

Active Path Updation for Layered Routing (APULAR) in Wireless Mesh Networks

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Abstract

One of the major research issues in the Wireless Mesh Network (WMN) is routing. The routing protocols of ad-hoc networks can be applied for WMN, but have limited success because, ad-hoc networks are mainly structure less networks with highly dynamic topology and harmonized nodes, where WMN are relatively static network with two types of nodes, one fixed mesh routers and mobile clients. In layered routing protocol, source node initiates a path establishing process whenever path breaks. It will cause huge control packets and increase packet loss. This is not an ideal method in WMN where every nodes rather than source and destination in the path are motionless. One way of overcoming this is by initiating the local route repair by destination node.. In this paper, we propose an active path updating procedure (APULAR) for quickly updating the broken path to recover from packet loss. Moreover, to improve throughput and to reduce the co-channel interference, we use multiple interface with multi channels. We are considering 4-hop as an interference range and will use fixed channel assignment within the mesh routers to reduce the inter flow interference. Our procedure is simulated in NS2 and compared with AODV and Infrastructure Wireless Mesh Routing Architecture (IWMRA). Simulation results show that our protocol performs better than IWMRA and AODV in key performance metrics like packet delivery ratio, control overhead, average throughput and end-to-end delay.

Keywords: Active path repair, channel assignment, multi channel routing, and wireless mesh network routing.

1. Introduction

The places where the wire network positioning is impossible or expensive there Wireless Mesh Networks (WMN) [9] came as a good thing to adhere coverage to build self-configuring, self-optimizing and self-healing network and serve as broadband wireless access to the Internet. These networks proved to be an effective substitute for various range of applications, such as public safety and emergency response communication, intelligent transportation system, and community network.

A WMN comprises of two kinds of wireless nodes [9]: Mesh Routers (MRs) and Mesh Clients (MCs). The mesh routers have soprano computational, communication and power resources as compared to mesh clients. Mesh routers are generally static and form a multi-hop backhaul network with high-capacity connections. Moreover, mesh routers are characteristically kitted with multiple wireless network interfaces to associate auxiliary nodes. The existing communication infrastructure provided by the mesh routers aid the mesh clients, mobile devices. Wireless networks can operate as [19]: infrastructure and ad-hoc. In the infrastructure mode, a device node termed as access point is answerable for centralizing communications amid all other nodes. However, in the ad-hoc mode, there is no such special centralized device and offered nodes are homogeneous. Each node has alike routing potential, packet delivery and moreover all the nodes have the same kinds of limitations. On the other hand in paradigm of WMN three kinds of networks are present [17]: Infrastructure, Client and Hybrid. Client network and ad-hoc network are alike. However, in case of an infrastructure network, the mesh router forms the spine of the network and dynamically involves in routing, where as mesh clients procure access through the mesh routers and are passively involved in forwarding the packets and routing. A network of infrastructure WMN is portrayed in Figure 1. Therefore, infrastructure WMN comprises all the nodes of the mesh router, which forms the spinal column and the mesh clients, which are immediate neighbors of the mesh router. A hybrid network combines the connective pattern of both the infrastructure and client WMN. Routing and packet forwarding is mainly done by mesh routers, mesh clients are used only when there is no mesh router within the radio range.

Usually, for route updating, source node commences the route detection procedure in case of any link malfunction. This is not favorable for infrastructure wireless mesh networks. In WMN all the nodes in the path excluding source and destination are static. Therefore, to discover the entire path from source takes elongated time and generates huge control packets overhead and increase packet loss. In this paper, we have proposed an active path updating procedure where the destination node takes the obligation of doing the local repair restoration. As mesh routers have less resource limitation and high computational power, in common each mesh router use multiple channels multiple radios. We also proposed a routing protocol for multi-channel multi-interface based on the layered routing architecture. We identify three key parameters (1) Packet delivery ratio (2) Average control overhead (3) End-to-end delay to make efficient routing in WMN. Our method is simulated with layered routing architecture, which reduces the packet loss, delay and control packet overhead than AODV and IWMRA. We term this as Active Path Updation for Layered Routing (APULAR)

The rest of the paper is organized as follows: In the next section, we give a brief survey on routing procedures in wireless mesh networks. The section III describes the Active Path Updating for Layered Routing (APULAR) in Wireless Mesh Networks. In the section IV, we give the simulation result and the analytical comparison of our protocol with AODV and IWMRA. The last section concludes with future research directions.

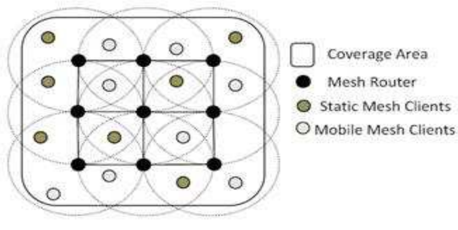

Fig.1

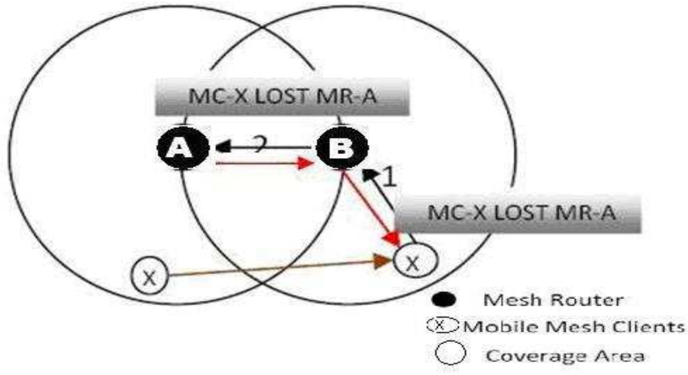

Fig. 2

Figure 1.
Infrastructure Wireless Mesh Network
Figure 2. Notification of Neighborhood Lost

2. Routing In Wireless Mesh Network

Wireless mesh networks and mobile ad-hoc networks both use the same key concept communication between nodes over multiple wireless hops on a network graph. So the initial researchers applied various MANET routing protocols to WMN [17]. However, these attempts had little success due to the following structural difference [9]:

- Multiple Performance Metrics: All the routing protocols in an ad-hoc network are generally based on the hop count as a routing metrics. As WMN has two different types of node structure so only hop count need not be optimal. We have to first consider the mesh router then mesh clients in routing for WMN.
- Scalability: Setting up or maintaining a routing path in a very large wireless ad-hoc network is difficult because all the nodes are involved in routing and packet forwarding and each node have same energy and routing operation constraints. In WMN, only mesh routers are involved mainly in routing and packet forwarding since they have less constraint of energy and routing operation. Mesh clients participate in the routing only if there is no MR but to perform different routing procedure for different node is difficult.
- Robustness: It is also required to balance the load for routing protocols but for WMN, it is difficult because the different node has been different routing capabilities. Routing in WMN must be robust to avoid link failures and congestion.
- Efficient Routing with Mesh Infrastructure: Routing for mesh router is simpler than ad-hoc network routing because it has minimal mobility and less power constraints than the ad-hoc network node. To compatible with mesh routers the routing protocols for mesh clients can also be made simple.

Ad-hoc as well as wireless mesh routing is usually classified on the basis of routing information maintained, which are: topology-based and position-based routing protocols. Topology based routing protocols select path based on the topological information, such as links between nodes. We describe some of the important protocols below.

Improved Hierarchical AODV Routing Protocol for HWMN (IH-AODV) [13] is a hierarchical based AODV routing. It combines the property of Cluster Head-Gateway Switch Routing (CGSR) and Way Point Routing (WPR). It divides the network into clusters, inside the clusters, there is no cluster head, and instead it uses the special nodes named Way Point (WP). Outside the clusters, it uses AODV for routing. As WMN has many static nodes in the networks, it defines them as WP nodes; other nodes are termed Cluster Member nodes (CM).Route discovery is done by WP nodes. Each WP maintains its own Cluster Member List Table (CMLT). In every cluster, there are two WP nodes named start-WP and end-WP. Two neighboring clusters share a common WP node, which acts as the end-WP node of the upstream cluster and the start-WP node of the downstream cluster. For link breakage, the WP nodes first find another CM within the cluster, if possible then starts sending data otherwise send the local repair to the source.

Wireless Mesh networks Routing Protocol (MRP) [10] and Dynamic and Reliable Mesh Routing Protocol (DRMRP) [7] use the hierarchical approach for the routing purpose, and they only maintain routing tree between clients and the gateway nodes. Each node has information of its nearest gateway node. Routing operation performs in two phases, in first phase all the clients get the path information of the nearest gateway node and in second phase, the nearest gateway node has the knowledge of its new clients. If any node detects the loss of path information with the neighboring upper layer node, it sends the Route Error (RERR) message to all of its children. And all the disconnected nodes want to find the path for the gateway node. Even if the node discovers the new path, the previous children do not be able to use the path to receive the data coming from the gateway node. Design and Implementation of Infrastructure Mesh Networks

(AODV-ST) [11] [14] is a hybrid routing protocol developed specifically for infrastructure mesh networks. It mainly developed for providing internet access to clients from one or more gateways. To discover the routes between Mesh Router and gateway use proactive strategy and routes between Mesh Routers use reactive strategy. The gateways periodically broadcast special RREQ packets for the creation of spanning trees from gateway to mesh routers. All the nodes after receiving these RREQ packets create a reverse route to the gateway. The mesh routers also send a RREP packet to the gateway in order to enable the formation of forward routes. All subsequent RREQ packets with a better routing metric are used to update the existing reverse route to the gateway before being re-broadcast in the network.

An improvement of the quality of service in AODV routing protocol for WMN is described in [15]. It modifies the route reply procedure for maintaining several paths from the source and through intermediate nodes to reduce the packet loss. In this case, RREP packets are broadcasted through the network for maintaining multi path from source and intermediate node. If link failure occurs, the node stops transmission and repeat the operation after the selection of a new one from the other paths. Position based routing [12] protocol selects path based on the geographical information with geographical algorithms, using the position of the nodes. Example of the position based routing for wireless mesh networks are Orthogonal Rendezvous Routing Protocols (ORRP) [4] [5], an architecture for Seamless Mobility in Spontaneous Wireless Mesh Networks [8]. There are routing protocols, which uses both the property. One way of improving the throughput of routing protocols is by using multi radio and multi channels.

Multi Radio Ad-hoc on demand distance vector Routing (AODV-MR) [2] Establishing High Capacity Routes in Wireless Mesh Networks (AODV-S) [3] are multi interface AODV, which broadcasts RREQ message on all node interfaces. Thus, the intermediate node with one or more interfaces, which operate on a common channel, will receive duplicate copies of the RREQ Packet. In AODV-MR the first Route Request received at the intermediate node is selected, and all subsequent Route Requests are discarded but in AODV-S instead of receiving the first copy of the RREQ only and discarding the rest, receives and processes all incoming copies on all interfaces. After receiving the first RREQ in AODV-MR a reverse path is established with the recommend interface. In AODV-S the route request process stops after receiving the multiple copies of RREQ in multiple channels by the destination node or any other node, which has active route information to the destination. That node responds with a RREP, which contains information about the channels through which the next hop is accessible. Using this route discovery process, all nodes have information about the channel numbers that can be used to directly communicate with their adjacent nodes. The link selection is carried out based upon two criteria - first to achieve a two-hop channel diversification, and second least congested links, indicated by the minimal interface queue (IFQ) length.

The High performance AODV routing protocol for HWMN (HP-AODV) [18] and a wireless mesh network routing protocol for incident area communications (SafeMesh) [1] both modified version of AODV. Both try to establish routes preferentially via mesh routers and involve mesh clients only when absolutely necessary. HP-AODV uses the (hop count) - (mesh router count) as a routing metric instead of simple hop count and nodes forwarding a RREQ packet also recommended the optimal channel, which is subsequently used to communicate with the next hop. SafeMesh selects two hops as an interference range and the node selects the channel, which is not used in previous two hops. In both cases if the node has no free channels with the previous considering channel, selects the least congested channel from the available channels. If a link break occurs, the protocol immediately repairs locally by switching the alternative link with lowest congested. If no alternative link is available, it generates a RERR to initiate a new route discovery. Then the new route will be discovered by the node observing the link breakage or the source node.

3. Active Path Updation in Layered Routing

In infrastructure WMN, mesh routers are almost static and clients are mobile. In such scenario route failure can happen because of mobility of source or destination nodes. In traditional routing protocols source initiates the route discovery procedure whenever route failure occurs. This can generate huge control packets and increase packet loss. One way of overcoming this is by initiating the local route repair by destination node. We can use this local repair to any routing protocols but for the sake of completeness we have integrated these routing protocols with layered routing architecture [6].

Layered routing architecture [6] performs routing in three independent layers: neighborhood layer, topology layer, and routing layer. Neighborhood layer is responsible for finding the neighbors based on flooding and this actually done by the MR's not by MC's. When an MC receives a HELLO message sent by an MR, first, it includes the MR in its neighborhood table and replies with a HELLO message to notify the MR about its existence. Using, the exchange of a pair of HELLO's the neighbor relation between two MRs and MR and MC is fully established. After finding the neighborhood information, topology layer use flooding to disseminate the neighborhood information all over the network. Only MR's involve in maintaining all the routing information of the network. Our protocol considers two types of clients, static MC's and mobile MC's. The MC's which are slowly moving or static is called static MC's and highly mobile MC's are called mobile MC's. Every time an MR detects the neighborhood with an MC as missing, the MR compares the neighborhood time interval with a threshold defined by the topology layer. When the time interval is lower than the threshold, the MR designates the MC as mobile, otherwise static. An MC will be only designated as static again when an MR detects that the mobile MC stays in its neighborhood for a time interval higher than the threshold employed to define the MC as mobile

The Routing Layer follows different strategies depending on the type of node. Mesh router adopts a proactive approach to find the route for static nodes (mash router and static mesh clients) and reactive approach for mobile clients. Mesh client adopts a reactive approach for route discovery. Each MR's use the proactive procedure to maintain shortest path information to all MR's and static MC's in routing table. MC can change its neighbor MR and its state from static to mobile or vice-versa. The topology layer decides MC is static or mobile, based on the duration of their link time interval. Whenever an MR detects a link with an MC is lost, the MR compares the link time interval with the threshold time defined by the topology layer. If the time interval is lower than the threshold, the MR designates the MC as mobile otherwise static.

In infrastructure WMN all the mesh clients receive packets through the mesh router because mesh routers mainly participate in routing and packet forwarding. There may be a chance that mesh clients change its neighbor while receiving packets. It is a very difficult condition to control. Link failure in infrastructure WMN can happen due to change of neighbor MR of either source or destination. If the source node changes, than whole route information fails and source again sends the RREQ packet to the new neighbor MR's and MR's take care of this. But if the destination client changes its MR than, there are two procedures to handle. First, an up-link node of the link break performs the local repair. Other, up-link node sends the error to the source node and source node again finds the optimal path. But both the procedures are not optimal. Because in the first method route is not optimal for infrastructure WMN and the second method takes longer time to find the path.

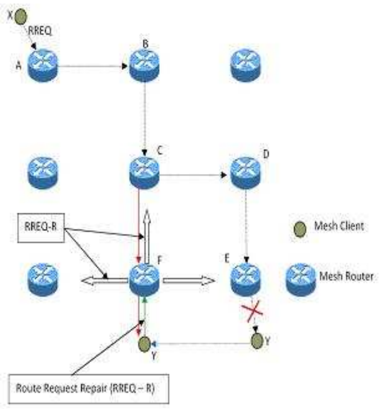

Fig.3.

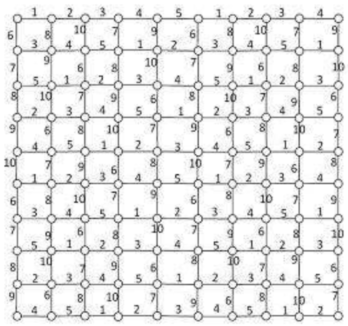

Fig.4

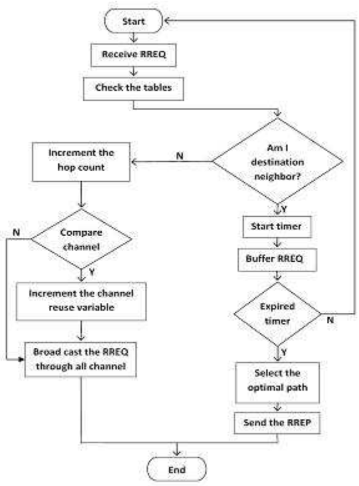

Fig. 5

Figure 3. Route Updation Procedure

Figure 4. Fixed Channel Assignment

Figure 5. Flow chart of the destination/intermediate node

In our proposed method if MC is moving within the radio range of a MR then the MC finds that it is under the same MR and MR considers the MC as a static node. A MC can be static for one MR and mobile for another MR. A node is static or mobile is decided by the Topology Layer and if it is static then only the node information is distributed to other MR's. Any changes in neighbors generate a cascading update in the network. During the data transmission if the source node moves to another MR then source node stops packet delivery and starts finding a new route. If destination node moves to another neighbor MR then source has no information of this and it continues the packet sending. New neighbor MR forwarding the notification to the lost MR. Note that the forwarding do not generate additional messages because it piggybacks on periodic HELLO's of neighbor MR. Considering the example network given in the figure 2, when the MC-X leaves the MR-A's neighborhood area, the neighborhood entry associated with MR-A expires in MC-X.

As a result, MC-X sends a HELLO including the notification that the neighborhood with MR-A has been lost (arrow 1). MR-B receives the HELLO message and forwards the notification in its next periodic HELLO (arrow 2). When MR-A receives the HELLO message from MR-B, it discovers that the neighborhood has been lost and then removes MC-X from its neighborhood table.

If mesh clients want to send data, it simple broadcast a RREQ packet. The neighbor MR's within the communication range receives the RREQ packet and starts finding the path for the destination node. The node, which has the destination node information or neighbor of the destination node, sends the RREP to the source node. This is the general route request procedure for infrastructure wireless mesh network. In order to assist in efficient local route repair, neighbor table contains source node and flag in addition to neighbor MR and expire time for each flow. Initially the flag is set to zero. If the node receives any data packet then set the flag to 1 and writes the source node address from where it is receiving the data packets with the corresponding neighbor MR. Below we describe the route repair procedure.

1. If a mesh client change its neighbor MR then mesh client inform the new neighbor mesh router about the neighborhood loss with the previous MR. Now the new MR inform the neighborhood loss to the previous MR through the HELLO message with piggybacking
2. For each flow in the neighbor table of the client, MC sends a Route Request Repair (RREQ-R) packet.
3. When nearest MR receives the RREQ-R it first checks the status of the source node. If the source node is static then the MR has route information but it has to inform the source node about the new minimum hop path. MR sends the RREQ-R unicast to the source node with set destination field. Here set destination field means only the destination node can send the reply. After getting the new path information the source node follow the new route to send the packet.
4. If the source node is mobile then MR has no information about the source node, so it broadcast the RREQ-R packet for the source node. If any intermediate node is receiving the packet for that source node to this destination node then it simple updates the routing information and automatically packet flow through the new path.

Consider the example network given in the figure 3. It has 3 x 3 grid MR's topology with two MC's, MC-X and MC- Y. MC-X and MC-Y are respectively neighbors of MR-A and MR-Y. The source node MC-X uses the path X, A, B, C, D, E, and Y to send data to MC-Y. When MC-Y finds the neighbor relation lost with E due to change in its position, it broadcast neighborhood loss information through HELLO packet. MR-F informs the MR-E after receiving the HELLO packet. MR-E forwards the buffered packets and the packet, which is receiving currently. For the present flow MC-Y sends a RREQR packet to MR-F. Now MR-F, after receiving RREQ-R, checks whether the source node (MC-X) is static or mobile node. Here we are considering both source and destination are mobile nodes. So, MR-F broadcast RREQ-R for MC-X. MR-C, after receiving the RREQ-R, finds that he is receiving the packet from the source node MC-X to the destination node MC-Y so, MR-C immediately sends the RREP to the MR-F. If MC-X is static than MR-F unicastly sends the RREQ-R with set 'destination field'. That means only destination node can send the reply. This is because, neighbor MR, MR-Y, has shortest path to source node but neighbor MR has to inform the source node to follow this route for sending the packets

Consider a source node S that requests to send packets to a destination node D. Both nodes S and D have their own local notions of orientation. Source S sends route discovery packets in four orthogonal directions and the destination D does the same for route broadcasting packets. The route discovery packets will rendezvous at a node touched by a route broadcasting packet at up to two rendezvous points on the plane. We refer to the intersection that facility a shorter path as the rendezvous node R. Node R directs packets from source S to the destination D. If source is mobile MC's then it is a periodic route updating procedure when destination neighbor MR starts flooding RREQ-R and the packet finds a rendezvous node [4], which has the knowledge of the searching node, and packet start forwarding through this rendezvous node. That means now the destination MR stop flooding RREQ-R packet but the packet, which MR has already broadcast, may find new rendezvous node. If the new rendezvous node has less number of hop distance than the previous one then route automatically update and packet flow through the new route. The format of RREQ-R packet is similar to RREQ. Please note that there is no RREP for RREQ-R

3.1 Multi Channel Multi Interface (MCMI)

In this section, we consider routing with multiple interfaces. In our fixed channel allocation we use channel 0 to communicate between MC's and MR and MC. Remaining available channels we have assigned between adjacent MR's such that the interference among neighborhood is the minimum. We divide the ten mesh router into two groups with five channels each; first five 1-5 for assigning row wise and second five 6-10 for assigning column wise. The whole channel assignment is shown in the Figure 4. To assign a channel with zero interference is N-P Hard [20] problem. Here we are using one simple procedure to reduce the inter flow interference. To assign channel in the first row we start from 1. We continue up to 5 and then repeat from 1 again. But when we are assigning second row we select the third channel assigned to the first row as a first channel. And for the third row we select the third of the second row. That means, we are considering third channel assigned to this row as a first channel for the next row. Using this procedure we assign all the rows and follow the same procedure for column assignment also.

When the node is broadcasting the neighbor information, it also broadcast the channel assignment with the neighbors. Each mesh router maintains a shortest path to all static nodes. Such that distance between same channels in each path is optimum. For mobile MC's each node uses the reactive procedure for finding the path. For reducing the interference of the proactive procedure we use one channel-reuse variable in the RREQ packet which keeps track the number of times the same channel is using within 4-hops. Here we are considering 4-hop as an interference range. That means if all the channel within the 4-hop is different than the path is interference free. The route request procedure for mobile MC's is described below.

1. Each mesh clients contain two tables' one neighbor table and another routing table. Neighbor table contains all the one hop neighbors. Neighbor table collects the value from the receiving of HELLO messages. Routing table contains all the route information.
2. When mesh clients want to send data it first checks in the both table. If the node is in the neighbor table then simple sends the data unicastly to the destination node, or if the node information is available to the routing table then send the packet through the path. If not then broadcast the RREQ packet in its channel.
3. All the neighbor mesh routers receive the RREQ because all the mesh routers have one common channel to communicate with mesh clients.
4. After receiving the RREQ from mesh clients, now the mesh router is responsible to find the shortest path with less number of same used channels within the interference range of each channel. We are considering 4-hop as an interference range.
5. Each mesh router has one different common channel to communicate with its different neighbor mesh router and the channel assignment of the mesh router is shown in the figure 4.
6. After receiving the RREQ the mesh router first checks its neighbor table. If the information is present then sends the RREP to the source node immediately. Otherwise it broadcast the RREQ to its all channel.
7. Each RREQ packet contains previous four hop channel assignment information.
8. When the mesh router wants to broadcast the RREQ packet it simple checks the previous four hop channel assignment information. If the mesh router is broadcasting through the channel which is already used within the previous four hop channel assignment then increment the `channel reuse' variable by one for this channel RREQ.
9. If the node has fresh route to the destination or the node is neighbor of the destination node then sends the RREP.
10. Here we update the route reply procedure. After receiving the first RREQ the node waits for some time to receive more number of RREQ packets from different paths or same path with different channels.
11. When the node is receiving the more number of RREQ it simple checks the number of hop and the channel `reuse variable'.
12. If the two routes has same number of hop count then only store the minimum value of the channel reuse path.
13. After the time expire the node selects the minimum hop count path with minimum number of channel reuse and unicast the RREP through the path.
14. After receiving the RREP the mesh router forwards the route information to the source mesh clients and starts data sending.

Here we are using 250m as a transmission range and 550m as an interference range. So, the same channel use with more than 550m distance does not generate any interference and we use 10×10 grid topology. That's why we use 4-hop as an interference range and all 4-hop distance must be more than 550m, interference rang. In the channel assignment of multi-radio multi-channel networks, there are two types of interference - inter flow and intra flow interference. The channel assignment procedures need to consider both these interferences. We use fixed channel assignment within the mesh routers to reduce the inter flow interference. We have assigned channels such that there will be less inter flow interference. Our proposed routing protocol reduces the intra flow interference.

The figure 5 gives the idea of the operation of the destination or intermediate node. Here when the node is receiving the RREQ packet it first checks the table because all the route find operation is done in mesh routers. Each mesh router has its neighbor information. So, when the neighbor of the destination node receives the RREQ it find the node in its neighbor table and if the node is an intermediate node and has the destination node information then the node is in its routing table. If the node is destination node or the node has the route information then after time expire it sends the

RREP to the source mesh router unicastly through the reverse route of the receiving packet. If the node is not a destination or intermediate node then increment the hop count by one, checks the channel reuse procedure and broadcast the RREQ again.

Here we also simulate AODV and our routing protocol APULAR with APULAR – 3 multi interfaces. In which, we are considering three radios per node – one for communicating with mesh clients and two for communicating with mesh routers. Here we consider one radio to communicate row wise and one radio to communicate with column wise.

4. Simulation

We use the network simulator 2 (NS - 2), practically popular in wireless networking community, to simulate. The performance of our protocols APULAR is evaluated by comparing with AODV and modified IWMRA protocols in same conditions. The simulated network topology consists of 100 static mesh routers (nodes 0 - 99) placed in a regular 10x10 grid in a 2000m x 2000m area. Distance from one mesh routers to another mesh router is 200m in horizontal and vertical direction. So there is no connection from one mesh router to another in diagonally because it is more than 250m and we are considering the transmission range of all the nodes are 250m.

Connection of the mesh router is shown by dotted line in the Figure 4. MAC protocols are the IEEE standard 802.11. The network further consists of 200 mobile mesh clients (Nodes 100 - 299), initially placed uniform randomly in the simulation area. Concurrent Constant Bit Rate (CBR) flows using the UDP protocol are established between randomly selected source and destination mesh client pairs. The traffic patterns consist of a predefined number of CBR flows. Different transmit data rates can be achieved by varying CBR parameters. CBR lets you limit the maximum number of packets that need to be sent from source to destination. Each sample data we use is an average of 5 simulations. All other default simulation parameters if not mentioned, are given in the table I.

Table I: Simulation Parameters

Examined protocols for routing & channel assignment	AODV, IWMRA, APULAR and APULAR-(MI2, MI3)
Simulation time	300 seconds
Simulation area	2000m x 2000m
Propagation model	Two-ray Ground Reflection
Mobility model of Mesh Clients	Random way point
Transmission range	250 m
Interference range	550 m
Packet Size	512 Bytes
Packet Rate	4 pkts /sec
Transmission Flow	16 Kbps/flow
Number of CBR Flows	20
Maximum Speed of Mobile Clients	10 m/s

The IWMRA is an architecture, which simply describes the procedure of routing and packet forwarding, but to apply in practical it needs some full procedure. It has no local repair procedure. So when we want to compare it with our protocol and AODV we need to include some local repair procedure. As IWMRA is a hybrid procedure it has few proactive and few reactive updating. For proactive updating there is no need of local repair but the procedure takes more time to update the whole mesh router. So the better way is to use one local repair procedure, which will inform the node immediately. The IWMRA maintains link layer updating for all static mesh router and static mesh clients. So for each link break the mesh router updates its routing table but to update all mesh routers it takes much time so better to use local repair procedures, which inform the node quickly. In case of reactive updating the protocol has no procedure to inform the node about the link failure. So in this case also we need one local repair procedure. For all the mobile mesh clients, there is no updating so when data transfer is done by mobile mesh clients there should be one local repair procedure otherwise after link break all the packet flows through the previous path and drops immediately without getting any fresh path. Here we use simple local repair procedure where the upstream node of the down link will inform the source node about the link failure and the source node again find the new path for the destination.

4.1 Performance Metric

In each simulation we consider the following three simulation metrics.

1. Packet delivery ratio: The ratio of the data packets delivered to the destinations to those generated by the sources.
2. Average control overhead: The control packet overhead that for route discovery, clusters maintain and route repair etc.
3. End-to-end delay: The average delay includes all possible delays caused by route discovery, propagation, and transfer times etc.
4.

4.2 Results and analysis

1) Simulation 1 varying the number of flows: In this simulation, we vary the number of CBR flows from 20 to 60. For all other simulation parameters we use the default value, as mentioned in Table I.

Figure 6 shows the average control packet with varying flows. The figure shows that in all points APULAR is taking less control packet than AODV and IWMRA. Our protocol reduces the control packet from three aspects. First in AODV all node broadcast the HELLO messages for finding his neighbor but in our protocols only Mesh Router broadcast the HELLO message periodically and all the clients' unicast the reply HELLO message to the routers only. Second for finding the route, AODV use the broadcast procedure which travel through the whole network but in case of APULAR all the Mesh Clients sends the route request packet only to the router and router has a fresh path if the node is router or static mesh clients otherwise find the path using broadcast if the node is a mobile mesh client. So it reduces the control packet by half but to maintain the path of mesh router and static mesh clients APULAR needs some extra packet but we use only the event- driven strategy to reduce this without using periodic broadcast. If there is any change in static mesh clients then only route updation procedure comes. And third one is the route repair procedure where APULAR takes less control packet than AODV. The first two procedures of APULAR and IWMRA are same but difference is in the route updation procedure. According to our modified IWMRA, it use the route updation procedure and source node again find the new path but in APULAR down link node finds the path for the rendezvous [11] node so obviously APULAR has much packet delivery than IWMRA. APULAR-MI3 takes more packets because each mesh router sends the broadcast packets in all of its interfaces. But as APULAR using efficient route updation procedure, the control packet of APULAR-MI3 is also less than single radio AODV.

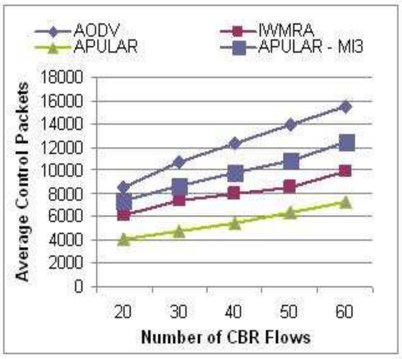

Fig. 6

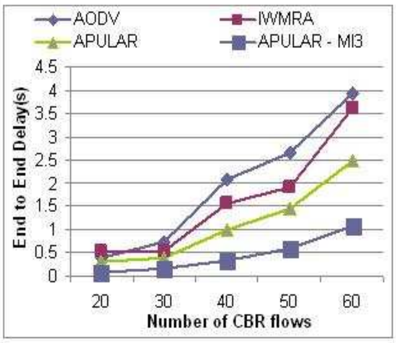

Fig. 7

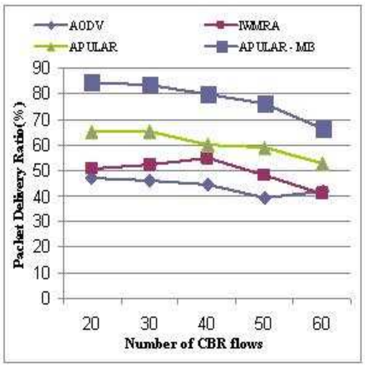

Fig. 8

Figure 6. Average Control Packets with Varying Number of Flows

Figure 7. End to End Delay with Varying Number of Flows

Figure 8. Packet Delivery Ratio with Varying Number of Flows

End-to-End Delay (ETED) is shown in Figure 7. For finding the end-to-end delay we consider only the packets, which are successfully received by the destination. The figure shows that when the number of flows are low the end-to-end delay is almost same for all three protocols but if the number of flow increases the overload of the network increases and for AODV the source node will take too much time to find the path, and if the link brake occurs it also takes the lager amount of time to find the new fresh path or to perform local repair. The end-to-end delay of IWMRA is almost same when flow is 20. But when the number of flows increases the overload of the node also increase and it takes too much time to send the packets through the new path. The end-to-end delay of IWMRA is between AODV and APULAR. Because it reduces the delay than AODV and for poor local repair procedure it takes much time to find new a path after link break and takes much time to send the packets. As APULAR has fewer amounts of control packets so it can find the path quickly and to perform local repair it takes less amount of time. ETED of APULAR-MI3 is very less than other three. Because all the routers of APULAR-MI3 have three interfaces with all different channels so it can communicate with three neighbors simultaneously. The load of the network is also become less and mesh routers are less congested than other three.

Figure 8 gives the packet delivery ratio of AODV, IWMRA and APULAR. Here AODV and IWMRA give almost 44% and 49% respectively where APULAR gives near about 64% and APULAR-MI3 gives 80% packet delivery. Because AODV is taking much more time to find the new path so packet drops occurs and IWMRA takes much time to find the fresh new path after link failure. But as APULAR use route updation procedure and all the nodes maintains a fresh path so the request node will get an immediate reply of the requested path and APULAR-MI3 has three interfaces with each mesh router so there are more free paths to communicate with neighbor routers.

2) Simulation 2: Varying Maximum Speed of Mesh Clients: The result of the simulation is shown in figure 9, 10, 11. Figure 9 shows the average control packet with varying mesh clients speed. The figure gives the idea that AODV is taking more control packet than IWMRA and APULAR. The APULAR is mainly for highly mobile network because it uses advanced local repair procedure so it needs more link brakes. So to give highly mobile network we need to vary the speed of mobile nodes and if mesh clients speed increase then the number of link brake also increase. Here we are varying the speed of the mobile nodes and our APULAR is giving much less packet than AODV and IWMRA. We can see the APULAR reduces the control packet almost 40% from AODV and APULAR-MI3 takes almost same control packet with AODV.

End-to-End delay depicts in figure 10. Here we are considering varying mobile nodes so more link brake occurs when mobility of the node increases. AODV and IWMRA take more control packets to perform the local repair and take much more time to find the new path for the destination the figure gives the idea that APULAR gives less end to end delay than AODV and IWMRA. Because of multi channel multi radio the APULAR-MI3 takes very less ETED than other three.

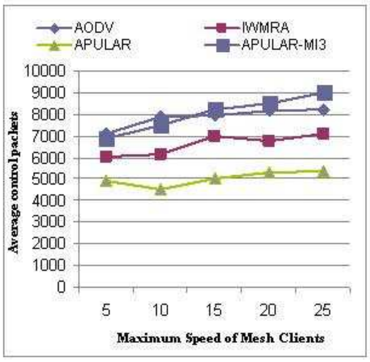

Fig. 9

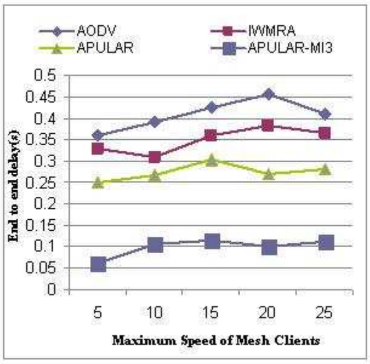

Fig. 10

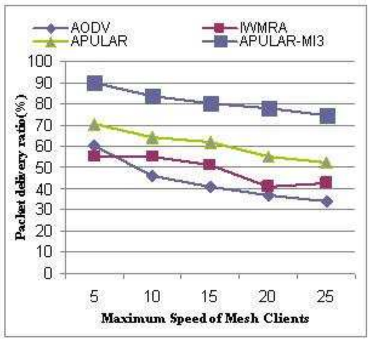

Fig. 11

Figure 9. Average Control Packets with Varying Mesh Clients Speed

Figure 10. End to End Delay with Varying Mesh Clients Speed

Figure 11. Packet Delivery Ratio with Varying Mesh Clients Speed

Figure 11 gives the Packet Delivery Ratio (PDR) of the three protocols. If link brake increases then more number of packets drop occurs and the packet delivery ratio will decrease. As AODV and IWMRA is taking much time to find the new path so the number of packet drop also increases. Figure shows that packet delivery ratio is more than 50% when the mobility of the node is less and it decreases highly when mobility increase and it becomes 35% in case of AODV. IWMRA has less packet delivery ratio than AODV when mobility is 5 but it becomes more then AODV when mobility of the node increases. But APULAR has always more packet delivery then AODV and IWMRA and it is almost 62%. APULAR-MI3 gives on an average 80% packet delivery.

3) **Simulation 3:** Varying Packet Size: In simulation 3, we varied the packet size from 64 to 1024 bytes, while maintaining the number of simultaneous flows at 20. The results, shown in figure 12, 13 and 14, indicate the APULAR is able to minimize packet losses compared to standard AODV and IWMRA. Here APULAR has less number of ACP as shows in fig. 12 than all other routing protocols and IWMRA has less number of ACP than AODV but more than APULAR. This is because with increasing number of interface the control packet also increases. In multi interface each node sends all control packets (HELLO, RREQ, and RERR) to its all interface. So with the increasing of interface per node, the control packet overhead of the network is also increase.

In Fig. 13, ETED of all the routing protocols have very less up to packet size 256. When packet size becomes 512 all the ETED of all the routing protocols becomes triple than the previous one. As to calculating the end-to-end delay we consider only the packets, which are successfully received by the destination. when the size of packets are less the end-to-end delay is almost low but when the size of packets increases the overload of the network increases and the source node will take too much time to find the path, and if the link break occurs it also takes the lager amount of time to find the new fresh path or to perform local repair. Because of multi channel multi radio the APULAR-MI3 takes very less ETED than other three. Each time the ETED of APULAR is less than AODV and IWMRA. But in case of 1024 packet size the ETED of all three routing protocols becomes very high. Because of we are using the maximum packet size 1000 bytes but in last we consider packet size of 1024. So, it divides the packet into 2, one 1000 bytes and another 24 bytes. That's why the load of the network becomes very high than the previous four and ETED of network becomes high.

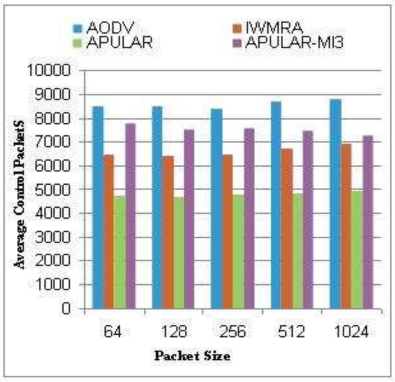

Fig. 12

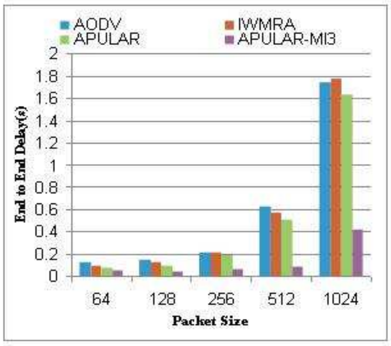

Fig. 13

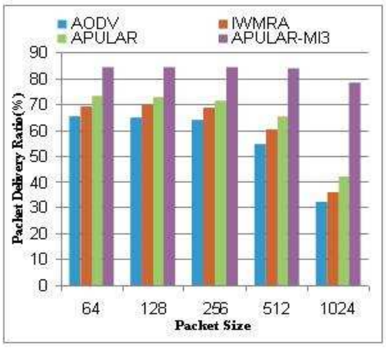

Fig. 14

Figure 12. Average Control Packet with Varying Packet Size

Figure 13. End to End Delay with Varying Packet Size

Figure 14. Packet Delivery Ratio with Varying Packet Size

In Fig. 14 the PDR of APULAR shows an improvement of more than 5% over AODV and more than 3% over IWMRA for a packet size of 64, 128 or 256 bytes. At the packet size of 512 and 1024 the PDR of APULAR is more than 10% than AODV and more than 5% than IWMRA. IWMRA improves the packet delivery ratio than AODV but has less PDR than APULAR. As IWMRA does not have route repair procedure.

4) Simulation 4: Different Number of Mobile Nodes: In simulation 4, we varied the number of mobile nodes from 150 to 250, while maintaining the number of mesh router fixed 100 and concurrent CBR flows at 20. So, here we are increasing the network density with all other parameters are as shown in table I. The control packet overhead is also increasing with increasing number of mobile nodes. In case of APULAR, all the routing and packet forwarding is done by mesh routers only so with the increase of mesh clients the increment of control packet overhead is not that much. In our simulation the increment of ACP of APULAR is very less than the others. Though IWMRA use the same concept of APULAR but the ACP is higher than APULAR and almost near to AODV. Because IWMRA has no route repair concept so it generates huge route error messages. The effect of IWMRA depends upon the situation. If more number of link breaks occurs, the ACP of IWMRA becomes more because of no repair mechanisms. But all other two i.e. AODV and APULAR has repair mechanism that's why the increment of ACP for these routing protocols is almost straight line. The ACP of APULAR-MI3 is increase because of multi interface in each node. Though we are using the multi channel for APULAR, the ACP of APULAR-MI3 is also less than standard AODV. The ACP of different number of mobile nodes is shown in figure 15.

The ETED in the figure 16 shows that APULAR takes less ETED than other two (AODV & IWMRA). The main reason of this is wireless infrastructure provided by mesh routers. In any routing ETED increases if, the number of hops increases in the routing path. In AODV all the nodes are same, routing path consists of more number of hops. As all the mesh routers in APULAR has only one radio so the ETED is very high than APULAR-MI3.

As it reduces the number of hops but the load of the mesh routers is very high and it takes much time to forward. In APULAR-MI3 all the mesh routers has three radios with different channels so it can communicate with its three neighbors simultaneously that's why the ETED of APULAR-MI3 is very less than others. The PDR of different mesh clients is shown in figure 17. As APULAR has less ACP and ETED than AODV, IWMRA, the PDR of the APULAR becomes more than this two. In the figure we can see with the increasing number of mesh clients the PDR of AODV decreases rapidly. But in APULAR and IWMRA the rate of decrement is very less because of mesh infrastructure provided by mesh router. APULAR has few more PDR than IWMRA because of active path updation. In all cases the PDR of APULAR-MI3 has more than 80% and it almost fixed through all time because of less loads.

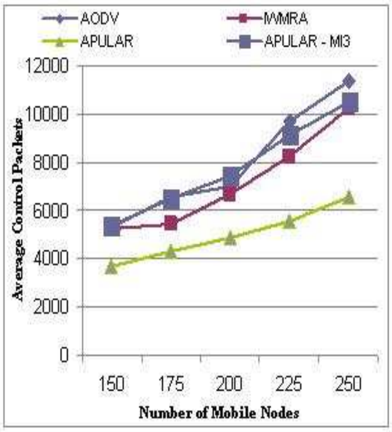

Fig. 15

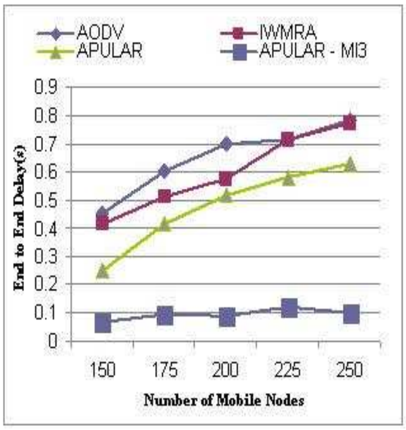

Fig. 16

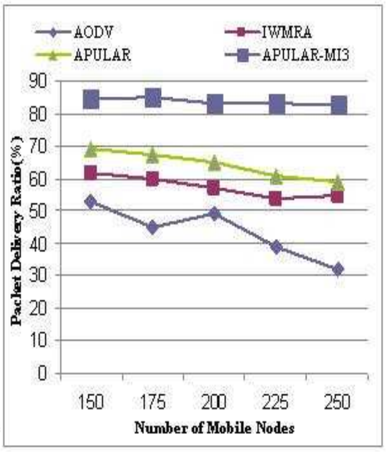

Fig. 17

Figure 15. Average Control Packet with Different Mobile Nodes

Figure 16. End to End Delay with Different Mobile Nodes

Figure 17. Packet Delivery Ratio with Different Mobile Nodes

5. Conclusion and Future Work

In this paper, we present the updated version of the layered routing architecture mainly for infrastructure wireless mesh networks. It is a good procedure for routing and packet forwarding. Even to reduce packet loss we use the property of rendezvous node.

Most probably all the routing protocols use the link updating where uplink node of the link breaks is taking the responsibility of finding the new path. When a link breaks along an active route, there are often multiple destinations that become unreachable. The node that is upstream of the lost link tries an immediate local repair for only the one destination towards which the packet was travelling. Other routes using the same link must be marked as invalid and whenever the nodes receive the data packet for that destination node the uplink node again finds the new path. The drawback of this procedure is that the data packet has to wait to find the new path for destination. Alternatively, depending upon local congestion, the node may begin the process of establishing local repairs for the other routes, without waiting for new packets to arrive. But in this case there may be chance that all the links are not in use and the uplink node has too much overload and computation. Here we are considering that after link break all the source and destination will continue the packet forwarding. In our procedure the down link node of each flow of the link break is taking the responsibility. As each down link node is taking the responsibility of finding the path for source node so the overload of the uplink node decreases. Here we have to find the path from down link node to the rendezvous node. It reduces the packet loss and transmission time of the whole data. Even it also reduces the control packet flow for route maintenance of the whole network. We can also get better result if we find the path depending upon bandwidth; buffer queue and throughput instead of only hop count. So it is not the optimal measurement for finding the minimum path.

Here we also give one channel assignment procedure for multi radio environment. In this protocol we consider two types of interference - intra flow and inter flow. To reduce inter flow we use one static channel assignment and to reduce intra flow we consider up to the four hop all the channels must be different. And the destination node or rendezvous node selects the path with minimum reuse channels. For future work we can consider the combinative [16] metric as a measurement of minimal path cost or we can consider another new routing metric as minimal path cost because in our routing protocol and channel assignment procedure we consider hop count as a routing metric but it does not include the load of the node or link and two different types of node (mesh router, mesh client). Here we are using one fixed channel assignment but we can use one dynamic channel assignment, which will reduce the co channel interference and also takes less time for switching channels

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