

Performance Enhancement of AODV Routing Protocol in Wireless Mesh Networks

Tayyeba Minhas, Xu Ning, Satish Anamalamudi, Minglu Jin, and Zahid Minhas Khan

Abstract—Performance of routing protocols mainly depends on efficient channel path establishment, route optimization and control overhead. Route optimization plays a pivotal role in self-healing” and “self-configuring” wireless mesh networks (WMN). State-of-the art routing protocols rely on IEEE 802.11 MAC and TCP congestion control mechanisms to optimize the performance of routing protocols. Since, traditional end-to-end TCP is designed for network congestion, it is difficult to identify route failure due to node mobility and buffer overflow. In addition, IEEE 802.11 MAC works on link connectivity which takes relatively long time to recover end-to-end route path. Hence, it is important to design a congestion control mechanism at the network layer to enhance the performance of routing protocol during mesh client handover. In this paper, Active Queue Management (AQM) is implemented in the network layer to avoid congestion due to buffer overflow and client mobility. Simulation results (NS-2) show that proposed AQM based routing protocols are outperformed compared with the existing routing protocols in wireless mesh networks.

Index Terms—Route optimization, congestion control, packet buffering.

I. INTRODUCTION

Wireless mesh networks [1] build a stationary multi hop wireless backbone to interconnect isolated LANs which guarantees reliability, coverage and reduced equipment cost that enhances the edge mobile node internet connectivity. WMNs can self-organize, self-configure with other nodes in the network and can operate as both host and router i.e., it can forward the packets on behalf of other nodes which are not in the direct transmission range of their destination. Mesh clients and routers can communicate with each other and form a backbone network which forwards the traffic from mobile clients to the Internet. The wireless mesh network backbone consists of mesh routers, which can be connected in an ad-hoc manner via wireless links. The major problem with existing IEEE 802.11 wireless networks is the capacity reduction due to collisions among multiple simultaneous transmissions which degrades the performance of the network. With backbone mesh routers and utilization of multiple channels and interfaces, wireless mesh network will have better capacity utilization than that of the

infrastructure-free ad hoc network.

Mesh routers with multiple radio transceivers can greatly alleviate this problem by simultaneously transmitting or receiving on multiple channels [2]. However, due to the limited number of available channels, interference cannot be completely eliminated which causes frequent route failures at the link layer. Performance of routing protocol in wireless mesh networks mainly depends on three factors. Firstly, packet drops may occur due to mobile handoff from one sub-network to another sub-network which results link failure at MAC layer(RTS/CTS failure)[3,4]. Secondly, a wireless mesh router can drop the packets from different connections due to buffer overflow which leads to aggregate packet drops and performance degradation of mesh networks. Thirdly, dynamic and unpredictable traffic demand is hard to estimate which leads to packet drops at mesh routers. Whenever, the traditional TCP protocol is used in Wireless mesh networks, it will decrease the congestion window size to half whenever, acknowledgment has not been received from the destination. Hence, data transmission rate from sender to receiver will be minimized even though there is no network congestion, but due to client handover from one sub-network to another sub-network or buffer overflow at mesh routers. Most of the research work is done to optimize end-to-end hop count and energy efficient route path in between the source and destination. But, it is crucial to design optimal buffer management based routing protocol to enhance the performance of mesh networks with respect to buffer overflow and client mobility. This paper proposes Active Queue Management [5] based AODV routing protocol to enhance the performance of wireless mesh network by reducing packet drops due to buffer overflow and packet drops due to intra-subnet and inter-subnet client handover. The rest of the paper is organized as follows. Section II explains about related works with pros and cons of existing routing protocols without queue management. Section III briefly explains about proposed buffer management based AODV protocol. Section IV explains about simulation results and Section V ends with a conclusion.

II. EXISTING WORKS

Currently, three classes of routing protocols were developed from wired to wireless and mesh networks namely table driven, on-demand routing and geographical routing protocols. Most of the existing routing protocols propose on-demand distance vector (AODV, DSR) and modify to corresponding technology (sensor networks, mesh networks, ad-hoc etc.) because of its dynamic route discovery and

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maintenance nature [6]. State-of-the-art research at the network layer comes up with ample of routing protocols to minimize route control message overhead, reduce end-to-end hop count and conserve energy consumption of wireless mesh networks. Little research focuses on congestion, mobility and buffer management at the network layer of WMN's. Firstly, packet drops at the network layer is due to longer handover delays in between access points (AP). [7] And Fig.1 explains about the hands-off scenario of client mesh node from one router to another router.

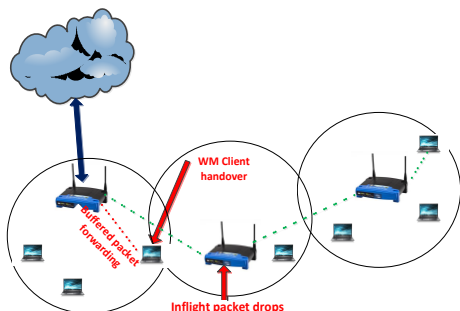


Fig. 1. Handover scenario in wireless mesh networks.

Whenever, mesh client handover from one router to another router, packets at the old router from sender node will be dropped due to mesh client link failure and acknowledgments will not be transmitted back to the source. This is because the old router doesn't know the exact location of mesh client for a fraction of seconds called handover period. Whenever, the same traditional TCP protocol is used in wireless mesh networks, it will decrease the congestion window size to half whenever acknowledgment has not been received from the mesh client (destination). Hence, data transmission rate from sender to receiver will be minimized which will severely degrade the performance of mesh networks even though there is no network congestion but due to mobile handover from one sub-network to another sub-network.

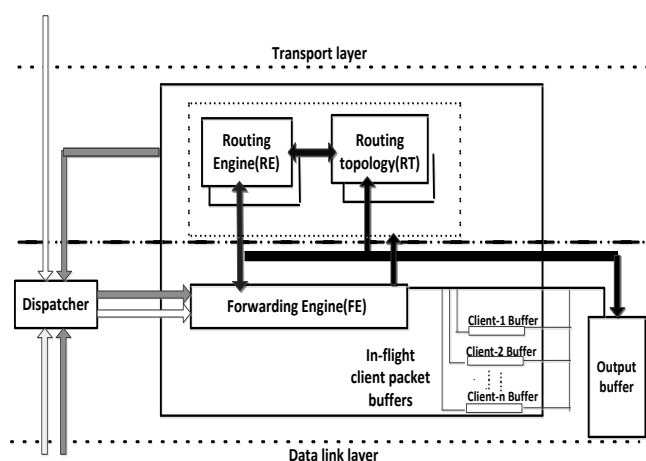


Fig. 2. Packet buffering Implementation at WM network layer.

To solve this problem, separate packet buffers were introduced at each and every router to store the in-flight packets and forward once it gets the exact location of the mesh client current router. Fig. 2 shows the implementation of packet buffers at mesh router to store and forward inflight packets during client handover. Random Early Detection [8],

[9] buffers are originally introduced to avoid the congestion within the gateways in packet switched networks. All the existing solutions use RED as a packet buffer for each and every client node to store its corresponding in-flight packets at a mesh router whenever, a node handovers to another sub network. Buffered Packets that are being transmitted from the old router to new router were marked with higher priority. Same RED buffers were used as input buffers to store and forward priority buffered packets as well as normal packets from different connections at new router. Hence, input buffer at new router may be congested, whenever a traffic flow increases from other wireless connections. [10], Suggests that whenever, the average queue length of input buffer at new router is in between $Min_{threshold}$ and $Max_{threshold}$ then it has to discard other than priority packets. Whenever, the Input buffer average queue length is greater than $Max_{threshold}$ then both priority and non-priority packets will be discarded and acknowledgments won't transmit back to sender. Hence, Sender TCP will decrease the congestion window size which results in performance degradation of mesh networks. In [11], apart from the Input RED buffer, a separate priority buffer is used in new router and all the priority packets has to be passed through a priority RED buffer of the new router. Even though this solution improves the performance of TCP at the congested router, additional network resources (priority buffers) are required at each and every mesh router. Moreover, priority buffers are used to store only priority marked buffered in-flight packets of mesh client at new router even though the input buffer is not congested. Hence, this solution doesn't make use of network resources (buffers) efficiently even though it improves the performance of TCP at congested base stations. One important consideration is performance of routing protocol should be effective, at the same time resources should be efficiently utilized. In [12], control information is implemented in the registration reply message which contains buffer queue length, average queue length, minimum threshold, and maximum threshold of the client new mesh router buffer. Subsequently, it is transmitted from client new router to old router during registration update. Analytical calculations need to be done at old router to know the current status of new router input buffer. Whenever, the current router is congested ($Avg_{Queue} > Max_{Threshold}$) then buffered packets are going to be dropped at old router. Otherwise, packets will be forwarded from the old router to the new router. RFC-3220 explains that wireless link has substantially lower bandwidth and higher error rate than traditional wired networks. Moreover, mesh clients are likely to be battery powered and minimizing power consumption is crucial in wireless networks. Hence, the total number of control messages sent over the link by which a mesh node is directly attached to the Internet should be minimized and the size of these messages should be kept as small as possible. Even though priority buffers are not used in [12], binding update message needs to carry additional buffer information which increases the control message size. In addition, buffered packets at old router are getting drop whenever, the analytical calculations show that current mesh node base station is congested. In our proposed work, based on the current status of input buffer at mesh node current router, priority buffer will be introduced to reduce the packet drops

at congested router so that buffers will be efficiently utilized and performance of routing protocol with respect to congestion and mobility will not be degraded.

III. PROPOSED WORK

When mesh client has data to transmit it broadcast RREQ using unlicensed control channel (802.11 MAC). MAC Control messages include the minimum transmit power necessary to communicate with the neighbor based on the signal strength of the received packet and the *power level* at which the packet was sent. The information of the latter is included inside the packet by the sender. Route discovery procedure is shown in Fig. 3.

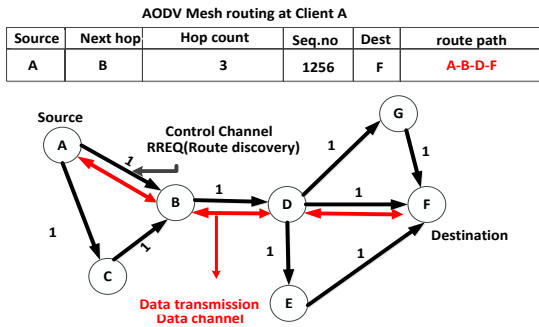


Fig. 3. AODV Route discovery in WMN's.

In traditional wired networks, route failure occurs mostly due to network congestion at stationary routers. Routing in wireless mesh networks introduce additional route failure due to handover delay and link failure overhead apart from buffer overflows. Fig. 4 explains about various link failure scenarios at the time of end-to-end application data transmission in wireless mesh networks. This paper propose a new algorithm to identify whether the route failure is due to client mobility(handover) or link breakage(channel degradation) or buffer overflow which is explained in (1).

Mesh Client Handover Algorithm

```

{
WMco-ordinate message update = True;
Neighbor discovery(broadcast route) = True; // control channel
Sender-destinationroute = True. // Data channel
Case I: if (RouteFailure == Nodemobility)
{
if (TTL < Localroute re-construction time)
{
C1: Localroute re-construction = True;
Next hop = new route ; // Control channel
}
} else {
C2: Localroute re-construction = False;
GlobalRe-route = True;
Neighbor discovery(route) = True;
Sender-destinationroute = True.
Newroute = RREQroute(broadcast) + RREProute(unicast)
}
}
    
```

(1)

Next hop active link breakage can be identified through failure to get CTS, even after sending the maximum number of RTS retransmission attempts at MAC layer of mesh networks. A buffer overflow can be mentioned explicitly using congestion notification algorithm during ACK message from the router to mesh client. Explicit Congestion Notification (ECN) [13] is an IETF standard that is widely used to notify to destination TCP protocol whenever, congestion is going to happen within the network. The basic functionality of congestion in TCP/IP networks is known through packet drops. When congestion notification is successfully negotiated, ECN-aware mesh router will set a mark in the IP header instead of dropping a packet in order to signal impending congestion. Whenever, route failure is other than first two techniques then it is presumed as a handover link failure. It is crucial to determine RTT (Round Trip Time) to enhance the performance of routing protocol in mobility based wireless mesh networks.

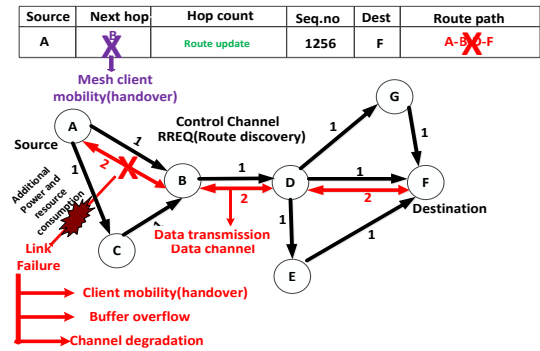


Fig. 4. Various route failure scenarios in WMN's.

Time delay can be calculated with the equation (2) shown below.

$T_{sen-rout}$: Time taken to transmit a data packet from a sender to mesh router.

$T_{sen-des}$: Time taken to transmit a packet from sender to destination.

$T_{router-des}$: Time taken to transmit a packet from router to destination.

$T_{router-success}$: Time taken to successfully transmit a packet from router to destination.

$T_{oldrout-newrout}$: Time taken to transmit a packet from the old router to the new router.

$T_{new-reg}$: The relative difference of when the mesh client moves into the new sub network to the time when the mesh client receives a beacon message from the new router (registration).

$T_{bec-newrout}$: The relative difference of when the mesh client receives a beacon message to when the new router receives the registration request message or the binding update message.

$T_{bec-oldrout}$: The relative difference of when the new router sends the binding update message to when the old router receives it.

$T_{pac-des}$: The relative difference of when the old router sends the buffer packet to when the destination receives it through new router.

$RTT_{oldrout-des}$: Round-trip-time between old router and mesh client.

$RTT_{newrout-des}$: Round-trip-time between new router and mesh client.

D_{BBUC} = Total route delay before mesh client location update (before handover)
 D_{ABUC} = Total route delay after mesh client location update cache (after handover)
Route_Loss Delay = $T_{new-reg} + T_{bec-newrout} + T_{bec-oldrout}$
 $D_{BBUC} = RTT(\text{sender} \rightarrow \text{old router} \rightarrow \text{current router}) = 2.T_{sen_des} + RTT_{oldrout_dest}$
 $D_{ABUC} = RTT(\text{sender} \rightarrow \text{current router}) = 2.T_{sen_des} + RTT_{oldrout_dest} + RTT_{newrout_dest}$
 $RTT_{Delay} = \text{Queuing}_{Delay} + \text{Trans}_{Delay} + \text{Prop}_{Delay}$
Delay_{Total} = $D_{BBUC} + D_{ABUC} + RTT_{Delay}$ (2)

The congestion indication is transmitted back to sender, which reduces its packet transmission rate to half even though the packet drop may occur due to buffer overflow or client mobility or link failure. Hence, whenever a packet receives to destination node with ECN notification it has to send congestion NOTIFY message to the sender TCP which will reduce the transmission rate until congestion gets avoided. In TCP with ECN, new data packets are transmitted with an ECT code-point set in the IP header. When only one ECT code-point is needed by a sender for all packets sent on a TCP connection ECT(0) SHOULD be used. Whenever, sender mesh node receives an ECN-Echo (ECE) ACK, and then it knows that congestion is encountered in between sender to receiver path of end-to-end connectivity. Congestion indication should be treated just as a congestion loss in non-ECN-Capable TCP i.e., the TCP source halves the congestion window "cwnd" and reduces the slow start threshold "ssthresh". Hence, sender TCP SHOULD NOT increase the congestion window in response to the receipt of an ECN-Echo ACK packet. This terminology works fine for wired networks because of stationary nature. But, in wireless and mesh networks, most of the packet drops are due to node handoff and link failures. This shows that there should be change in explicit congestion protocol to notify the sender TCP about the packet drops are due to congestion or client handover or link failure so that performance of TCP and routing protocol will be enhanced due to handovers. Proposed work has modified TCP ACK message to carry the notification messages from destination to source TCP. In wireless mesh networks, apart from node handovers, packet loss may occur due to congestion at input buffers in current routers of mesh client.

Case I: Packet Buffering at new mesh router without priority packets and priority buffer

```

while (Avg < min threshold)
{
    REDpriority = False;    // No need to create Priority buffer.
    Markerpriority = 0;    // Non-priority packets
    RED Input ()           // Input RED buffer.
    {
        REDInput = PacketsNon-priority;
        Calculate ProbabilityNon-priority = PNon-priority;
        Congestion Notification Flag = 0;
    }
}
    
```

(3)

Case II: Packet Buffering at new mesh router with priority packets and without priority buffer // While

```

(((Avg_queue > minthreshold) && (Avg_queue < maxthreshold)))
{
    REDpriority = False;    // No need to create Priority buffer.
    Markerpriority = 1;    // Adding Priority to buffered packets
    RED Input ()           // Input RED buffer.
    {
        REDInput = PacketsNon-priority;
        REDInput = Packetspriority;
        Calculate ProbabilityNon-priority = PNon-priority;
        Calculate Probabilitypriority = Ppriority;
        Congestion Notification Flag = 0;
    }
}
    
```

(4)

Case: III : Packet buffering at new mesh router with both priority packets and priority buffer // while ((Avg_queue) > (maxthreshold))

```

{
    REDpriority = True;
    Markerpriority = 1;
    RED Input ()           // Input RED buffer
    {
        REDInput = PacketsNon-priority;
        Calculate ProbabilityNon-priority = PNon-priority;
        Congestion notification _Flag = 1;
    }
    REDPriority ()         // Priority RED buffer.
    {
        REDPriority = Packetspriority;
        Calculate Probabilitypriority = Ppriority;
        Congestion Notification _Flag = 0;
    }
}
    
```

(5)

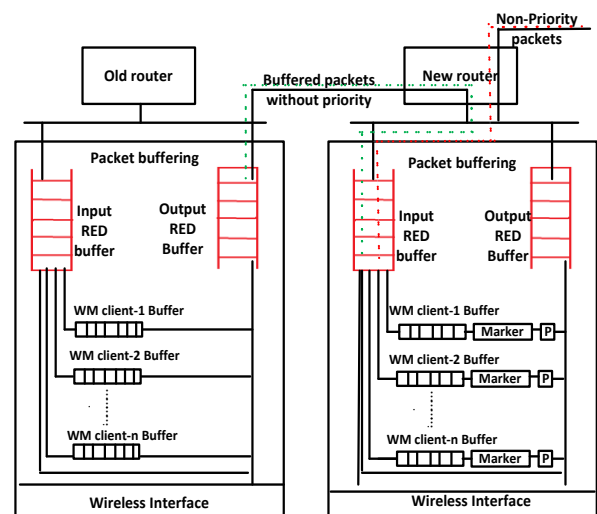


Fig. 5. Packet buffering without priority buffer and marker.

Whenever RED input buffer is congested, packets of both mesh client and other connections will be dropped and performance of routing protocol is degraded. In proposed

work, RED buffer is implemented as input buffer to store and forward inflight data packets. Analytical calculations will be done at router of current mesh client to know the input buffer status (congestion) of current router. Whenever, Avg_Queue length of input buffer at a current router is less than $Min_{threshold}$, no packets will be dropped at the router. This is shown explained (3) and Fig. 5. Node priority bit will be disabled in the mesh client registration message and transmitted to old router. One way to enhance the performance of routing protocol is by considering the characteristics of input RED buffer like total queue length, average queue length, $Min_{Threshold}$, $Max_{Threshold}$, maximum window size (MWS), roundtrip time etc Packet buffering with input buffer and without forwarding buffer at new mesh router is explained in (4) and Fig. 6.

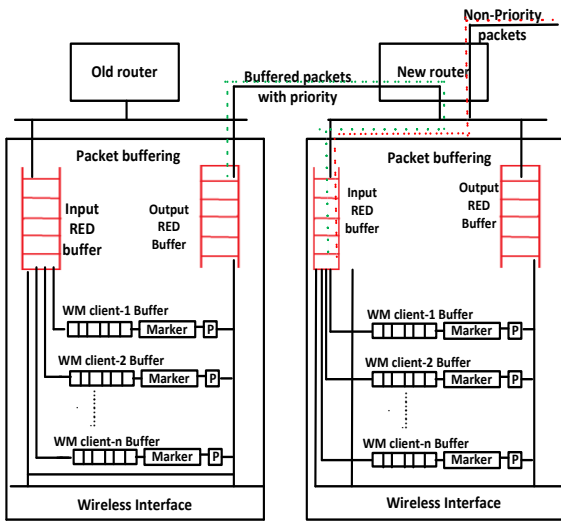


Fig. 6. Packet buffering with marker and without priority buffer.

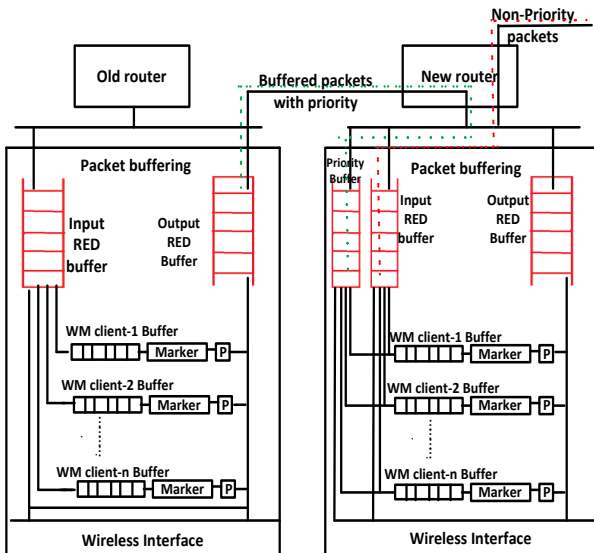


Fig.7. Packet buffering with marker and priority buffer.

Priority markers are used to enable the priority bit whenever, Avg_Queue length is in between $Min_{Threshold}$, $Max_{Threshold}$ or greater than $Max_{Threshold}$. This is clearly shown in (5) and Fig. 7. New router may also have marker to make priority bit enable for its handover mesh clients to another router. Buffer packet drops may occur due to packet

re-ordering problem at the destination mesh client, which is another crucial problem that degrades the performance of routing protocol in mesh networks. Moreover, all the buffered packets from the old router to new router should be transmitted before the first arrival packet directly from the source mesh client.

IV. SIMULATION RESULTS

Network Simulator NS-2 [15], [16] is used to analyze the throughput, end-to-end delay, normalized routing overhead of AODV routing protocol with and without packet buffers at network layer. The network topology of wireless mesh network in NS-2 is shown in Fig. 8 which contains mesh clients, mesh routers and communication links. AODV [14] which is an on-demand distance vector routing protocol is used to route and forward the packets from source to destination. AODV is a reactive routing protocol aims to solve the routing control overhead in wireless mesh networks. It maintains a routing table which contains the sequence number of each end-to-end connectivity. Queue size of the interface queue at the link layer is considered as 50 to store and forward the packets whereas Queue size of the each proposed packet buffer during client handover is considered as 25.

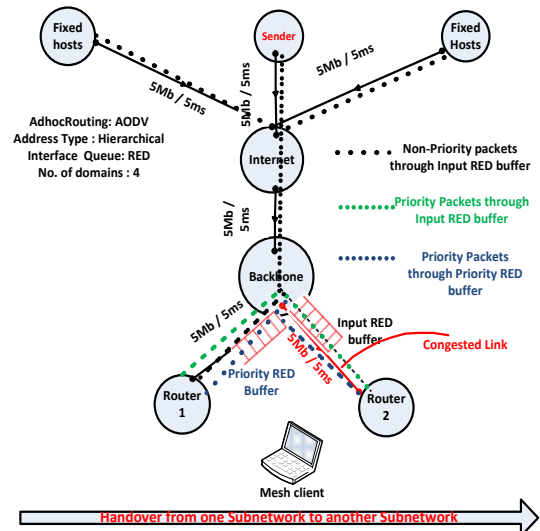


Fig. 8. Network scenario in NS-2 simulator.

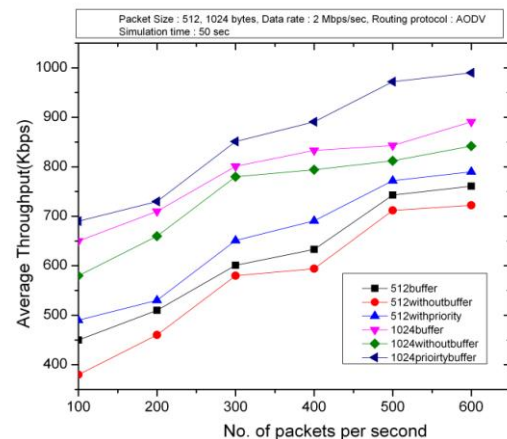


Fig. 9. Average throughput with respect to packet arrival rate.

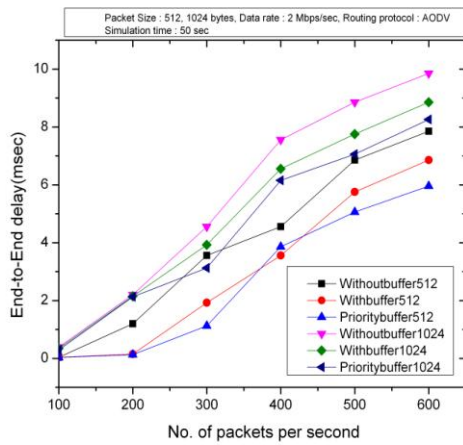


Fig. 10. End-to-End delay with respect to packet arrival rate.

Topology dimension is considered as 800×800 with start point at 0 sec and stop point at 150 sec. Figure.8 explains about network scenario in NS-2 simulator. Mesh client may handovers from one sub-network to another sub-network within a same domain or different domains. Initially the client node is a router-1 at time 0 Sec. Packets destined for a destination mesh client is transmitted from router-1 without packet forwarding buffer. The forwarding Packet buffer is used to store the in-flight packets when a mesh client handovers from one router to another router at 't' Sec. Once registration and re-association message is exchanged among mesh routers, old router forwards the buffered packets to destination via new mesh router. Fig. 9 and Fig. 10 explain about various average throughput (Kbps) and end-to-end delay in wireless mesh networking with different packet sizes (512, 1024 bytes). Comparison is done with and without packet buffers. Firstly, wireless mesh network is implemented in NS2 and throughput, end-to-end delay and normalized routing overhead are calculated without congestion. Secondly, the results are drawn with congestion at mesh routers without any implementation of packet buffers. Thirdly, Packet buffers are introduced for each and every handovers mesh client and results are drawn. Finally, priority packet buffer is introduced (Case: III) is implemented at the current mesh router to reduce congestion with respect to other wireless connections. From Fig.9 it is clear that routing with packet buffer implementation has better throughput compared with routing without packet buffers during client handover. This is because of reduced routing control overhead and reduced RTT due to packet drops at mesh routers. Average throughput for 1024 byte data is relatively higher than the average throughput with 512 data due to reduced ACK and control message transmission.

End-to-end delay with respect to data rate is shown in Fig.10. It clearly shows that end-to-end delay for lower data size is less than delay with respect to high data size. This is because higher data packets will take relatively long time and needs extra buffer space at each and every intermediate mesh router. Throughput, end-to-end delay and normalized routing overhead are calculated at $\text{Minimum}_{\text{Threshold}} < \text{Avg}_{\text{Queue}} < \text{Maximum}_{\text{Threshold}}, \text{Avg}_{\text{Queue}} > \text{Max}_{\text{Threshold}}$ of current mesh client router RED buffer without adding priority to packets or without creating priority buffers and compared to

previous solutions. Simulation results have shown that the performance of the AODV routing protocol with respect to handover is getting degraded whenever, packet forwarding buffers are not implemented at the handover mesh router. This is due to increase in end-to-end delay and routing control overhead due to path reconstruction. With buffer implementation at the old mesh router, packet drops during client handover is getting reduced but, packet drops due to congestion at current client mesh router cannot be avoided (case III). With the priority buffer implementation, packet drops due to congestion at case III can be avoided at the same time network resources are efficiently utilized in both case I and case II. With proposed results, it is clear that the performance of the AODV routing protocol with respect to client handover is enhanced with forwarding and priority buffer implementation. Fig. 11 and Fig. 12 explains about routing control overhead with respect to packet rate. Routing without packet buffers will have a lot of packet drops during client handover, which need to perform route discovery. Hence, routing control message broadcast increases which result decrease in throughput. In other hand, with packet buffers and priority buffer packet drops with respect to client handover is relatively low compared with routing without handover which results increased throughput and reduced normalized control overhead.

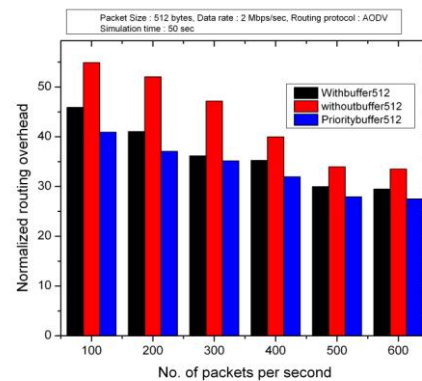


Fig. 11. Normalized routing overhead with respect to packet arrival rate (512 byte data).

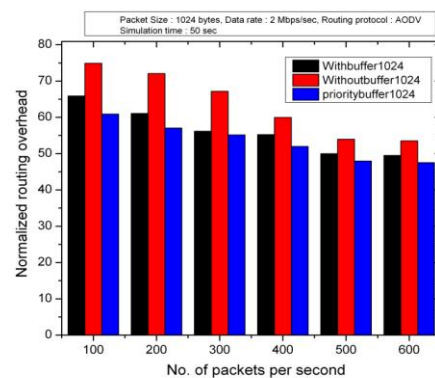


Fig. 12. Normalized routing overhead with respect to packet arrival rate (1024 byte data).

V. CONCLUSION

In order to enhance the performance of mesh routing

protocols, state-of-the-art research proposes different routing protocols with respect to hop-count and congestion. But, it is crucial to design mesh routing protocol to enhance the performance with respect to client handover and buffer overflows. This paper proposes a routing protocol to enhance the performance by implementing forwarding packet buffers and priority packet buffers at the network layer. Simulation results (NS-2) clearly show that proposed algorithm has increased throughput and reduced normalized routing control overhead with respect to routing protocol without packet buffers.

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