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Effective Route Failure Recovery Mechanism on Multicast Routing in Cognitive Radio Networks

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Abstract: A Prudent Cognitive Multicast Protocol (PCMP) is introduced to employ the multicast routing services for Cognitive Radio Networks (CRNs). The channel allocation and route establishment are performed simultaneously by considering the Primary Users (PUs) activity. In the multicast route establishment phase, the protocol establishes a concrete multicast tree with optimum channel utilization to ensure a stable path. The channel diversity of route selection and endways delay of packet delivery is balanced by Weighted Accumulative Expected Transmission Time (WAETT). The Secondary Users (SUs) used in the network share the channel availability information between them. With the help of this shared information, a route recovery is also performed during the sudden emerging of PUs in the CRN environment. The Novel PCMP protocol is implemented using Network Simulator 2 (NS2) and its performance is accessed in terms of the packet delivery ratio and end-to-end delay. The existing methods such as Genetic Algorithm (GA) optimized Fuzzy Decision System (FDS), Stability-based Multipath Quality of Service (QoS) Routing Protocol (SMQRP) and Optimal Relay and Channel Selection (ORCS) are used to evaluate the PCMP. The PDR of the PCMP is 0.9975 for 100 nodes, it is high when compared to the GA-FDS, SMQRP and ORCS.

Keywords: Cognitive radio networks, Multicast routing, Packet delivery ratio, Prudent cognitive multicast protocol, Route recovery, Weighted accumulative expected transmission time.

1. Introduction

In recent times, Multicast routing is widely used in various applications such as battlefield, video conference, group communications and so on [1]. Multicasting requires very fewer resources to transmit the information than several multiple unicast routing services. Moreover, this multicasting also offers good service than the broadcast communication system [2]. Many multicast routing protocols can't be used in CRN, due to the heterogeneous nature of the network i.e., the channel property in respect to space and time. The CRN provides an appropriate solution for spectrum scarcity in wireless networks to satisfy the growing requirement of high bandwidth in mobile communications [3-5]. The CRN's key features are spectrum sensing, management, assignment, and analysis [6]. Two distinct users exist in the CRN such as Primary Users (PUs) and Secondary Users (SUs). If PUs are required to broadcast the data, then the respective PU accesses the licensed channels. On the other hand, the SUs accesses licensed channels, when it is not occupied by PUs [7-9].

CRNs are used in a variety of applications that includes public safety systems, dynamic spectrum access, smart grid communications, cooperative networks, intelligent transport systems, and femtocells [10]. Using multicast, the source has to send information to more than one receiver that is scattered at different locations [11, 12]. The multi hop routing is considered an essential issue for routing over the SUs. The important reason is that the opportunistic spectrum access, as well as the source and destination, cannot use the same channel for communication. Hence, the routing method utilizes the intermediate SUs for solving the aforementioned issue [13-17]. Due to the heterogeneous nature of the network, a conventional algorithm is not effectively implemented in CRN due to its heterogeneous property. The CRN has a considerable number of SUs that require making use of the cross-layer mechanism to have information about the channel availability. In the standalone layer mechanism, despite having a major focus on the multicast communication link, it lacks in the efficient utilization of natural resources.

This research paper paves a way to optimize the network resources in the cognitive radio networks that employ multicast routing services. The allotment of channels and routing technique are performed simultaneously on considering the PUs activity. The protocol design which has been proposed in this paper is to establish a precise multicast tree ensuring the utilization of static path in a multicast route. The SUs used in CRN share information between them which is used to form a static tree where the path recovery is possible by flash emerging PUs in the CRN environment.

The organization of the paper is followed as: Section 2 describes the related work towards the CRN on multicast routing and Section 3 explains the CRN model with assumptions. The proposed work is described in Section 4 followed by the result is provided in section 5. The conclusion of this research paper is presented in Section 6.

2. Related work

Robert, and Vidya [18] developed the GA optimized FDS to perform the different tasks such as spectrum allocation, channel selection and channel switching in the multi-hop CRN. Subsequently, the signal-to-noise ratio, interference temperature of node and transmission power were considered to rank the channel for communication. Moreover, the handshaking protocol was used by time management for minimizing the deafness issue which resulted in less packet loss. However, the packet delivery of the GA-FDS was less, when the CRN has less number of SUs.

AlQahtani and Alotaibi [19] presented the SMQRP to transmit the data through the cognitive radio ad hoc networks. This SMQRP was used to identify appropriate primary and alternate transmission paths among the SU source and an SU destination. Moreover, this SMQRP has supported the utilization of optimal primary and alternate channels along with the transmission paths. Here, the throughput and delay were improved by avoiding the path which has a huge amount of PU activities. However, the packet loss of the SMQRP was increased when the nodes in the network were in dynamic nature.

Indumathi, and Vaithianathan, [20] developed the ORCS method to accomplish the multicast routing over the network. The Distributed Minimum Spanning Tree (DMST) was utilized to achieve the multicast tree structure. In ORCS, the relay nodes were selected with less interference, less energy utilization, and less delay to satisfy the restrictions of interference, delay, and energy. However, this ORCS was failed to perform the route recovery which resulted in packet loss during communication.

Dhingra [21] developed the integrated service (intserv) model for discovering the routing path from the source to destination. After accomplishing the spectrum verification by intserv model, the admission control and flow scheduling were performed at PU nodes whereas the SUs specified the essential QoS level path for the route request packet. Moreover, the intserv model was combined with any of the on-demand routing protocols for delivering the QoS support. However, the resource consumption of PU nodes was high during data transmission.

Salameh [22] presented a minimum-segment maximum-availability (MinSMaxA) based adaptive routing for the multi-hop peer-to-peer CRNs. This MinSMaxA has recognized the ability of every device in the CRN. The developed MinSMaxA was used to increase the available time for the communication through the path. Here, a higher available time per hop was obtained based on the channel allocation per-segment. However, the MinSMaxA was required to discover a huge amount paths for achieving better performances, which resulted in high delay during communication.

The limitations found from the existing researches are high resources consumption, high delay and high packet loss. The packet loss is occurred because of the dynamic nature of the nodes and the inexistence of the route recovery process [18] [20]. Additionally, a high delay is occurred in the network, because there is a requirement to identify more routing paths [22]. To overcome the aforementioned limitations, the PCMP uses the WAETT for balancing the delay of the data delivery. Moreover, the packet loss during the communication

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is avoided based on the route recovery process developed by the PCMP.

3. System model

In general, CRN houses both primary and secondary networks. Nodes in the CRN are employed with cognitive devices and a different node uses a conventional radio signal. Routing in CRN's must be aware of spectrum availability which is achieved by monitoring the spectral environment. Probabilistic counter-based route discovery (PCBR) did not consider the effect of the traffic load, mobility, and topology size of the route discovery. A hybrid routing protocol involving multipath discovery and route recovery prevents frequent collision and degradation in the network performance. In a cross-layer framework, a path maintenance mechanism can be implemented to avoid path breakages and the major drawback in the design is the delay. A route failure in the primary route can be detected by, overhearing neighbour, which institutes an indigenous retrieval track with the supreme bandwidth from its pathhoard and this principle is also employed so that nodes in CRN's will be able to obtain data related to spectrum from its lower layer. An effective route failure recovery mechanism has been proposed on multicast routing in CRNs. The proposed multicast routing protocol PCMP for CRN is very must robust as it offers an effective route recovery mechanism. Route failure is recovered locally in PCMP protocol. Hence the improved network capacity is achieved even though the network size increases. So the PCMP provides good scalability of the network. The channel diversity is maintained effectively. The simulation is carried out with NS2 using CRCN patch on packet delivery ratio and end to end delay with increasing the number of nodes and primary users and channel availability. In this proposed model, an environment is created in which SUs could perform operations such as channel assignment and spectrum monitoring. Each SUs is installed with a transceiver which could reduce the functional cost of the SUs devices, but it leads to the deafness problem. Some channels are assumed is Cn and the block diagram for PCMP is shown in the following Fig. 1.

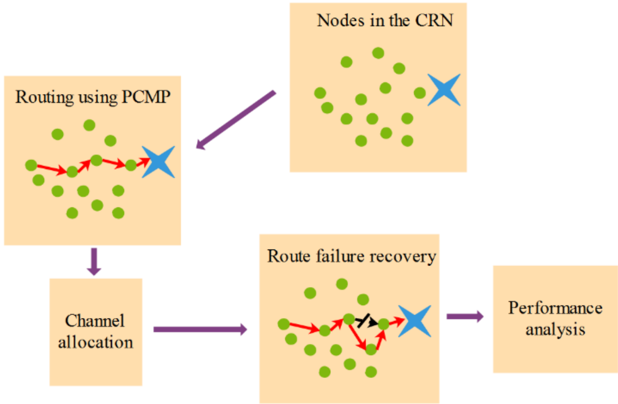

Figure. 1 Block diagram for PCMP

4. PRUDENT cognitive multicast protocol

4.1 Multicast channel availability

In the network, each SU would monitor the radio spectrum and identify the channels that have not been engaged. These unoccupied channels could act as an alternative frequency spectrum for SU. Usually, channel allocation and availability are done based on an asymmetric mode, which means that the channel of one slot for a node could not be the same for another node. This channel monitoring process maintains a list that needs and the availability of channels for SU. In the multicast route for the construct of a constant path between source and destination, a channel list maintained by the SU is exchanged. The list is refreshed at a regular interval to update the latest information whenever data transfer takes place. SU has to be aware of any control message. A deafness problem may occur if there is only one transceiver whenever a switching in the channel slot is to have happened. This problem can be resolved with the help of ADD/ REMOVE control data packets. By the time SU changes a channel from normal operation to control channel. It would send a REMOVE control packet message to ensure that no packet loss has occurred.

4.2 Establishment of multicast route

Multicast refers to casting the packet to multiple receivers. The proposed work is implemented on the underlying on-demand protocol. The metric used is Weighted Accumulative Expected Transmission Time (WAETT). It maintains the balance between the channel diversity in route selection and end-to-end delay in packet delivery. The source transmits a request (RREQ) to its neighbor nodes within the network. A control message on the current channel K has the access to WAETT value and it can use the channel. The routers that have lower costs are likely to be considered for a reverse path. The node which received RREQ would check if there exists any common channel for the transmission of data. If no common channel is discovered, the process of the broadcast would be stopped otherwise the node would rebroadcast the RREQ control message. Every time RREQ is rebroadcast, the sequence number is renewed and the WAETT value is updated. The route with the lost cost is determined when the sequence number of RREQ is old and the value of WAEET is less than that of previous RREQ messages. Whenever the members of a group get a request message, it would send a response message (RREP) that is padded with channel information. Among the available channel list, the channel with the least cost is considered as the primary channel and other acts as a backup channel. The originator usually chooses the more stable path to ensure the successful data transfer and also maintain information about the channel. All nodes hold a table named Multicast Adjacent Set (MAS). This table deals with information about adjacent nodes. This table maintains five attributes such as group identity, adjacent node information, common channel list, and WAETT value and vector information. Group identity helps to know about session details. The common channel along with the adjacent nodes helps to identify the router with minimum cost. The vector information gives the data about the uplink or downlink of a neighbor node.

4.3 Path recovery

If the PU occupies the channel all of a sudden, the communication link among the SUs would disappear that causing the route failure in CRN. By considering various channels an abrupt event is to be established with a new path. If any of the SUs senses that PUs activity is on, it would undergo a local multicast Path recovery mechanism. In this recovery mechanism, the node verifies the local channel list if any channels are engaged or not. A single channel switch is established rather than triggering the global re-route method. The above event would be possible only if adjacent nodes have a minimum of two common channels, then the node would try an alternate method to re-establish the route. In this case, the victim node would send a route error message embedded with a route update message (RERR) to the adjacent nodes. RU message has information such as node identity, node's channel list, victim channel details and vector. The adjacent nodes, then resume the route rescue process on the interrupted route and offer alternate paths to reestablish the path. Now, the adjacent nodes compare the channel information of RU with its original list. If it identifies any of the channels are common, then common channels are made available for transferring data in a multicast tree.

4.4 Channel diversity

To achieve the proper synchronous communication in CRN, the control messages are to be shared at regular intervals between nodes. It is a difficult task as the CRN has a unique property like a diversity of channels. Each SUs may have different channel availability which leads to the changing behavior of PU's bandwidth and frequency.

Algorithm:

Algorithm A: Managing PREQ message

1. Node 'I' receives the request message from node j
2. If RREQ has a new sequence number, check on common channel availability
3. If there exists a regular channel between i and j
4. Lay in WAETT value in the adjacent set (MAS)
5. Else if the sequence number is old
6. Compare the WAETT; if a message has less value, update the table otherwise ignore the message

Algorithm B: To send RREQ Message

1. Node' I' sends the request message
2. For every *j* that belongs to Ni do update on channel information with RREQ and delete uplink node channel details
3. Calculate WAETT for all available channels
4. Broadcast RREQ with these channels
5. Ensure that each channel has calculated WAETT value

Algorithm C: To handle the RREP message

Node has received the response message from node *j*

1. Save the commonly available channel list
2. Discards already stored channel list from node *j*
3. Update the common channel list in both the Uplink node and the node

Algorithm D: To send a response message

1. Node'I' will send the reply message
2. Based on less value of WAETT the path is selected
3. Update the available common channel list to uplink nodes

Algorithm E: To handle Path recovery

1. Path recovery is performed I on PU s of the node i and *j*
2. Then the local table is verified in node *I* for common channel
3. If a common channel exists, I would shift to that channel
4. Else procure a route update message in RU
5. Flood the RU to all adjacent nodes with attribute table
6. Route discovery is initiated from the adjacent node

The explanation of the PCMP process is described with an example as follows:

Table 1. ACS along with its nodes

Nodes	S	B	C	D	E	GM
ACS	1,2,3	1,3	2,4,5	3,6,5	5,6	4,5,3
Adjacent nodes	B,C,D	S	S,D,E,GM	S,C	C,GM	C,E

Table 2. MAS of node B

Node Id (N-Id)	S	S
Group Id (G-Id)	X	X
Common Control Channel(CCL)	1	3
Cost	1.3	1.5

Table 3. MAS of node C

N-Id	S	D
G-Id	X	X
CCL	2	3
Cost	1.25	1.6

Table 4. MAS of node D

N-Id	S	C
G-Id	X	X
CCL	3	5
Cost	1.4	1.6

Table 5. MAS of node E

N-Id	C
G-Id	X
CCL	5
Cost	1.8

Table 6. MAS of node GM

N-Id	C	C	E
G-Id	X	X	X
CCL	4	5	5
Cost	1.35	1.55	1.75

Step1. Route request

Consider a CRN that consists of six SUs and six available channels on the network. Every SU maintains its available channel set (ACS) on the addition to multicast adjacent set (MAS). Node S transmits available information to its set members. Hence rule message is broadcast to adjacent nodes. The Available channel set availability for its nodes is shown in Table 1. Table 2 to 6 shows the MAS of each node. The cost is assumed randomly, it may vary while considering the fact.

Step 2. Path reply

Based on least cost priority, the next best hop is chosen by the destination is represented in Eq. (1). Table 7 shows the procedure for Path reply.

$$Path\ relay = minimum(cost\ (MAS\ (node)) \quad (1)$$

Table 7. Procedure for path reply

Nodes	GM	GM	C
NH	C	C	S
Channel	4 (Primary)	5 (backup)	2

Step 3: Path recovery

From Table 7, it is found that the route is determined for data transmission in such a way that S uses channel 2 through neighbor node c using channel 4 to group members (GM). Thus, for the transmission of data, the replying node makes use of the Adjacent channel set (ACS). Through C and GM, PU reaches 4. Currently, node C verifies if its MAS has an alternate channel or not. Channel 5 is presented in MAS. Hence the route is re-established by changing the channel from 4 to 5. Now the new path from S to GM is constructed using channel 2 for S and 5 for C. Let it be that PU reached on channel 2 that is the link between S and neighbor node C. When S does not find an alternate channel, it starts creating a route update message.

Lemma for proof checking

Lemma1: Maintaining the order of messages

Proof: The order of delivery should be maintained as the message generated from the source.

Case 1: A element in a network (i.e. Node), for instance, X procure both messages $ms1$, $ms2$ and X should send $ms1$ firstly and then $ms2$, it is denoted in Eq. (2)

$$S_u(ms1) -> S_u(ms2) \quad (2)$$

Node Z which is to be one of the members of a multicast group should have received $ms1$ first and $ms2$ second. It is denoted as Eq. (3)

$$R_u(ms1) -> R_z(ms2) \quad (3)$$

In this proposed mechanism, the FIFO strategy is followed as the transmitting protocol. The entire relay node strictly follows the FIFO transmitting rules, the message ms1 is sent early, so ms1 is received before $ms2$ is received by the intermediate relay node. This process is maintained in all intermediated relay nodes.

Case 2: The message $ms1$ is procured by node X and $ms2$ is procured by V. The message $ms2$ is sent by V after the $ms1$ is received by X. it is true and denoted in the Eq. (4)

$$R_v\ (ms1) -> R_z\ (ms2) \quad (4)$$

Lemma2: Optimized path that free from the loop

Proof: It is proved using truth by contradiction.

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It is assumed that a loop is formed in the route from any node X_k to node S. When a node X_k chooses a node X_i as its next hop for node S, i.e. in Eq. (5).

$$d_s(X_i) < d_s(X_k) \quad (5)$$

Hence if any loop is there, the downstream node X_j with the condition that X_j=X_k and is expressed in Eq. (6).

$$d_s(X_o) > \ d_s(X_1) \ldots \ldots \ldots \ d_s(X_i) > d_s(X_k) \ldots \ldots \ldots > \ d \quad (6)$$

Where d_s exist. Hence it is proved that d_s (X_j)>i.e. $d_s(X_i)$ is true and X_j is a downstream node. Thus a node can be free from loop. It is proof of contradiction.

5. Simulation result analysis

Energy capability measurements are essentially used in different manners for various reasons, yet it is generally utilized in contrasting the productivity execution and the energy utilization of different frameworks of the same level. The performance of energy consumption for Prudent Cognitive Multicast Protocol (PCMP) is explained by considering the set of parameters as the number of nodes, simulation area, traffic, packet size etc. To carry out the work of the urged algorithm, the Ns2 tool is used with an aid of the CRCN patch. Consider the area of a node is $1500\ m \times 300\ m$ simulation area and the random speed of a node varies from 0 to 20 m/s. Table 8 shows the parameter settings of the PCMP.

The metrics chosen for performance assessment are End to End Delay (EED), residual energy, Packet Delivery Ratio (PDR) and packet drop. The existing researches such as GA-FDS [18], SMQRP [19] and ORCS [20] are implemented using the same specifications mentioned in Table 8 for evaluating the PCMP. Here, the comparison is done by varying the nodes from 25 to 100.

Table 8. Parameter settings of the PCMP

Parameters	Values
Simulator	NS2 with CRCN patch
Number of nodes	25, 50, 75 and 100
Simulation area	$1500\ m \times 300\ m$
Transmission range	250 m
Antenna model	Omni antenna
Propagation model	TwoRayGround
Traffic	Constant Bit Rate (CBR)
Packet size	Minimum 512 bytes
Mobility of nodes	0 to 20 m/s

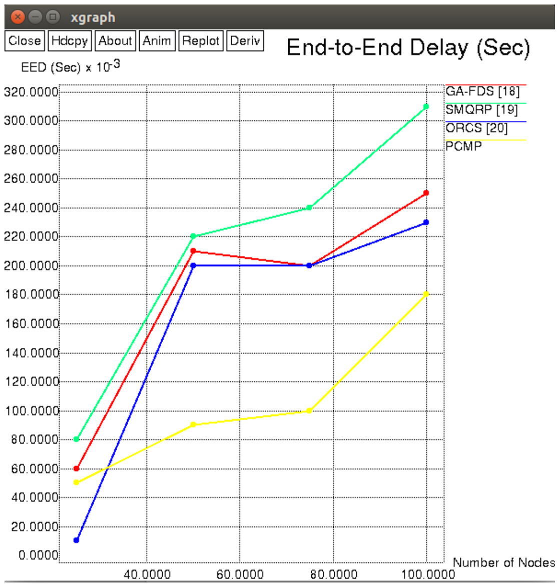

Figure. 2 EED for varying nodes

5.1 End to end delay

The EED is defined as the time difference between a packet transmission to a packet received, where EED is represented by Eq. (7).

$$EED = PacketTransmissionTime - PacketReceivedTime \quad (7)$$

The EED comparison for the PCMP with GA-FDS [18], SMQRP [19] and ORCS [20] is shown in Fig. 2. The EED for PCMP is varied from 0.05 s to 0.18 s. From Fig. 2, it is known that the EED of the PCMP is less when compared to the GA-FDS [18], SMQRP [19] and ORCS [20]. For example, the EED of the PCMP is 0.18 s for 100 nodes, while the EED of GA-FDS [18], SMQRP [19] and ORCS [20] are 0.25 s, 0.31 s and 0.23 s respectively. The utilization of WAETT in PCMP is used to minimize the EED during the packet transmission.

5.2 Residual energy

The amount of remaining energy that exists after the data packet transmission and collection is referred to as residual energy.

Fig. 3 shows the residual energy comparison of GA-FDS [18], SMQRP [19], ORCS [20] and PCMP whereas the residual energy of PCMP varies from 13.0 J to 13.5 J. The residual energy of the PCMP is higher than the GA-FDS [18], SMQRP [19] and ORCS [20]. For example, the residual energy of the PCMP for 100 nodes is 13.0 J whereas the residual energy of GA-FDS [18], SMQRP [19] and ORCS [20] are 12.3 J, 12.1 J and 12.5 J respectively.

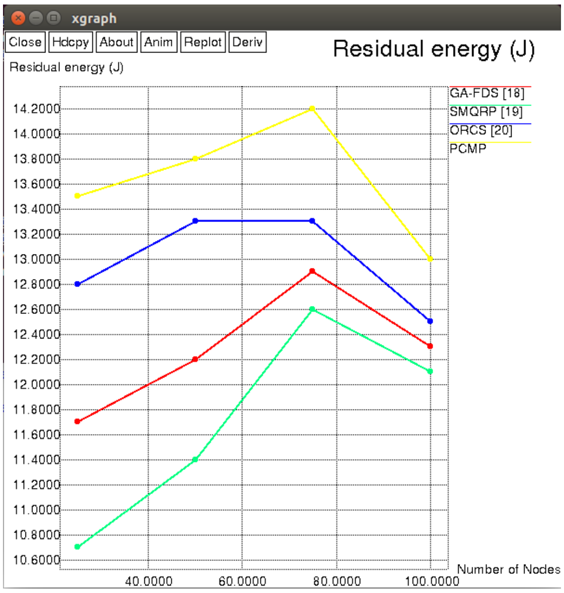

Figure. 3 Residual energy for varying nodes

5.3 Packet delivery ratio

The PDR is defined as the ratio of the total amount of packets received by the end node to the total amount of packets sent by the origin node. The formula for representing PDR is given in Eq. (8).

$$PDR = \frac{Total\ Number\ of\ Pakets\ Received\ By\ End\ Node}{Total\ Number\ of\ Packets\ Sent\ By\ Origin\ node} \tag{8}$$

The PDR comparison for the PCMP with GA-FDS [18], SMQRP [19] and ORCS [20] is shown in Fig. 4. The PDR for PCMP is varied from 0.9975 to 0.999. Fig. 4 shows that the PDR of the PCMP is outperformed well when compared to the GA-FDS [18], SMQRP [19] and ORCS [20]. For example, the PDR of the PCMP is 0.9975 for 100 nodes, while

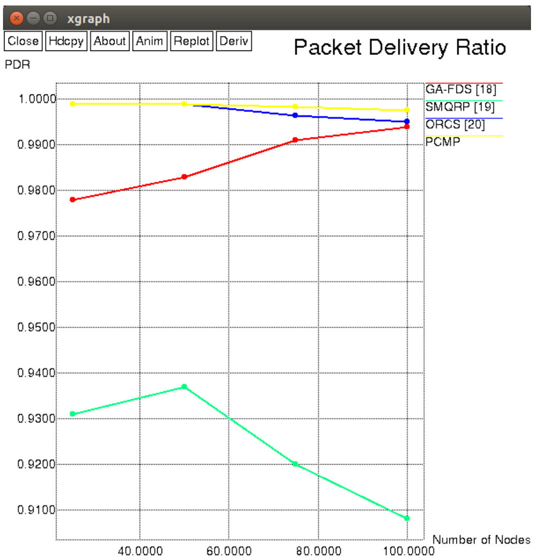

Figure. 4 PDR for varying nodes

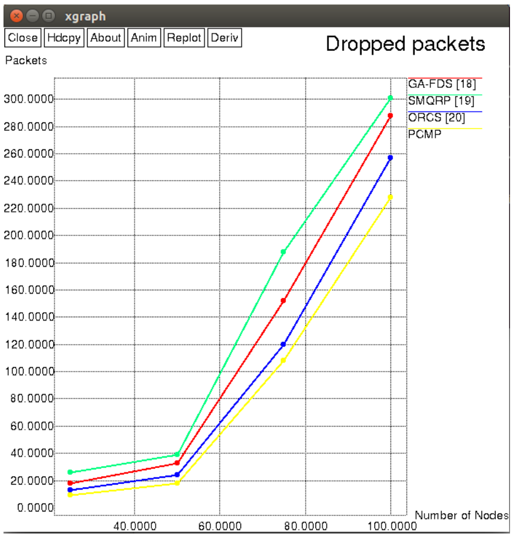

Figure. 5 Dropped packets for varying nodes

the PDR of GA-FDS [18], SMQRP [19] and ORCS [20] are 0.994, 0.908 and 0.995 respectively. The PDR of the PCMP is improved by avoiding the issues related to path breakages and frequent collisions.

5.4 Packet drop

The packet drop is the difference between the total number of packets sent by the origin node and packets received by the end node.

Fig. 5 shows the dropped packets comparison of GA-FDS [18], SMQRP [19], ORCS [20] and PCMP whereas the dropped packets of PCMP vary from 9 to 228. The dropped packet of the PCMP is less than the GA-FDS [18], SMQRP [19] and ORCS [20]. For example, the dropped packet of the PCMP for 100 nodes is 228 whereas the dropped packets of GA-FDS [18], SMQRP [19] and ORCS [20] are 288, 301 and 257 respectively. The developed route failure recovery using PCMP minimizes the packet losses that occurred because of the link breakage. Moreover, the developed PCMP based multicast routing is used to avoid the collisions occurred in the CRN which leads to reducing the packet loss.

Table 9 shows the comparative analysis of the PCMP with GA-FDS [18], SMQRP [19] and ORCS [20]. Here, the comparison is made by varying the nodes from 25 to 100. Table 9 shows that the PCMP outperforms well than the GA-FDS [18], SMQRP [19] and ORCS [20]. The reason for the GA-FDS [18], SMQRP [19] and ORCS [20] with less performance is that the developed routing algorithm doesn't have a route recovery process. However, the route recovery process developed in the PCMP is used to perform an effective multicast routing, even when the CRN faces the link breakage issue. Since the route recovery is accomplished by sharing the channel

Table 9. Comparative analysis for PCMP SMQRP and ORCS

Performances	Methods	Number of nodes			
		25	50	75	100
EED (s)	GA-FDS [18]	0.06	0.21	0.2	0.25
	SMQRP [19]	0.08	0.22	0.24	0.31
	ORCS [20]	0.01	0.2	0.2	0.23
	PCMP	0.05	0.09	0.1	0.18
Residual energy (J)	GA-FDS [18]	11.7	12.2	12.9	12.3
	SMQRP [19]	10.7	11.4	12.6	12.1
	ORCS [20]	12.8	13.3	13.3	12.5
	PCMP	13.5	13.8	14.2	13.0
PDR	GA-FDS [18]	0.978	0.983	0.991	0.994
	SMQRP [19]	0.931	0.937	0.920	0.908
	ORCS [20]	0.999	0.999	0.9965	0.995
	PCMP	0.999	0.999	0.9983	0.9975
Packet drop	GA-FDS [18]	18	33	152	288
	SMQRP [19]	26	39	188	301
	ORCS [20]	13	24	120	257
	PCMP	9	18	108	228

availability information using the SUs. Moreover, the metric of WAETT used in the PCMP is used to balance the route selection's channel diversity and delay of packet delivery.

6. Conclusion

The proposed multicast routing protocol PCMP for CRN is robust as it offers an effective Path recovery mechanism. Route failure is recovered locally in PCMP protocol. Hence, the improved network capacity is achieved even though the network size increases. So the PCMP provides good scalability of the network. The channel diversity is maintained in an effective way using WAETT. The simulation is carried out with NS2 using CRCN patch on packet delivery ratio and end to end delay with increasing the number of nodes and primary users and channel availability. From the analysis, it is concluded that the PCMP outperforms well than the GA-FDS, SMQRP and ORCS. The PDR of the PCMP is 0.9975 for 100 nodes that are high when compared to the GA-FDS, SMQRP and ORCS. In the future, an optimization based multicast routing protocol can be developed to improve the performances of the CRN.

Conflicts of Interest

The authors declare no conflict of interest.

Author Contributions

The paper conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, visualization, have been done by 1st, 2nd and 3rd author. The supervision and project administration, have been done by 4th and 5th author.

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