Scalable Local Route Repair-Hybrid Wireless Mesh Protocol (SLRR-HWMP) for IEEE 802.11s

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Abstract — Mesh Wireless Networks provide encouraging approach to provide network connectivity to the users at low cost. Wireless Mesh Networks became an important research area nowadays due to many of its advantages. Wireless Mesh Network uses Hybrid Wireless Mesh Routing Protocol (HWMP) protocol as a default path selection protocol and Air Time Link Metric (ALM) as default metric. HWMP is a MAC layer protocol used to create a path from source to destination. Even though HWMP is a default path selection protocol for 802.11s, many challenges remain unresolved, especially in routing. The results of many researches reveal that Control overhead is the main cause for not achieving scalability in all types of networks. In this paper, we have proposed a localized route repair mechanism named Scalable Local Route Repair-Hybrid Wireless Mesh Protocol (SLRR-HWMP) for Wireless Mesh Network. The proposed routing mechanism shows better performance in terms of throughput and end to end delay, especially in a large network; and hence provides scalability. This paper also shows the comparison of SLRR-HWMP and HWMP in terms of Throughput and end to end delay. Qualnet simulation tool is used for evaluating the proposed mechanism. The results shown by evaluation reveal that proposed routing technique shows better results compared to HWMP protocol.

Keywords - WMN- Wireless Mesh Networks, HWMP- Hybrid Wireless Mesh Protocol, Scalable, Local Route Repair.

I. INTRODUCTION

Mesh Networks are getting popular because of flexible infrastructure for providing Internet. WMN acts as a backbone network, so that different networks can be integrated and form a Mesh network. WMN uses existing infrastructure rather than creating new infrastructure. So WMNs are very helpful especially in rural areas where there is no enough infrastructures for forming a network. WMN combines the features of Different networks such as WLAN, Ad Hoc, mobile networks and other types of networks. WMN shows many advantages compared to other types of networks. WMN have characteristics of self-reliance, self-ruling and self-serving. So, managing of WMN is also easier. WMN with the above-mentioned advantages becomes an interesting topic for the researchers. WMN is an extension of an existing Wireless Local area network designed to provide scalability.

A. Architecture of wireless Mesh Networks.

Architecture of WMN consists of Mesh Points (MP), Mesh Access Points (MAP), Mesh Portal Points (MPP) and Stations (STA)[1][3] as shown in figure 1.

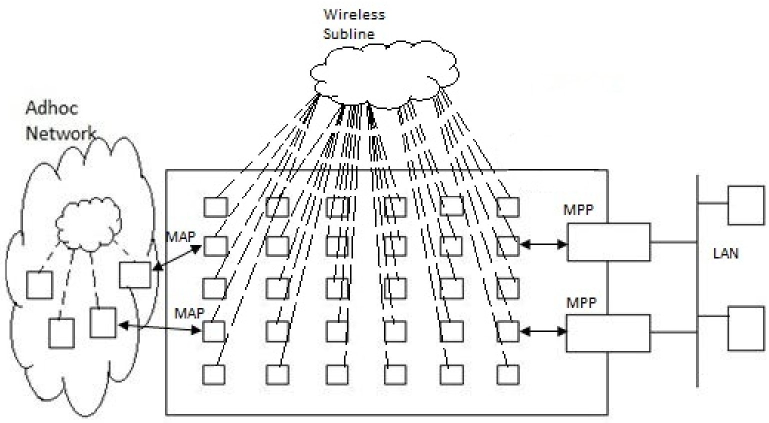

Fig.1

Mesh Points/Mesh Routers (MP) acts as backbone routers for forwarding the traffic from source to destination. Most of the functionalities are implemented in Mesh Points. Mesh points act as a router forwarding a packet from source to destination. Mesh Points are provided with multiple interfaces to accept the requests from various types of Wired/Wireless stations, Mesh Access Points (MAP) and Mesh Portal Points (MPP). Mesh Access Points (MAP) are stations situated in between mixed type of stations and Mesh Routers. MAP is responsible for providing interface to 802.11 stations and Mesh Points. Mesh Portal Points (MPP) act as an intermediate node between Mesh Points and 802.3 networks. MPPs serve as gateways for non mesh network. Mesh Stations are devices, which take part in exchanging of messages to/from wireless mesh networks. Mesh stations are equipped with NIC card and protocol stack and can connect to the mesh routers. Mesh Stations can communicate with mesh network through Mesh Routers, MAP or Mesh Portal Point.

The rest of the paper is organized as shown below: Sector II gives the working of HWMP Protocol, Division III gives the related work, Section IV sheds light on proposed routing mechanism, Algorithm and Mathematical model for proposed mechanism, Section V gives a brief overview of Routing metric used by HWMP protocol, and Section VI discusses Simulation Parameters, Results and discussions.

II. HYBRID WIRELESS MESH PROTOCOL

A. Route Discovery Process

The default route selection protocol for Wireless Mesh Networks is HWMP [2]. Path selection is nothing but finding a way to reach a given destination. The source that needs to find a route to the destination uses route discovery process. The source sends a Path Request (PREQ) frames to all their neighbors. PREQ frame is attached with Source MAC address, Destination MAC address, Path discovery ID, Time to Live (TTL), Hop count to originator, Metric and Target count and other fields [1]. If any of the neighboring nodes is a target address, it replies with a Path Reply (PREP) Frame else forwards the PREQ frames to their neighbors. This operation continues till it out reach the destination. While forwarding the PREQ frames to the next nodes, each node decrements the TTL, modifies hop count and metric to determine hop count and metric to the originator. Each station also discards PREQ frame, if the same frame reaches the nodes again. Each station uses the sequence numbers to discard the redundant frames. Once the PREQ frame reaches the destination, the destination learns the better hop count to originator. Then the destination sends PREP Frame to the originator through nearest route calculated; based on least hop count or metric. The PREP frame consists of Target MAC address, Hop count to the Target, Metric, TTL and other fields. The originator uses this path to forward the data frames. The Process of route discovery process is shown in figure 2.

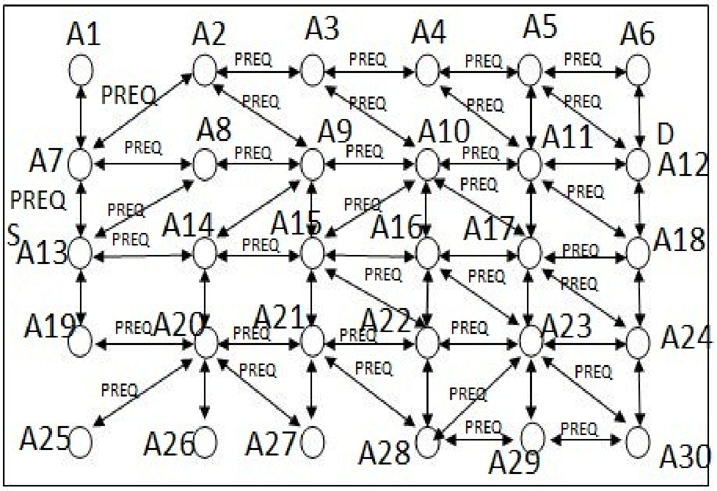

Fig.2: PREQ packets from source node.

Initially Source node A13 sends PREQ request to their neighboring nodes. These neighbor nodes forward the PREQ frames until it reaches destination node A12. When node A12 receives PREQ frames,it finds the shortest route towards source and PREP will be sent back towards A13.The PREP sent by the destination node is shown in fig 3. The route formed by this process is A13-A8-A9-A10-A11-A12.

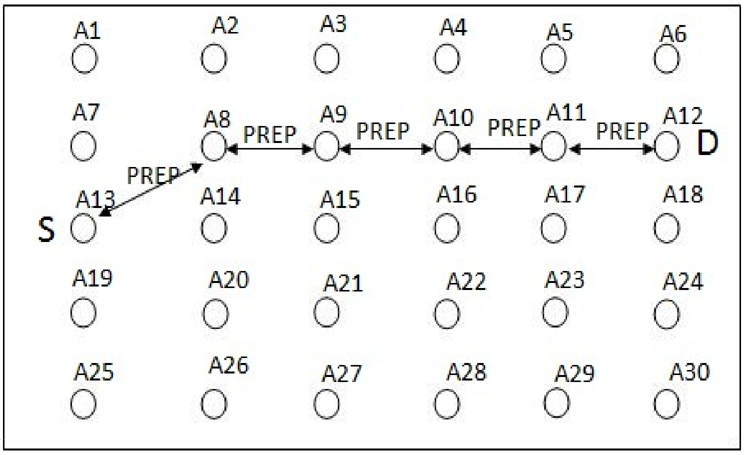

Fig.3: PREP packets from destination node

B. *Route Maintenance in HWMP*

When error occurs in nodes or links due to occurrence of faults; sends RERR frame to precursor nodes. Precursor nodes maintain the route information related to path. After receiving the Route Error (ERR)/ Path Error (PERR) frames each node checks and invalidates the path, which is affected by errors; and forward RERR frames towards source. The source also invalidates the existing path towards destination and reinitiates path discovery process as shown in figure 2.

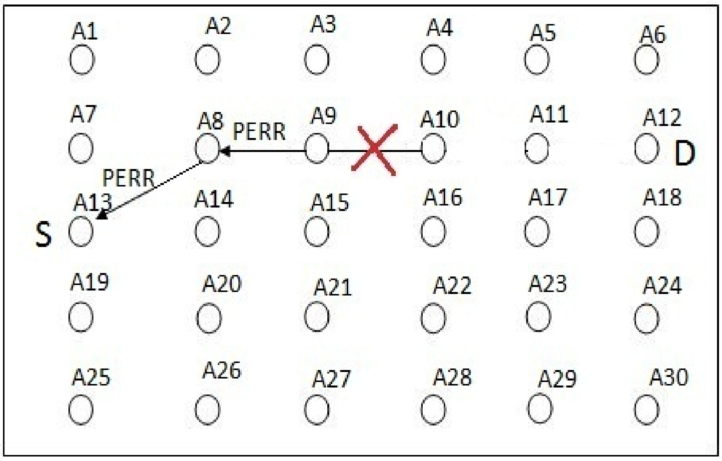

Fig.4: RERR from immediate neighbor node

As shown in fig 4, when the link between the nodes A9 and A10 is broken due to faults; usually it broadcasts the RERR frames to their neighbors. RERR frame are forwarded until they reach source node. Even though RERR contains minimum fields, it causes more overhead in a large network.

Here considering this problem; solution is worked out to avoid too much overhead. When node receives RERR frames, it unicast RERR frames to source; instead broadcasting. As shown in figure 3, the origin node begins route discovery process, when it receives RERR frames from node A8.

III. RELATED WORK

Some Researchers have proposed self-healing mechanisms for Wireless Mesh Networks.

S Menaka and M K Jayanthi [4] shed light on construction of stable route for Mobile Ad hoc network in the event of a link/node failure due to the movement of nodes. They proposed a new idea of finding a stable route using a cross layered routing metric. They stated that once the link/node is failed, the connectivity would take time to resume therefore steadiness of way is important in routing. Hence the authors considered stability factor and Received Signal Strength of a link as a metric. Here the researcher has found the principle that prevention is better than cure i.e. even before the connectivity is disconnected, routing scheme gracefully selects an alternate route. The researchers have considered Dynamic Source Routing (DSR) protocol to design a new approach.

Michel Bahr [5] describes his proposed routing for IEEE 802.11s mesh network. IEEE 802.11s standard supports multi hop routing. The Bahr revealed new mesh data frame format for 802.11s standard. He also defined the format of frames and working of HWMP. The routing in Mesh Network is different from routing in Ad hoc network. In WMN, the nodes/routers/Mesh Points are static in nature and in Ad hoc network the stations are mobile in nature. WMN acts as a backbone for Wireless LAN Access points. Ad hoc network uses different routing protocols such as Ad hoc on demand Distance Vector Routing (AODV) protocol and Dynamic Source Routing (DSR). Since the architecture of Mesh wireless network is different from Ad hoc Network, the protocols designed for Mobile Ad Hoc network may not be suitable for WMN. At present, Wireless Mesh Network using HWMP as a standard routing protocol, which uses MAC address for finding a shortest path; whereas AODV and DSR uses IP addresses for finding a shortest path.

Kishwer Abdul Khaliq . [8] Proposed a congestion avoidance technique. Here modifications are done to HWMP protocol for IEEE 802.11s for avoiding the congestion. This proposed mechanism offers localized rerouting, which minimizes overhead. This mechanism works similar to HWMP protocol but checks for threshold queue level. The proposed mechanism considers Queue level to detect congestion. Queue level is set to some threshold value. When queue level is below a threshold rate, it onwards the PREQ packet to another nodes. When Queue size reaches threshold value the neighbor node sends Congestion Control Notification Frame (CCNF) to its neighbors. These neighbors send PREQ (Path Request) frame to discover a new route to destination. Once PREQ frames reaches destination, sends PREP frame to source to form an alternate Route. Khaliq also shows that his routing mechanism has better performance compared to HWMP protocol, but there is a chance of more overhead due to sending of CCNF frames, so it may degrade the scalability features.

IV. PROPOSED ROUTING MECHANISM

In the proposed routing mechanism, when the node receives RERR frame from the node which is affected by the fault, normally it broadcast RERR frame to their intermediate nodes. All the neighbor-nodes which receive RERR frame, they forward RERR frame until they reach the Source. Then source reinitiates route discovery process to find the way from starting node to goal node.

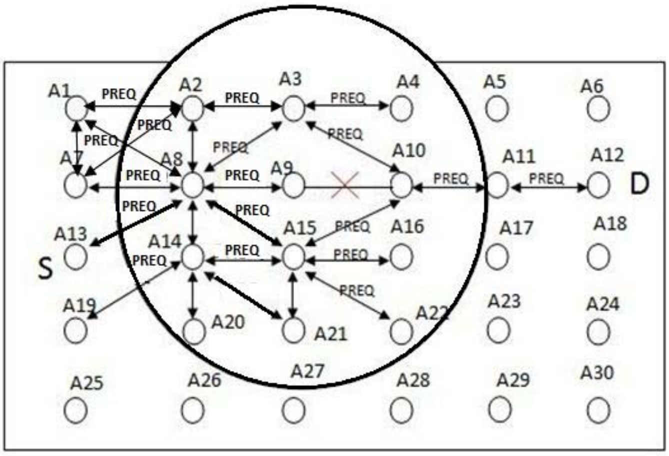

Fig.5: PREQ packets after applying LRR-HWMP.

In this proposed mechanism, the node which receives RERR frame is responsible for finding a new route towards destination instead of source node. This particular node acts as a origin node and goal node is kept the same. Once it receives RERR frame; it triggers path inventing process by sending PREQ frames to their neighbor nodes. Here instead of sending the PREQ packets to entire network, it limits the journey of PREQ packets; the PREQ packets are broadcasted only to few number of hops (2 hops) which are assigned initially as shown in figure 5.

A. Methodology

In case of failure, only the node which has the path towards the source receives RERR frame i.e. the RERR frame is unicast towards the source node. This node is responsible for finding the alternate path towards destination. So make the node which received the RERR as a source (temporary source node) and next node to error node towards destination as temporary destination node. The temporary source node is in charge of discovering a path to temporary destination node and hence broadcast the PREQ frames with limited hops to their neighbors. The PREQ frames are forwarded until it reaches temporary destination node. The temporary destination node sends a PREP frames to the temporary source node along with minimum hops or better metric. This proposed mechanism avoids forming a path twice from source node to temporary source node and temporary destination node to destination node; since path is already available from source node to temporary source node and temporary source node to temporary destination node i.e. A13- A8 and A11-A12. So in this paper efforts are made to repair the route locally.

B. Algorithm

- Let Ns is the sender, N_d is the destination, Ni is the intermediate nodes where i=1,2,3...
- N_{iu} (A8) is the immediate upstream intermediate node which receives Error; N_{ie} (A9) is the Error node which sends error.
- N_{id} (A10) is the immediate downstream node to error node.
- N_{idn}(A11) is the next immediate downstream node from error node

If path between N_{ie} (A9) and Nid (A10) is broken

Nie (A9): Send (RERR frame)

N_{iu} (A8): Receive (RERR frame)

Number of hops = 2

Temporary source = Niu (A8)

Temporary Destination= Nid (A10)

Niu (A8): Send (PREQ Frames)
Nid (A10): Receive (PREQ frames)
A10 sends PREP Frame to A8 via Different path
PREP Frame consists of shortest route based on Metric

- Locally route is Formed and unicast the route to A8 and A10
- Join the local route to the main route so that it can again form route A13-A8-A9-A10-A11-A12.

C. Mathematical Model

a) Existing Routing Mechanism

Normally Total Time taken for processing a Frame along the network from source to destination by HWMP protocol in the first iteration is given by.

$$\text{Total Time} = \sum_{i=1}^{n} t_{mi} + t_{pi} \quad \ldots (1)$$

Where n is the total nodes, t_{mi} is the time taken to calculate metric value and t_{pi} is the time taken to calculate remaining part of the frame. The above equation can be written corresponding to the figure 2 is given by

$$\text{Total Time} = \sum_{i=1}^{A8} t_{mi+} t_{pi} + \sum_{i=A8}^{A11} t_{mi+} t_{pi} + \sum_{i=A11}^{A12} t_{mi+} t_{pi} \quad \ldots (2)$$

Where A8, A11, A12 are the intermediate nodes from source towards destination. t_{mi} and t_{pi} are time taken to calculate the metric and remaining frame respectively.

Total Time taken for processing a Frame along the network from source to destination by HWMP protocol in the first iteration is same as equation 2. When the Link is broken between two nodes it reinitiates route discovery process than also the time taken by these nodes is same as in Equation 2.

b) Proposed Routing Mechanism

According to Proposed routing mechanism Total Time taken for processing a Frame along the network from source to destination by HWMP protocol in the first iteration is same as equation 2. But when the link is broken between two nodes, locally route will be repaired. So the Time taken for HWMP protocol in the second iteration is given by

$$\text{Total Time} = \sum_{i=A8}^{A11} t_{mi} + t_{pi} \quad \ldots (3)$$

V. ROUTING METRIC

Routing metrics plays an important role in judging the cost or efficiency of a route. In other words the design of routing metrics helps to identify the capable path to the destination in a network . Basic metrics are designed based on hop count, are not efficient for selecting the efficient path and some other parameters are also need to be considered. The design of a routing metric is a very challenging research problem because it helps to capture various parameters related to route stability, Asymmetry of wireless links, choosing optimum path and to avoid loops in routing, basic load interference and Quality of Service parameters. In this default routing metric called Air Time Link Metric (ALM) is considered as default routing metric for calculating a path from source to destination. The ALM metric is calculated by using following equation.

$$\mathbf{Ca= [O+Bt/r]*(1/(1-e_f))}$$

Where O and Bt are constants, r is the rate of transmission, ef is the frame error rate and Bt is the size of a frame.

VI. SIMULATION PARAMETERS

Parameters	Values
Number of nodes	16, 20, 24, 28, 32
Terrain	1500*1500
MAC layer	802.11s
Protocol	HWMP, SLRR-HWMP
Simulation Time	300 sec
Application	Constant Bit Rate
Packet Size	512 bytes
Packet Rate	2mbps
Transmission Range	150m
Topology	Random

Simulation results and Discussion

We have used Qualnet tool for measuring the performance of HWMP routing protocol. Qualnet is Proprietary tool which provides very good support for implementing a new routing mechanism. The experiment has been carried out in windows Operating system environment. Constant Bit Rate (CBR) application is used to create traffic in network. Random topology is used here to place the nodes in a network.

Simulations have been done by considering the below parameters:

Packet Delivery Ratio (PDR): Ratio of the total packets Received by destination to the Number of packets Sent by starting node.

End to End Packet Delay (E to E Delay): is defined as the Time used by the data packets to reach destination.

Control Overhead (CO): Specifies the total control packets used by routing protocol to route a packet from origin node to goal node.

- *Scenario A*

In scenario A, we have considered number of nodes and simulated for different parameters by considering number of nodes. Here the HWMP performance is evaluated by considering the normal execution of HWMP protocol and by considering broken route from onset node and finishing node. The same scenarios are considered and evaluated by considering our proposed mechanism named as SLRR-HWMP protocol. The results are calculated for Packet Delivery ratio, End to End delay and Control Overhead.

The figure 6 indicates the throughput when the nodes use HWMP protocol in the normal mode i.e. HWMP (N), and by introducing fault i.e. HWMP (D) and our proposed mechanism called SLRR-HWMP. Here we can observe that as the node number increases, more packets will be dropped; in turn reduces throughput. This situation is worse in the case of introducing the fault. This graph shows slight improvement for the proposed approach i.e SLRR-HWMP over HWMP (D).

The figure 7 indicates the Average End to End delay, when the nodes use HWMP protocol in the normal mode i.e. HWMP (N), and by introducing fault i.e. HWMP (D) and our proposed mechanism called SLRR-HWMP. Here we can observe that that as the node number increases, the average End to End delay increases when introducing a fault i.e. in HWMP (D). Because of path failure and time to repair will be more compared to HWMP (N).But in the case of SLRR-HWMP protocol, the average End to End delays decreases with respect to HWMP (D).

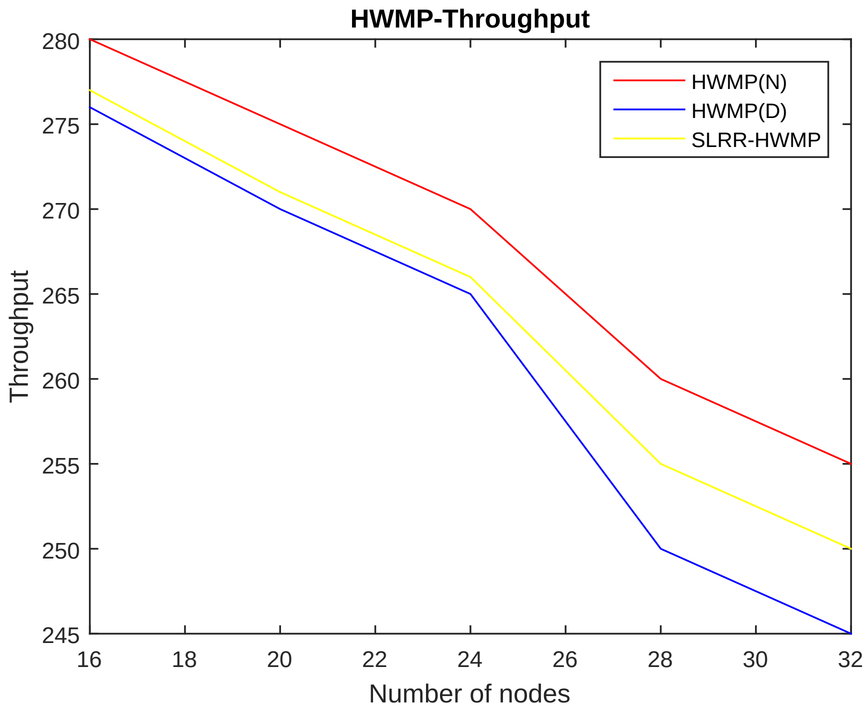

Fig.6: HWMP-Throughput

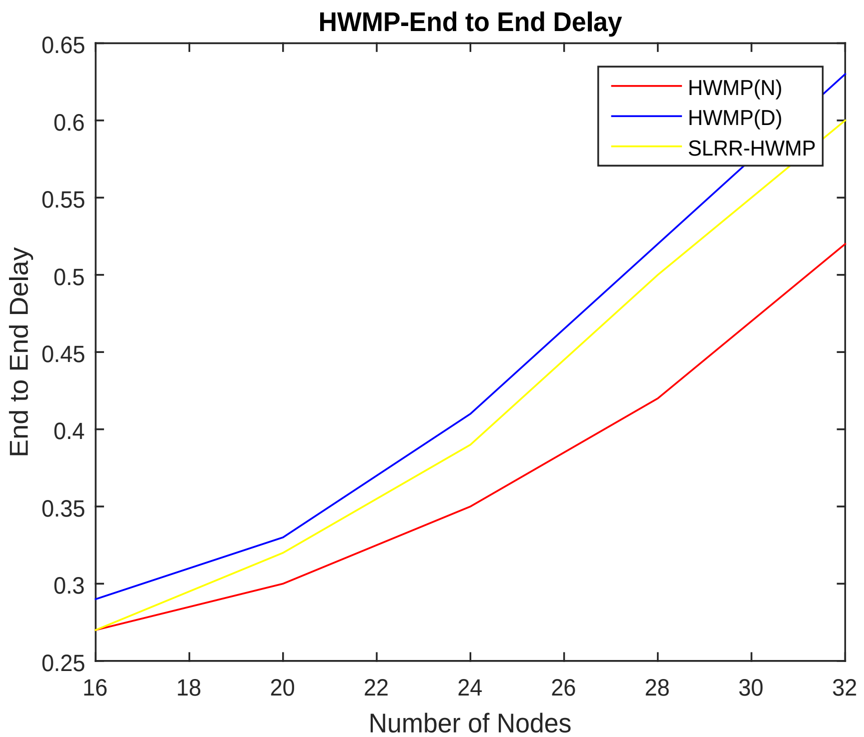

Fig.7: HWMP-End to End delay

The figure 8 indicates the Control Overhead, when the nodes use HWMP protocol in the normal mode i.e HWMP (N), and by introducing fault i.e HWMP (D) and our proposed mechanism called SLRR-HWMP.

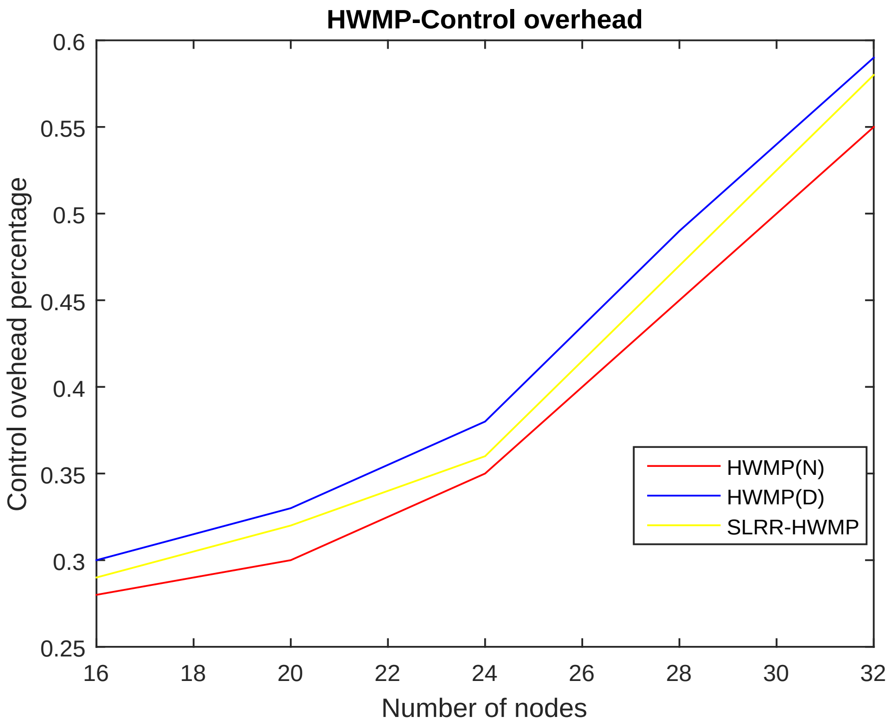

Fig.8: HWMP-Control overhead

The figure 8 also shows that as the node number increases, the control overhead increases when introducing a fault i.e. in HWMP (D). Because of path failure and control packets for discovering a route will be more compared to HWMP (N). But in the case of SLRR-HWMP protocol, the control overhead decreases when compared to HWMP (D).

- *Scenario B*

In scenario B, we have considered multiple inputs and multiple outputs and evaluated for different parameters. Here the HWMP efficiency is evaluated by considering the normal execution of HWMP protocol and by considering broken route from source node and destination node. The same scenarios are considered and evaluated by considering our proposed mechanism named as SLRR-HWMP protocol. The results are calculated for Packet Delivery ratio, End to End delay and Control Overhead.

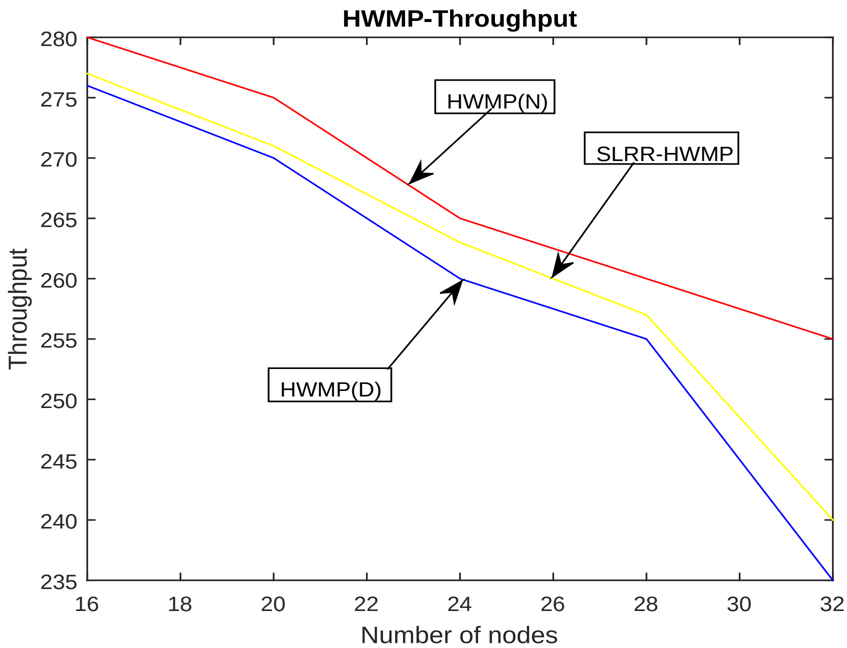

Fig.9: HWMP-Throughput (Multiple inputs and multiple outputs).

The figure 9 unveils the throughput when the nodes use HWMP protocol in the normal mode i.e. HWMP (N), and by introducing fault i.e HWMP (D) and our proposed mechanism called SLRR-HWMP in the case of multiple input and multiple output. Here we can observe the sudden packet loss rate, as the node number increases; which in turn reduces throughput. This situation is worse in the case of introducing the fault. This graph shows slight improvement in the throughput for the proposed approach i.e. SLRR-HWMP over HWMP (D).

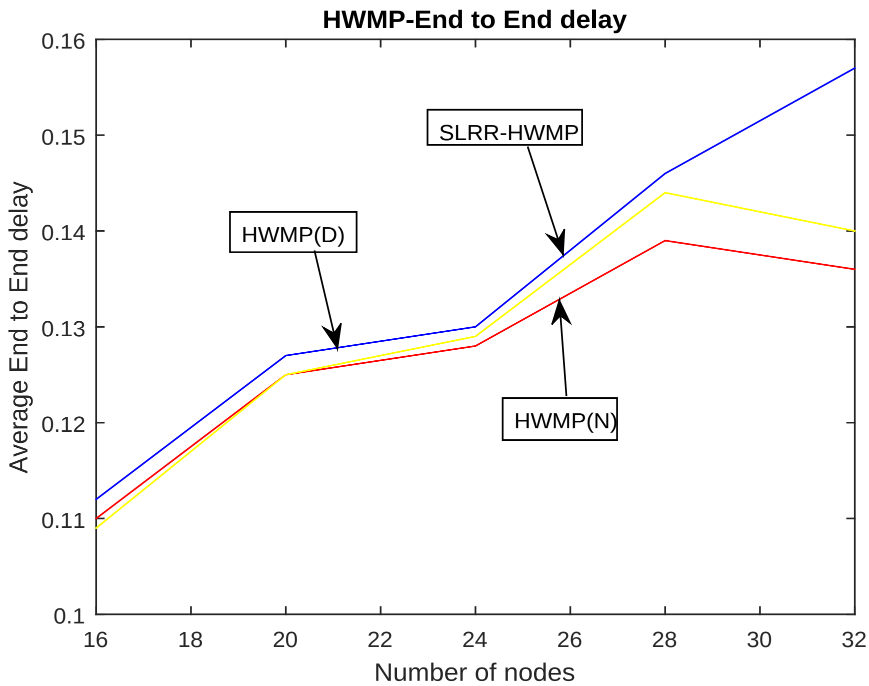

Fig.10: HWMP-End to End Delay (Multiple inputs and multiple outputs).

The figure 10 discloses the Average End to End delay, when the nodes use HWMP protocol in the normal mode i.e. HWMP (N), and by introducing fault i.e. HWMP (D) and our proposed mechanism called SLRR-HWMP. Here we can observe that that as the node number increases, the average End to End delay increases when introducing a fault i.e. in HWMP (D). Because of path failure and time to repair will be more compared to HWMP (N). But in the case of SLRR-HWMP protocol, the average End to End delay decreases compared to HWMP (D).

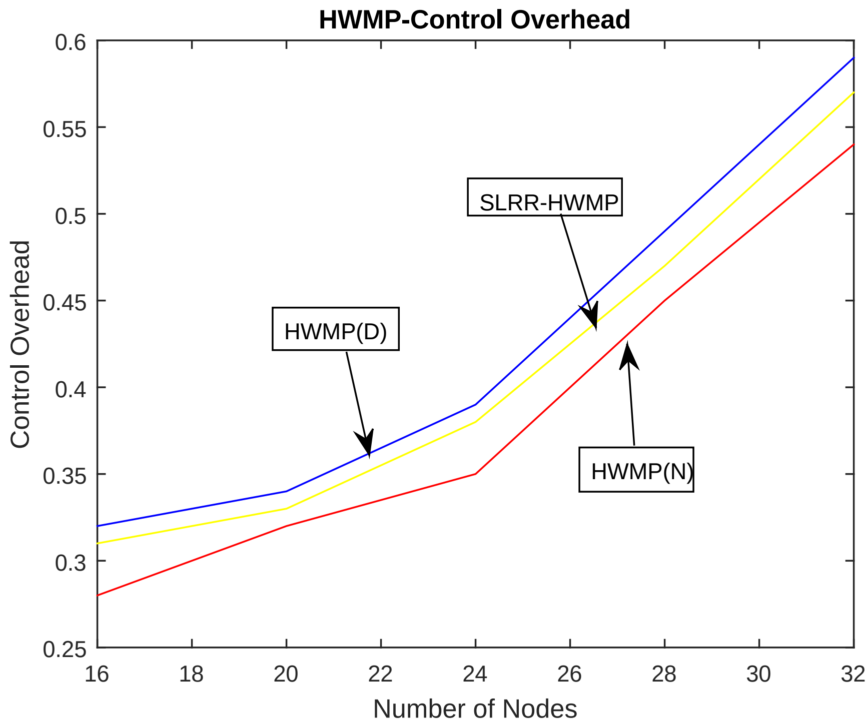

Fig.11: HWMP-Control overhead (Multiple inputs and multiple outputs).

The figure 11 represents that, as the number of nodes increases, the control overhead increases. This situation worsens when introducing a fault i.e. in HWMP (D). Because of path failure and control packets for discovering a route will be more compared to HWMP (N). But in the case of SLRR-HWMP protocol, the control overhead decreases when compared to HWMP (D).

The results reveal that, after applying proposed routing mechanism (SLRR-HWMP), results are improved slightly in terms of Packet Delivery ratio, End to End delay and control overhead since we have considered only a few numbers of nodes as shown in graph 3.

In the proposed routing mechanism, the default values of initial RREQ, RREQ TTL Increment, RREQ TTL threshold and mesh diameter values are limited to Minimum values. So when any node receive RERR packet from the neighbor node, it initiates path discovery process by calling Expanding Ring Search algorithm (with Mesh Diameter=2) and hence it sends RREQ packets only to their two hop neighbors and route is formed locally instead starting from the source node. This mechanism slightly reduces number of control packets and hence reduces overhead.

Since SLRR-HWMP limits the number of PREQ packets used for route formation; LRR-HWMP repairs the route locally. LRR-HWMP protocol shows better accomplishment in terms of Packet Delivery Ratio, Routing Overhead and Average E to E Delay. Especially for a large network; this proposed routing mechanism is a boon. Since it minimizes number of PREQ packets.

CONCLUSION

Wireless Mesh Networks getting popular because of flexible architecture for providing Internet. WMN is an extension of an existing Wireless Local area network designed to provide scalability. Even though HWMP protocol is the default routing protocol for 802.11s (Wireless Mesh Network), there are many challenges related to routing and remain unsolved. This is an attempt to design and evaluate a new routing mechanism called Local Route Repair mechanism for HWMP protocol called SLRR-HWMP. Fresh endeavor of research in this paper presents local route repairing technique; it considers only the neighboring nodes to repair a route locally and hence minimizes overhead, Time and cost. Under this mechanism route is repaired locally and avoids unnecessary control overhead and thereby increasing the scalability. The results also reveal better performance compared to existing protocol. It is evident from our newly attempted work of research output that SLRR-HWMP routing mechanism will be a boon for a large network.

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