointly selects spectrum and route. But this scheme has the drawback that within a cluster even at different locations it assumes similar spectral characteristics.

A LEACH routing protocol for CRSNs is introduced by Nayyer Panahi, et al. [7]. In this scheme, spatial distribution of CHs is good as they are equally distributed all over the network. It proposes a new duty cycle mechanism that considers both, the discovery of neighbor and sensing/allocation of the spectrum. It finds the appropriate locations of CHs with their optimal quantity by using the information from lower layers and the characteristic of random CH selection as in LEACH. Network lifetime gets raised with more suitable locations of CHs but it is at the cost of network instability.

Sisi Liu et al. [8] proposed a mechanism which is cluster based and it uses different control channel for each cluster in the network. It assumes that clusters have adequate number of channels which are common. It helps in smooth channel switching when PU becomes active and also exchange of control messages becomes easier. With this re-clustering is not to be carried out frequently. But this technique is applicable only to cellular cognitive radio networks.

A cluster-based routing protocol known as United Nodes for mobile CRNs is propose by .A.C. Talay et al. [9]. It is efficient and distributed technique. It is a spectrum as well interference

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aware routing protocol. It uses interference metrics and spectrum availability cost for establishing the route in cluster-based network. To repair the failure links with the PU activity, this scheme uses a route preservation method. It shows performance enhancement with respect to the throughput and data delivery latency. But it does not use any co-operation among the primary and secondary users during route decision, which may lead to inefficient routes.

Network wide performance of a routing scheme in terms of delay, throughput and routing overheads can be improved if strengths of both reactive routing and proactive routing approaches are combined. It is possible with the hybrid routing solutions which makes use of theses mechanisms for finding route selection towards destination. HPRR is a hybrid routing scheme which is discussed in next sections. It uses clustering which helps in overall improvement in the performance.

III. SYSTEM MODEL,ASSUMPTIONS AND NOTATIONS

A. Assumptions

The working of proposed algorithm in this paper is based on certain assumptions. It assumes the base station (BS) or sink node which collects information from all nodes in the network. The base station is considered as stationary. All nodes which are part of the network have same communication and data gathering capabilities. Also, each node of the network has same transmission and interference range i.e. they are homogeneous in nature. But network is heterogeneous in terms of mobile and stationary nodes. Each node has unique identification numbers (IDs). Every node senses the available number of channels correctly with its spectrum sensing capabilities [10, 11]. Whole network assumes a network wide common control channel (CCC) [10, 11] for exchange of routing packets amongst SUs. The network consists of n clusters. Every cluster selects one of the nodes as a cluster head (CH) and remaining nodes become member nodes.

B. Model

System model based on clustering [12] is considered for the routing algorithm HPRR, which is proposed in this paper. It is as shown in figure 1. It considers total of *N* nodes (which include both primary and secondary and varying as 50, 100, 150 and 200) are deployed randomly in the specified area. They gather the information with some specific interval. The network consists of *C* *(C={1,2,3,4,5,6,7,8})* data channels and one CCC. The network supports coexistence of SUs and PUs. Every PU uses the licensed channel assigned to it. There is one to one mapping between licensed channels and number of PUs. If PUs are using the channels assigned to them i.e. licensed channels, they are said to be active. The channels that are not used by PUs are utilized by SU, thus the mapping of channels with SUs is one to many. Every SU node has spectrum sensing ability to sense the channels not used by PUs (idle channels). Also, it is can calculate the probability of PUs presence on channel.

As discussed earlier, network has *n* clusters wherein each cluster is composed of a CH, cluster member nodes and gateway nodes. It is shown in figure 1. The member nodes of any cluster can directly communicate with their respective CHs. Thus, CH acts as the coordinator node for particular cluster wherein it gathers data from cluster members and transmits it to the common destination i.e. BS. Also, it does an important task of channel assignment with respect to the member nodes, when link failure occurs.

The intra-cluster communication is shown in figure 2 (a). It is the communication between the member nodes of the same cluster i.e. communication within the cluster.

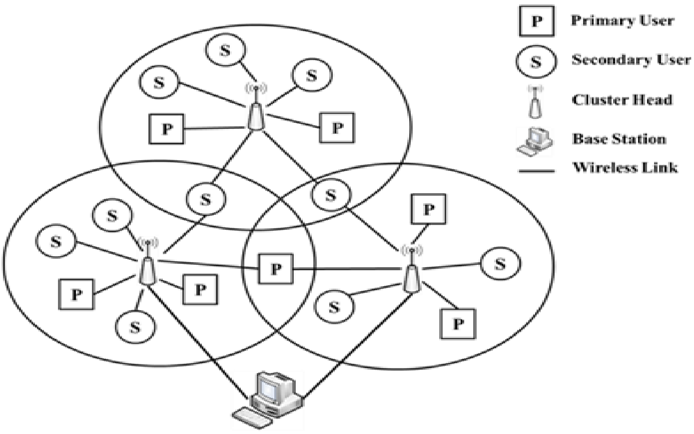

Fig. 1. Generalized system model

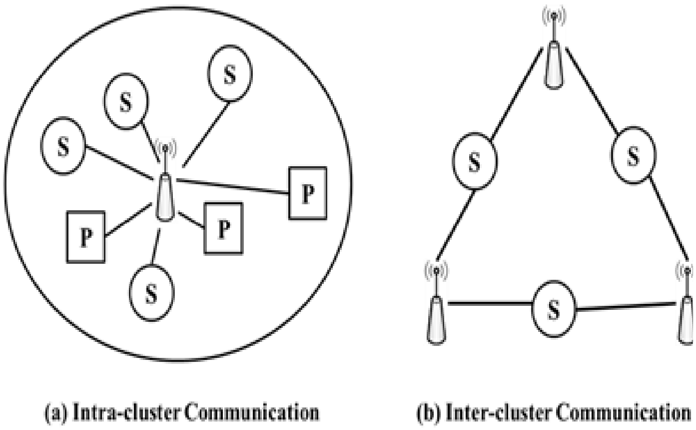

Fig. 2. Intra-cluster communication and inter-cluster communication

Gateway nodes are used during inter-cluster communication as shown in figure 2 (b). As these nodes are present in two or more clusters as shown in figure 1, they have ability to collect data from both clusters. Thus, they act as the bridge between two clusters. The communication pathway from any CRN node to BS is,

$$Member\ node\ \rightarrow Local\ CH\ \rightarrow Gateway\ node\ \rightarrow Remote\ CH\ \rightarrow BS$$

C. Notations Used

The description of proposed mechanism is given by considering following notations given Table I,

TABLE I NOTATIONS AND THEIR MEANINGS

Notation	Meaning
PU_s	Set of PUs
SU_s	Set of SUs
pu	Primary user, where $pu_i \in PU_s$
su	Secondary user, where $su_i \in SU_s$
$HOSU_x$	Set of one-hop neighbors of su_x
$HTSU_x$	Set of two-hop neighbors of su_x
C_s	Set of available channel in a network
C_{su}	Available channel set for su
C_{xy}	Set of common available channel between two SUs (su_x and su_y). It can be represented as $C_{sux} \cap C_{suy}$
LR_{xy}	Reliable link in between two SUs su_x and su_y
C_n	Channel used for communication $C_n \in C_{xy}$
p_n	Probability that PU do not use channel C_n for communication.

IV. HPRR

The aim of hybrid proactive-reactive routing mechanism (HPRR) is to find out the efficient route in between source and destination. The proposed algorithm is considered to be hybrid, as it considers the combination of proactive and reactive mechanism. The algorithm is considered to be proactive by considering that it construct a

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routing table by exchanging routing information, but if destination node goes beyond some specific number of hops then it keep the routing information with some in between node until and unless the receiver node receives it. Here, far destination node receives it through route request and reply messages. By considering this, the proposed algorithm uses following phases for establishing an efficient route.

- Finding a reliable link
- Deciding trustworthy routing relay
- Exchange of control messages

A. Finding a reliable link

The Link reliability is an important issue in case of secondary users. The link in between the nodes is considered to be reliable if more channels will be available for communication. At least one of the channels should be available from total available channel if two secondary uses want to do communication in between them. The probability of successful communication is more for nodes who have higher number of common available channels. If primary users occupy the channel for less time, then, probability of more common available channels for secondary users is more. Hence, for finding the reliable link for communication of secondary users, it is necessary to have knowledge about common available channels between the neighbors and the amount of channel occupancy of primary users. Therefore, reliable link in between two adjacent secondary users' su_x and su_y is given as,

$$LR_{xy} = \delta \left[1 - \prod_{C_n \in C_{xy}} (1 - p_n)\right] + \theta \frac{C_{su}}{C_s} \quad \text{……. (1)}$$

where, δ and θ are coefficients. δ, θ ϵ [0,1] and δ + θ=1

Here, every link for communication will be checked for reliable link according to equation (1).

B. Deciding trustworthy routing relay

In case of wireless network, for establishing the route in between source node and sink node, the source node floods information to neighboring nodes, until and unless it finds the destination node. This mechanism is simple but it generates large number of messages within the network. It further increases in case of CRN environment due to dynamic nature. Hence, it is necessary to reduce the amount information exchange during finding the route. Here, for reducing the amount of routing information trustworthy routing relay (TRR) is proposed. A set of TRR contains one-hop neighbors who have maximum link reliability, and the two-hop neighbors of these nodes. Here, every node forwards the information to only TRR, instead of flooding the information in entire network. The trust of the route is based on link reliability and neighboring node information. The selection of TRR is performed by using following algorithm,

Algorithm: For finding TRR for specific secondary users,

1. Determine the one hop neighbor list of su_x, $HOSU_x$
2. Determine the one hop neighbor list $HOSU_y$ for every, $su_y \in HOSU_x$.
3. Determine reliability $r_{xy}$of every link in between su_x and su_y.
4. Determine two hop neighbor list of su_x, $HTSU_x$.
5. Initially TRR_x set is null.
6. *for* each $su_i \in HTSU_x$, *do*
   a. *if* , d_i = *1then*
      i. Add su_y in the set ofTRR_x
      ii. $HTSU_x = HTSU_x - HOSU_y$
      iii. *for* $su_t \in HOSU_x$, $su_t \neq su_y$ *do*
         1. $HOSU_t = HOSU_t - HOSU_y$

iv. *end for*
v. remove$su_y$from $HOSU_x$
b. *end if*
7. *end for*
8. *if* $HTSU_x \neq \emptyset$ *do*
a. Determine $Minimum = \{su_i = \min LR_{xy}\}$
b. $Select\ su_y \in Minimum$, which has the minimum d_i
c. $Delete\ su_y\ from HOSU_x$
9. *end if*
10. *for* each $su_i \in HTSU_x$, *do*
a. *if ,* $d_i \neq 1$*then*
$Delete\ su_y \in Minimum$
b. *end if*
11. *end for*
12. *goto 5till* $HTSU_x = \emptyset$
13. *return* TRR_x

C. Exchange of control messages

Here, control messages are exchanged to determine the single hop neighbors and two hop neighbors. One hop neighbors are found by periodic exchange of control messages over direct link in between the two nodes. The control message consists of identification of sender node, available channel set, and one-hop neighbor list of sender node. The control message is used to update the status of link, detection of neighbors, and it also help in selection of TRR. The status is associated with every link, which is used during exchange of control messages. The link status consists of list of identification of instigator nodes, identification of neighboring nodes, and timing information.

Every node forms a routing table according to the exchange of control messages. The routing table records channel information of node, one-hop neighbors of node, link reliability information, neighbor type (single hop or two hop) and two hop neighbors of node. This information is updated periodically by using exchange of control messages. The information store in routing table also helps to select the TRR.

V. RESULTS OF SIMULATION

A. Particulars about simulation

HPRR is implemented by using the Network Simulator-2 (NS-2) [13] which is a discrete event simulator. Considerations about simulation are given in Table II. The simulation considers the area of network as 1000m * 1000m. The nodes are distributed uniform randomly within this area. Parameters for measurement considered in this simulation are:

Average end to end delay: It is the difference of time in between the instant at which the packet is received at BS and the instant at which the packet is sent by sender is known as the delay of one packet. Addition of delay of all individual packets which have been received successfully provides total delay. When this total delay is divided by the count of successfully received packets, the average end to end delay is obtained.

Average throughput: Throughput is calculated on the basis of Packet Delivery Ratio (PDR). It is obtained by dividing the count for number of packets received successfully at the destination node (BS) by the count for number of packets transmitted by different source nodes. It is expressed in percentage

TABLE II. PARAMETERS USED FOR SIMULATION

Name of parameter	Setting
Antenna	Omni-directional
Network Interface	Wireless Physical
Link Layer	Link Layer (LL)

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Name of parameter	Setting
Channel Type	Wireless Channel
Buffer size of Ifq	50
Interface Queue	Priority Queue
MAC	CRMAC
Routing Protocol	AODV [14], C2R2M-LS [15], HPRR
Traffic Model	CBR
Transport Layer	UDP
Node Placement	Random
Number of nodes	Changing from 50 to 200
Size of Packet	100bytes
Number of Simulation Runs	10

B. Simulation results

Figures 3, 4 and 5 show the effect of changing total nodes including PUs and SUs as against average delay, average throughput and routing overheads for AODV, C2R2M-LS, and HPRR routing protocols respectively.These results show the dynamic nature of CRN routing mechanism. Here, the evaluation considers the nodes, which are varying from 50 to 200 with an interval of 50, number of channels considered is two (2), and packet time interval is 1second.The results reveal that performance wise C2R2M-LS is better than that of AODV. The reason for better performance of C2R2M-LS that AODV are, the clustering algorithm used which decides the clusters by considering the node degree and number of channels, co-existence of SUs and PUs during route decision, and channel assignment algorithm used. These results also show that the performance of HPRR is even better than C2R2M-LS.

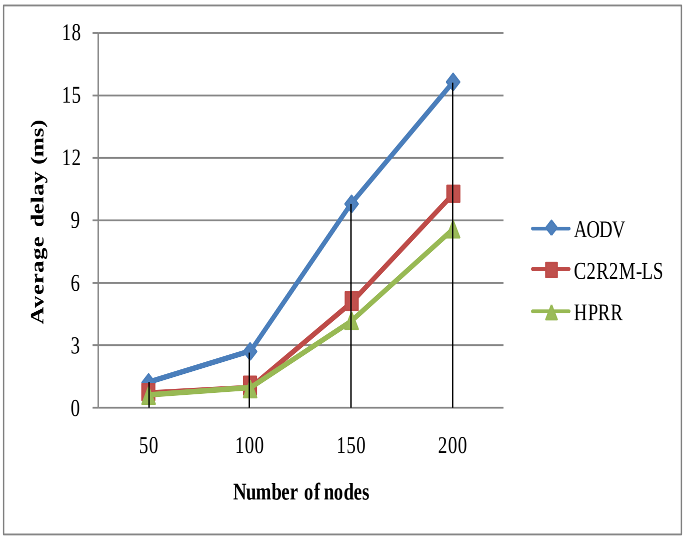

Fig. 3. Nodes vs. average delay

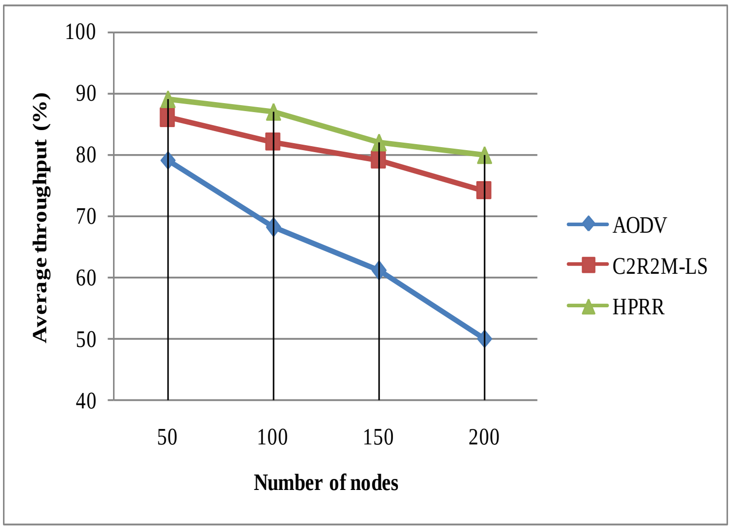

Fig. 4. Nodes vs. average throughput

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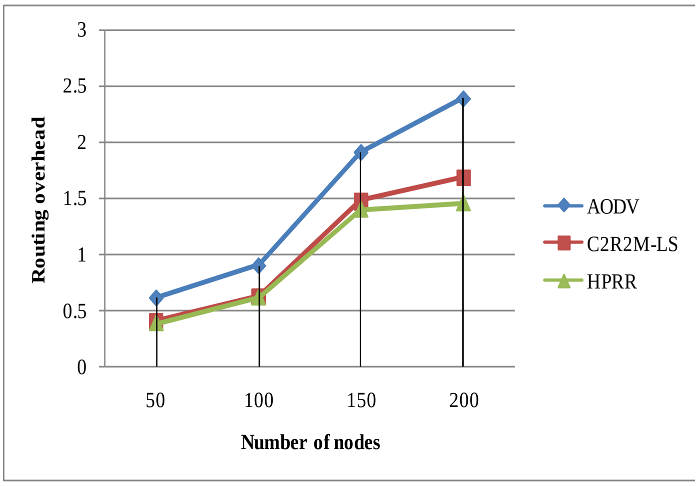

Fig. 5. Nodes vs. routing overheads

The reason for improved performance HPRR is its hybrid (proactive + reactive) nature. HPRR helps to reduce amount of information stored across the network. The routing information is stored at TRR instead of storing it at every node, which helps to reduce the time require to build routing information on each node and also helps to reduce the routing overheads. TRR also helps to reduce the amount of flooded messages in network, which in turn advantageous to decrease in amount routing overheads and link breakage. HPRR checks for reliability of link while making a decision of TRR. This helps to improve the reliability of link and in turn helps to improve the throughput of it, as compared with other algorithms.

Summary of results in terms of delay, throughput and routing overheads with node variation is presented in Table III.

TABLE III. SUMMARY OF RESULTS (NODE VARIATION)

Parameter	Nodes	AODV	C2R2M-LS	HPRR
Delay	50	1. 175	0.723	0.594
	100	2.663	1.020	0.906
	150	9.737	5.063	4.164
	200	15.581	10.195	8.532
Throughput	50	79	86	89
	100	68	82	87
	150	61	79	82
	200	50	74	80
Routing overhead	50	0.606	0.409	0.384
	100	0.894	0.629	0.613
	150	1.906	1.473	1.396
	200	2.385	1.682	1.453

Figures 6, 7 and 8 show the result of changing total channels from 2 to 8 in step of 2 against average delay, throughput, and routing overheads for AODV, C2R2M-LS, and HPRR routing protocols respectively. Here, the evaluation considers number of nodes as 200, and packet time interval as 1second. Here, too HPRR is showing improved performance over C2R2M-LS and AODV because of its hybrid behavior. The hybrid nature of HPRR is very advantageous in the environment where numbers of channels in a network are varying. The reason behind it is, (i) storage of routing information at few nodes instead of all nodes, (ii) minimizing the number of messages in a network.

The increasing number of channels improvises average throughput and reduce routing overhead as compared with increasing number of nodes. But it also causes increase in the average delay due to channel switching time which results in reducing the percentage of improvement with channel variation.

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Summary of results in terms of delay, throughput and routing overheads with channel variation is presented in Table IV.

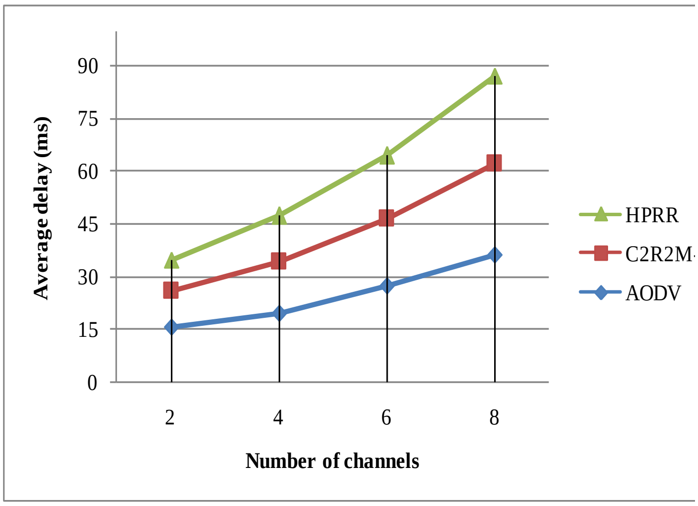

Fig. 6. Channels vs. average delay

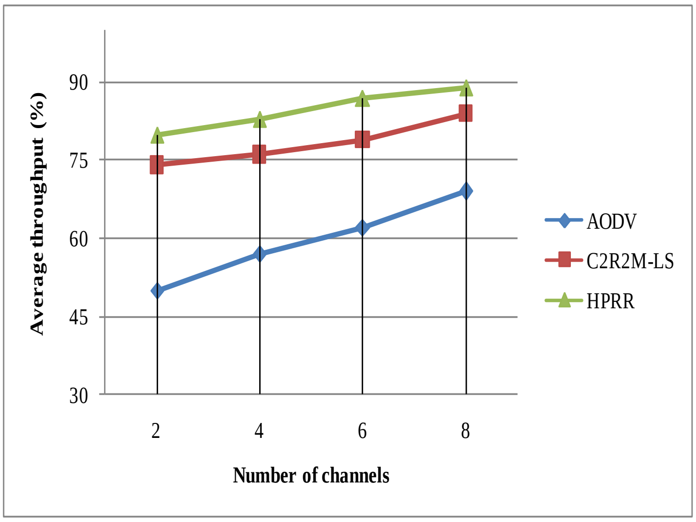

Fig. 7. Channels vs. throughput

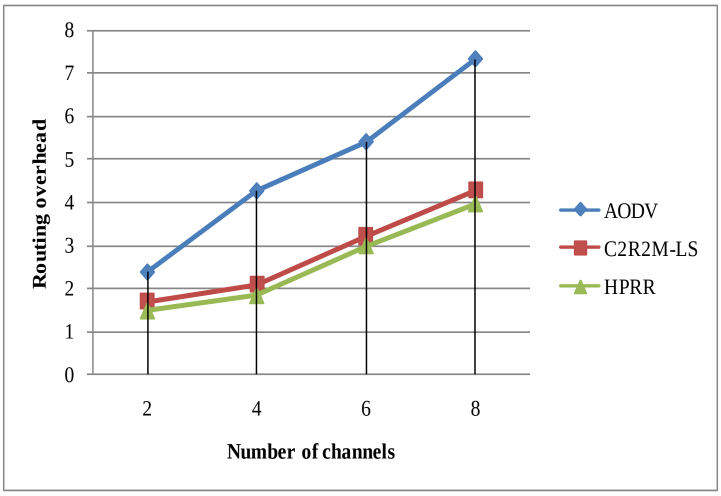

Fig. 8. Channels vs. routing overheads

TABLE IV SUMMARY OF RESULTS (CHANNEL VARIATION)

Parameter	Nodes	AODV	C2R2M-LS	HPRR
Delay	2	15.581	10.195	8.839
	4	19.597	14.715	12.951
	6	27.243	19.137	18.079
	8	36.064	26.214	24.917
Throughput	2	50	74	80
	4	57	76	83
	6	62	79	87
	8	69	84	89
Routing overhead	2	2.385	1.682	1.482

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Parameter	Nodes	AODV	C2R2M-LS	HPRR
	4	4.267	2.058	1.837
	6	5.406	3.201	2.991
	8	7.326	4.281	3.961

VI. CONCLUSION

A new routing technique called cluster based Hybrid Proactive Reactive Routing (HPRR) is proposed which improves network performance in terms of routing. HPRR helps to reduce amount of information stored in the system. The information about routing is stored at TRR instead of storing it at every node, which helps to reduce the time required to build routing information on each node and also helps to reduce the routing overheads. TRR also helps to reduce the amount of flooded messages in network, which in turn is advantageous to decrease routing overheads and link breakage. Increased routing performance at network layer will be beneficial to the smart IoT devices having cognitive capabilities in their operation.

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