Queue utilization with hop based enhanced arbitrary inter frame spacing MAC for saturated ad HOC networks

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Queue Utilization with Hop Based Enhanced Arbitrary Inter Frame Spacing MAC for Saturated Ad Hoc Networks

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Abstract – **Path length of a multi hop Ad Hoc networks has an adverse impact on the end-to-end throughput especially during network saturation. The success rate of forwarding packets towards destination is limited due to interference, contention, limited buffer space, and bandwidth. Real time applications streaming data fill the buffer space at a faster rate at the source and its nearby forwarding nodes since the channel is shared. The aim of this paper is to increase the success rate of forwarding the packets to yield a higher end-to-end throughput. In order to reduce loss of packets due to buffer overflow and enhance the performance of the network for a saturated network, a novel MAC protocol named Queue Utilization with Hop Based Enhanced Arbitrary Inter Frame Spacing based (QU-EAIFS) MAC is proposed for alleviating the problems in saturated Ad Hoc networks. The protocol prioritises the nodes based on its queue utilization and hops travelled by the packet and it helps achieving higher end-to-end performance by forwarding the packets with higher rate towards the destination during network saturation. The proposed MAC enhances the end-to-end performance by approximately 40% and 34% for a 5hop and 6hop communication respectively in a chain topology as compared to the standard IEEE802.11b. The performance of the new MAC also outperforms the performance of IEEE 802.11e MAC. In order to validate the protocol, it is also tested with short hops and varying packet sizes and more realistic random topologies.**

Keywords – Ad Hoc, MAC, Queue, QoS, Network Saturation.

I. INTRODUCTION

In resource constraint wireless Ad Hoc networks, increasing bandwidth capacity or multiplying the number of channels do not provide an ideal solution for enhancing the network performance, unless the inherent problems such as congestion, hidden node, optimization of limited shared channel are addressed thoroughly. Given the high degree of interference, unfavourable hidden and exposed terminals and a self-generating bottleneck in multihop paths during high offered load, providing Quality of Service (QoS) in such networks remains challenging despite substantial research undertaken over the past decade [1]-[5]. In a long chain topology, the degree of interference is the highest around the centre and it is less around the source and the destination. So, the success rate of accessing the channel around the source is high compared to the nodes which relay the packets, so the queue utilization pattern varies as the hop count along the path increases. Moreover longer path length results to higher degree of active nodes and induces higher interference. Thus, when the communicating path length is high, the network saturates more rapidly and the end-to-end performance decays faster due to limited shared channel capacity and rapid increase of active interfering nodes [6]-[7] in an Ad Hoc networks.

II. MEDIUM ACCESS METHODS IN AD HOC NETWORKS

Medium access control protocol plays a vital role in providing QoS in distributed and independently functioning nodes of Ad Hoc networks. The IEEE 802.11b standard MAC provides fairness across the active contending nodes within its transmission range [8] but IEEE 802.11e was introduced to differentiate between different categories of service and ensure QoS [9]-[11]. Different approaches and optimization techniques have been proposed to enhance the performance in such networks. Challenges and prospects of bandwidth allocation to have an efficient access mechanism in Ad Hoc networks are discussed in [12] and a new node-based mechanism of predicting the available bandwidth in a dynamic Ad Hoc networks is proposed in [13]. In view of supporting QoS, various priority based queuing techniques are also proposed, such as energy-efficient and load-balanced queue scheduling algorithm for mobile Ad Hoc networks [14]. Optimizing resource utilization and designing a resource aware dynamic MAC are also considered towards enhancing the end-to-end performance. Authors of [15] adapted the IEEE 802.11e MAC for voice service by avoiding unnecessary polling of a silent station. A hop-by-hop congestion control technique is discussed in [16] and the authors of [17] used the cross layering technique in controlling the end-to-end congestion. Other mechanisms like distributed contention window adaptation technique is discussed in [18], where the incoming and the outgoing traffic in the network are fine tuned. In order to optimize the utilization of contention window during the backoff stage, authors of [19] designed a backoff calculator based on the degree of contention and the channel bit error rate. This paper focuses on introducing priority based on the current state of the resource utilization of the network along the entire path by prioritising packets that have travelled longer paths and prioritizes the access mechanism based on the current status of the available buffer space. By prioritising traffic according to the traversed path and active resource utilization, the proposed method reduces the overall packet loss and enhances the end-to-end throughput even when the network gets saturated.

The remainder of the paper is structured as follows. The proposed QU-EAIFS MAC protocol is described in detail in Section III. Section IV provides the simulation results with detail evaluation, and then Section V concludes the paper by proposing some feasible future directions.

III. PROPOSED MAC

A. Overview

The proposed MAC, named Queue Utilization with Hop Based Enhanced Arbitrary Inter Frame Spacing (QU-EAIFS) MAC, is derived from the original IEEE 802.11b specification by incorporating the arbitrary inter frame spacing of IEEE 802.11e for QoS support. The new MAC operates within the context of the RTS/CTS control packet mechanism shown in Figure 1. When a node has a packet to send, the protocol dynamically adjusts the probability of accessing the wireless channel as follows: the active node waits for an Enhanced Arbitrary Inter Frame Spacing (EAIFS) based on the hop count of the packet and the priority mechanism uses the current queue utilisation status information of the active nodes. The details of the new features introduced in the access mechanism are described in the following paragraphs.

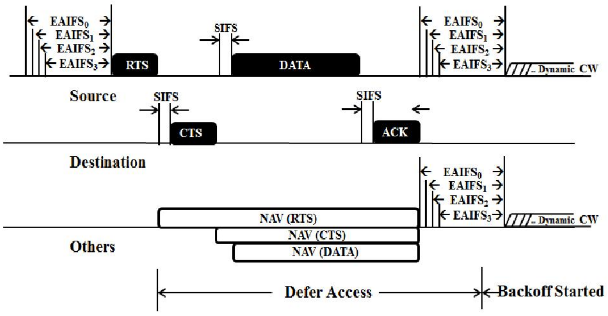

Figure 1. Medium Access Control Operation

B. An Enhanced Arbitrary Inter Frame Spacing

Initial Inter Frame Spacing (IFS) includes a waiting time when the node senses the channel as idle. A node with a packet which has travelled higher hops is allowed to wait lesser IFS time as compare to the nodes having fresh packets. The new inter frame spacing time is given by $EAIFS_i = \{SIFS_{Time} * (6-i)\}/2$, where i ranges from 0 to 3. The value of i=0 when the packet is locally generated, i=1 for frames that transited one or two hops, i=2 when the frames have travelled three to four hops, and i=3 for frames that have transited at least five hops.

C. The Backoff Mechanism

The second feature of the proposed MAC is prioritizing the nodes based on the active current utilization of the queue by varying CW_{Min} and CW_{Max} ranges during the backoff phase. The backoff slot value freezes, as in IEEE 802.11b standards when the channel becomes busy, so that it retains the higher chances of access as compared to the fresh packets during next round of contention. The information of the queue utilization is embedded in the packet header while queuing and the MAC layer extracts the queue utilization information from the packet header while making access decision, following a cross-layer design. When the node has a packet to send, dynamic CW ranges are generated in accordance to (1).

The buffering queue size of a node and its active current queue utilization are denoted by Ɋ and $\hat{U}$ respectively. A factor ƚ is used to generate various priority levels. Given a queue size of 100, ƚ = 30 is used to generate four different priority levels (low, fair, medium and high) and α is another adjusting factor which determines the initial width of the contention window and $\alpha = 3$ is used in this paper. The priorities (low, fair, medium, and high) are based on the queue utilization of <30%, 30-59%, 60-89% and >=90% respectively. Packet retransmission is triggered for unsuccessful packet until the packet is sent successfully or until the retrial limit is exhausted, whichever is earlier. The retry count of a packet is denoted by *r*; during retransmission of packets, *r*>0 and a new CW is generated exponentially as the retrial count increases with respect to each corresponding priority level based on the current status of the queue. The exponential increases of CW_{Min} and CW_{Max} during retrial sustains the network during high degree of contention. After the fourth retrial attempt, the contention window range freezes at each respective priority and packet retransmission is attempted up to seven more times without further increasing the CW ranges. The maximum number of retransmissions is taken the same value as used in IEEE802.11 standard following the work of [20].

$$[CW_{Min};\ CW_{Max}] = \begin{cases} \left[2^{\alpha}\left(\dfrac{\text{Ɋ}-\hat{U}}{\text{ƚ}}\right); 2^{\alpha}\left(\dfrac{\text{Ɋ}-\hat{U}}{\text{ƚ}}+1\right)\right], & r = 0 \\ \left[2^{\left(\frac{\text{Ɋ}-\hat{U}}{\text{ƚ}}+r+2\right)};\ 2^{\left(\frac{\text{Ɋ}-\hat{U}}{\text{ƚ}}+r+3\right)}\right], & r > 0 \end{cases} \tag{1}$$

Thus, in QU-EAIFS MAC, a node having a high degree of queue utilization avails the highest probability of accessing the medium. On the other hand a node with almost empty queue has the lowest probability of accessing the channel. This method of differentiation increases the probability of forwarding frames, if the node in the next hop has an emptier queue. When multiple nodes with similar queue utilization compete to access the shared channel, a node with packets that have transited a longer path gets higher probability of accessing the channel to the one with packets which has transited shorter path, because traffic which has travelled higher hop waits lesser IFS. The proposed protocol optimizes the performance when there is bottleneck in the network due to network saturation by forwarding the packets to the nodes whose queues are less utilized. Thus, this approach optimizes the utilization of the queues and reduces the packet drop along the path and leads to higher end-to-end throughput.

IV. SIMULATION AND EVALUATION

The proposed MAC protocol was tested and benchmarked against the standard IEEE802.11b and IEEE802.11e, a QoS MAC protocol in a variety of simulation environments, starting from a chain topology of 2 hops to 6 hops. In order to validate the testing of the new MAC, a random network topology with 50 nodes is also considered, with a random source and destination pairs, using both single and multiple traffic flows.

All simulations were carried out using NS2 [21], according to the network parameters listed in Table 1. Each simulation lasted for 800 seconds and an average value of 250 rounds of simulations is considered in analysing the result. The majority of simulations are performed using 1000 byte packet size, but smaller packet sizes of 500 byte are also considered. All the tests were performed with a supplied load over a saturated region of the network.

A. Five-hop chain topology:

Parameter	Value/protocol used
Grid Size	2000m x 2000m
Routing Protocol	DSDV
Queue Type	DropTail
Queue Size	100
Bandwidth	2Mbps
SIFS	10µs
DIFS	50µs
Length of Slot	20µs
Transmission Range	250m
CS Range	550m
Max_{Retry}	7
Simulation Time	800s
Traffic Type	CBR
Packet size	500, 1000 bytes

Table 1. Simulation Setup

The initial simulations used a regular chain of 5 hop topology with 1000 byte packet size, based on the node arrangement shown in Figure 2, followed by testing with a shorter path length and a higher path length of six hops. A set of random topology simulations is also carried out in order to validate the testing of the new protocol. During the testing, in order to measure the performance of the network, the offered load is gradually increased beyond the point of network saturation. Initially, node n_0 and node n_5 act as the source and the destination respectively for a UDP connection supporting CBR application traffic. The testing was carried out for IEEE 802.11b, IEEE 802.11e, with highest priority and lowest priority setup and finally the proposed MAC.

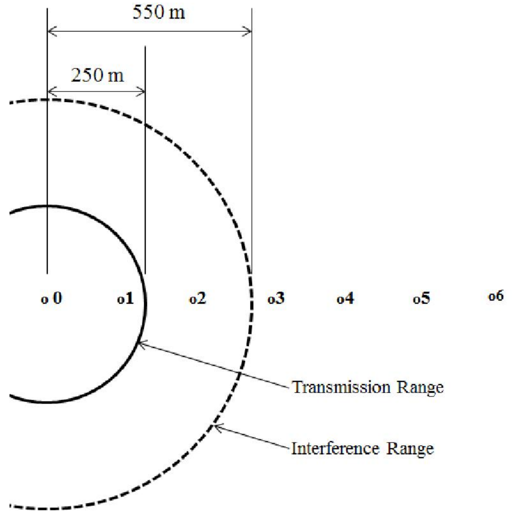

Figure 2. Chain Topology settings of the Ad Hoc Network

The MAC layer contention among the competing nodes in IEEE 802.11b is fair in terms of the backoff values of the contention window, but interference along the transiting path varies as the active participating nodes increases, and the incoming and the outgoing packets of an active node are not controlled. Consequently it is expected that the packet drop and queue utilization will not be uniform along the path. Figure 3 shows that the end-to-end throughput starts to saturate in IEEE802.11b when the offered load from the source is approximately 330Kbps, as shown in Figure 3. The performance deteriorates as the offered load increases, but stabilizes at after 600Kbps and upwards. The graph shows that the first hop creates a significant bottleneck; therefore packet loss is substantial when forwarding traffic to the next hop. The graph also indicates that most of the packets that arrive at the second hop eventually reach the destination successfully with insignificant loss. From the graph it can be deduced that the source occupies most of the bandwidth in sending data to the next hop and in turn the next hop neighbour has less chance to access the shared channel and forward the incoming packets. It resulted in a heavy loss of packets at the next hop from the source. Thus, most of the queues are underutilized and only the ones around the source are over utilized, resulted in a non-uniform loss of packets along the route. From the second hop onwards the overall degree of contention is reduced since the packet arrival at higher hop has reduced to large extend. The queue utilization has become uniform from second hop and has minimal loss thereafter. The maximum end-to-end throughput gradually decreases as the network gets saturated and the offered load increases, but stabilizes at approximately 200Kbps.

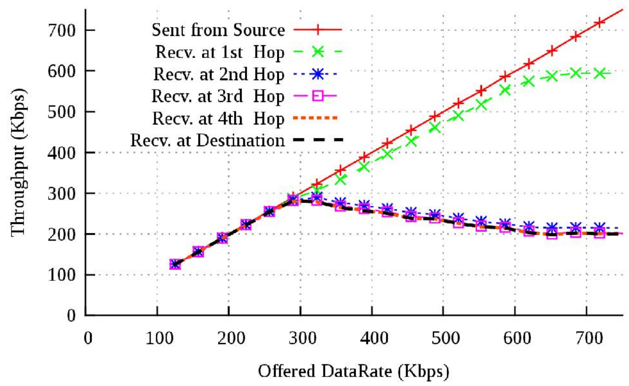

Figure 3. Throughput per Hop Vs Offered DataRate, IEEE802.11b on a 5-hop chain.

Figure 4 and Figure 5 shows the performance of IEEE 802.11e when the application is set with the lowest priority (used for best effort traffic) and highest priority (used for voice traffic) respectively. In both the cases, UDP connections are considered with CBR traffic and are tested with network parameters listed in Table 1 and chain topology of Figure 2. Even though it is same CBR traffic, priority of the application is set to the one as low and the other as high. In both the cases the end-to-end performance is worse than IEEE 802.11b.

Figure 4 shows the per hop performance evaluation of a source and a destination with 5 hop communicating path length using IEEE 802.11e with an application priority set to the lowest. The CW for best effort traffic in IEEE 802.11e ranges from 31 to 1023 with an Arbitrary Inter Frame Spacing (AIFS) of $7\mu s$. There is a heavy loss of packets around the source and the queue utilization distribution along the path is similar to that of IEEE 802.11b, but as the offered load increases the arrival rate at the first hop from the source stabilises unlike the IEEE 802.11b where the source node continues to capture the channel. The result also reveals that the queue utilization and packet loss rate is similar with IEEE 802.11b after the second hop from the source. It also shows that without much loss most of the packets which could make upto the second hop eventually reaches destination. The end-to-end performance of IEEE 802.11b is well ahead of the IEEE 802.11e.

In 802.11e with low priority application, the saturation point is relatively higher to that of the IEEE 802.11e with high priority application, because it has a wider range of contention window to withstand contention, but as the offered load increases the performance decreases and the end-to-end throughput stabilises around 160Kbps.

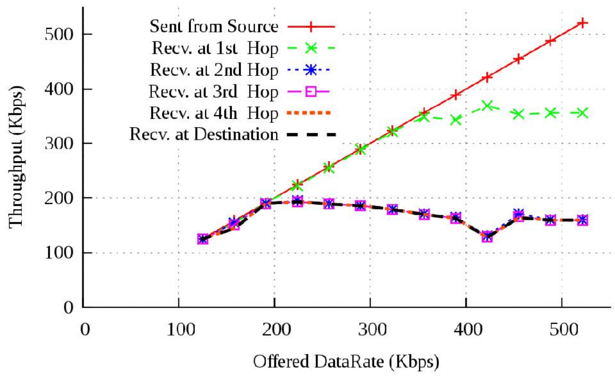

Figure 4. Throughput per Hop Vs Offered DataRate, IEEE802.11e (Lowest Priority) on a 5-hop chain.

Figure 5 shows that despite setting the connection with highest priority in IEEE 802.11e, the end-to-end performance is low, this is mainly due to the fact that the CW window range is only (7,15) which is too narrow for a saturated network, despite using small AIFS of $2\mu s$. The end-to-end throughput of IEEE 802.11e with highest priority starts to saturate much faster than the traffic load that the IEEE 802.11b could withstand. The result of Figure 5 also shows that there is a heavy loss of packets mainly at the source, but it also shows that the distribution of the queue utilization is more uniform in IEEE 802.11e with high priority traffic compared to the IEEE802.11b or IEEE 802.11e with low priority traffic in a 5 hop communicating path. After the saturation point, as the offered load increases the overall performance initially degrades and stabilizes with an end-to-end throughput approximately at around 150Kbps.

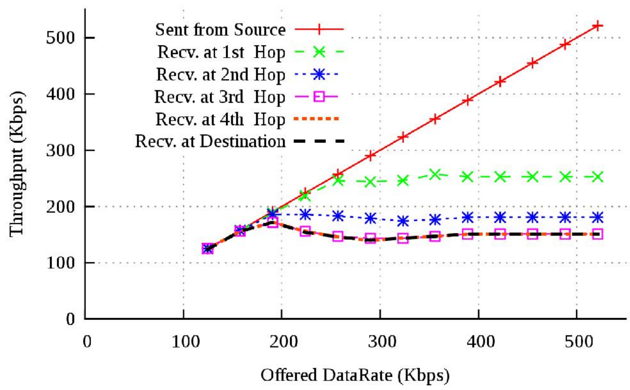

Figure 5. Throughput per Hop Vs Offered DataRate, IEEE802.11e (Highest Priority) on a 5-hop chain.

According to Figure 6, the saturation point of the new protocol QU-EAIFS MAC is similar to that of IEEE 802.11b. However, as the offered load further increases the performance of the network does not degrade like the standard IEEE 802.11b or IEEE 802.11e standards. In QU-

EAIFS MAC the queue utilization along the path is distributed more uniformly in comparison with IEEE 802.11b or IEEE 802.11e, and the end-to-end performance is retained at higher level when the offered load increases unlike the standard IEEE 802.11 standards where the performance sinks and stabilizes at a lower point. In QU-EAIFS MAC, the channel access is uniformly shared by the contending nodes unlike IEEE 802.11b and IEEE 802.11e. This is due to the fact that a node with a busier queue gets a higher probability of accessing the channel than the emptier ones and the traffic with higher hops have a lower IFS waiting time. As the queues fill up, there is a higher probability for the node to access the channel and forward the packets to the next hop. When two nodes have similar queue utilization, the data traffic with higher hops gets the privilege during contention because it waits a shorter IFS waiting time. A node having fewer packets waits longer than the ones that are overflowing, resulting in reducing the overall packet drop and enhancing the end-to-end network performance. The network becomes saturated with a high end-to-end throughput at approximately 280Kbps which is 40% higher to that of IEEE 802.11b, and 75%-87% higher to that of IEEE 802.11e standards (with lowest and highest priority levels).

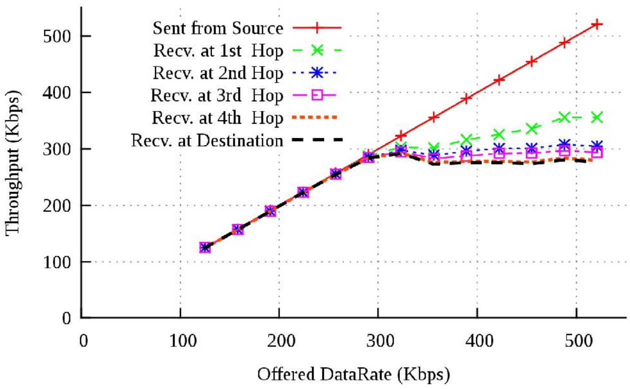

Figure 6. Throughput per Hop Vs Offered DataRate, QU-EAIFS MAC on a 5-hop chain.

B. Six-hop chain topology

Figure 7 and Figure 8 present the results from a topology with a path length of 6 hops between the source and the destination, with network parameters of Table 1, a packet size of 1000Bytes and a chain topology as shown in Figure 2.

The graph of Figure 7 shows arrival rate of packet at each intermediate nodes with an error bar when a specific load of 519Kbps is supplied in the 6-hop communicating chain. In case of IEEE 802.11b, the arriving data rate at the third hop is less than half the supplied rate and in case of IEEE 802.11e with highest priority application and the lowest priority application the packet arrival rate is less than half the supplied data rate from two hops from the origin. On the other hand, the new proposed MAC, QU-EAIFS never go below half at any intermediate node along the source and the destination. In IEEE 802.11b, more packets were forwarded upto second hop from the source as compared to QU-EAIFS MAC, but have a heavy loss thereafter unlike the new protocol which forward the received packets gradually with less loss rate along the route towards the destination. Similar to IEEE 802.11b, the QoS MAC IEEE802.11e also suffers a heavy loss as early as from second hop onwards despite receiving high amount of data upto the first hop from the source. The performance gain in QU-EAIFS MAC compared to the standard MAC protocols like IEEE 802.11b and IEEE 802.11e is due to the fact that the fuller queue around the source are given higher priority to forwards the packets towards the destination with less utilized queues and the packets with higher hops waits the least IFS waiting time which gives a good opportunity to forward the older packets than the fresh ones when the contending nodes have similar queue utilization. Since IEEE 802.11b and IEEE 802.11e are not given any form of priority based on the dynamic situations and conditions of the network like QU-EAIFS MAC, hidden nodes and lack of intelligent decision during contention highly impacted the performance of the network. Thus, during network saturation, the overall average arrival rate of QU-EAIFS MAC is higher to that of IEEE 802.11b and IEEE 802.11e. The end-to-end throughput of 6 hop communication with IEEE 802.11b, IEEE 802.11e (Lowest Priority Application), IEEE 802.11e (Highest Priority Application) and QU-EAIFS MAC are 200Kbps, 143Kbps, 103Kbps and 268Kbps respectively. Thus, the new protocol QU-EAIFS gains approximately 34% over IEEE 802.11b, approximately 87% over IEEE 802.11e (Lowest Priority Application), and 160% over IEEE 802.11e (Highest Priority Application).

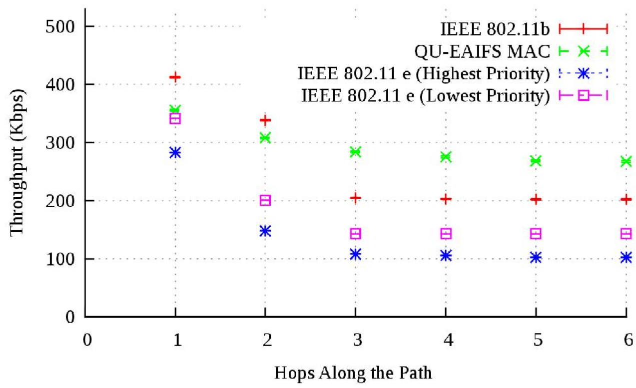

Figure 7. Avg. Throughput Vs Hops along the Path

Figure 8 shows the per hop packet loss in percentage at each hop, it directly reflects the queue utilization status of each node along the route. The graph shows that IEEE 802.11b does not lost as much as the QU-EAIFS MAC at the source, but there is a heavy loss of approximately 40% at the second hop which is very undesirable because it has already utilized resources for which the packets will never get delivered at the destination. Such pattern of forwarding higher packets from the source, but experience higher loss along the way is seen even in IEEE 802.11e. Interestingly, in the case of the new proposed protocol QU-EAIFS MAC, the loss along the path is gradual and uniform. The chances of forwarded packets getting delivered is very high in QU-EAIFS MAC unlike IEEE 802.11b and IEEE 802.11e where the forwarded packets faces higher chances of losing along the way.

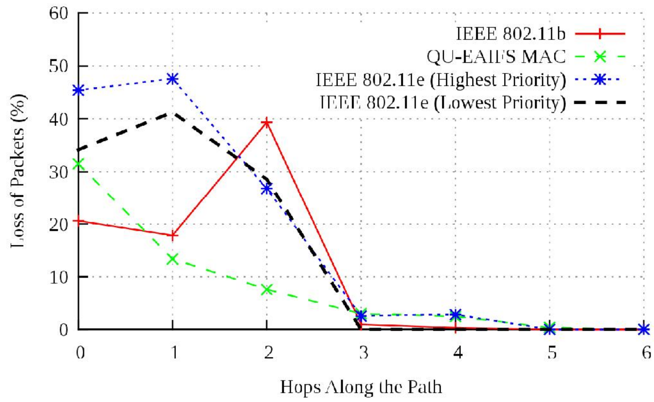

Figure 8. Per-hop packet loss distribution.

C. Shorter chains

IEEE 802.11e may differentiate different traffic well, but the end-to-end performance is not competitive, so the comparison of QU-EAIFS MAC is done only with IEEE 802.11b for rest of the paper. In order to saturate the network, a higher traffic load is supplied when path length is low compared to when hop count of the path is high. An offered load of 876Kbps is supplied for a 2 hop communicating path length. The performance gain of QU-EAIFS MAC over IEEE 802.11b for low hop path length of 2 hops is low when a packet size of 1000Byte is considered. This is due to the fact that the queue utilization within two hops is similar, because the interference range of the source node extends upto the second hop.

D. Other packet sizes

This section tests IEEE 802.11b over QU-EAIFS MAC with low hop and high hop path with a smaller packet size of 500Byte with the network parameters listed in Table 1 and linear topology of Figure 2. Generally, in Ad Hoc network the performance gain for a smaller packet size is greatly affected by the control overheads (RTS-CTS-ACK), since more packets and more hop means higher control overheads. When the application packet size is reduced to 500Byte from a 1000Byte packet size and a same load is offered, it increasing the control overheads by 100%. The performance gain of QU-EAIFS MAC over IEEE 802.11b for a high 6 hops communication with 500Byte packet size with an offered load of 519Kbps is approximately 11% and for a low hop communication of 2 hops with an offered load of 876Kbps the gain of QU-EAIFS MAC over IEEE 802.11b is 3.5%. Thus, in terms of performance gain, smaller packet size of 500Byte is better for 2 hop path than the 1000Byte in QU-EAIFS MAC.

E. Random topology

In order to make the testing and simulation more realistic, a random placement of 50 nodes is considered as shown in Figure 9. The node placement area is divided into three regions namely AREA 1, AREA 2 and AREA 3. AREA 1, AREA 2 and AREA 3 are randomly placed with 10 nodes, 30 nodes and 10 nodes respectively and source nodes are randomly picked from AREA 1 and destination nodes are likewise randomly selected from AREA 3. The randomly placed nodes in AREA 2 acts as the potential relay nodes. As shown in Figure 9, potential source nodes and the potential destinations are separated by at least 1000m to generate at least multiple hop communication between any randomly picked source and a destination pair. A fixed data rate of 519Kbps is offered to the network and tested with 1000 byte packets with the network parameter listed in Table 1. The actual path between the source and the destination is decided by the routing algorithm, DSDV. The data used in calculating the network performances are all in Kbps.

During the testing with a random topology, both single flow and multi flows are tested. A total of 250 different random topologies are considered in both the cases with a fresh random selection of source and a destination pair(s) for each topology. Initial testing is done with a single flow by randomly selecting a source and a destination from AREA 1 and AREA 3 respectively. Later, a case with a multiple flow (two flows in this case) with a random selection of distinct source and destination pairs from AREA 1 and AREA 3 respectively are considered. The work ignores the simulated data, if path could not be established between the source and the destination pair.

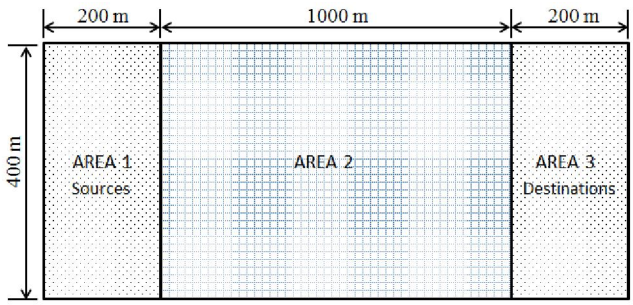

Figure 9. Node placement in a random topology

Since the placement of the node is defined within a boundary as shown in Figure 9 and extensive simulation is considered, during the analysis an average value is calculated for simplicity. The performance gain of QU-

EAIFS MAC over the standard MAC IEEE 802.11b in the case of single flow with random topology is approximately 23%. The data used for calculating the error bar is in Kbps. The error bar of IEEE 802.11b is 199$\pm$0.74 Kbps and that of QU-EAIFS MAC is 244$\pm$0.91 Kbps. It shows that both the protocols are consistent and also verified that different round of test does not fluctuate the end-to-end performance much.

In the multi flow scenario, one of the flows has an average end-to-end performance of approximately 103Kbps and the other has approximately 104Kbps for IEEE 802.11b MAC. In case of QU-EAIFS MAC, one flow has an average end-to-end performance of 122Kbps and the other has 121Kbps. Thus there is a performance gain of approximately 18% for the one flow and 16% for the other flow in QU-EAIFS MAC over IEEE 802.11b. If the total network performance is considered then there is a gain of approximately 17% in QU-EAIFS MAC compared to IEEE 802.11b. The correlation coefficient among the two flows using IEEE 802.11b is -0.66 and that of QU-EAIFS MAC is -0.55. The correlation coefficient shows that there is an effect of reversal impact of one flow over the other and it is more in IEEE 802.11b over QU-EAIFS MAC. The error bar using IEEE 802.11b for one flow is +0.98 and for the other flow it is +1.03. The error bar of QU-EAIFS MAC is +0.80 for one flow and +0.88 for the other flow. The error bar improves as the number of flows increases in QU-EAIFS MAC as compared to IEEE 802.11b.

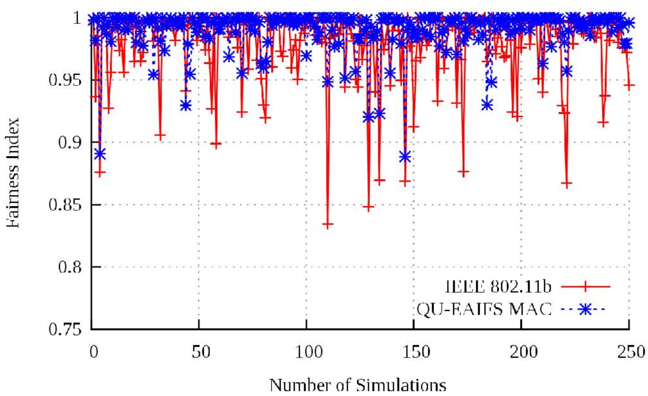

Figure 10. Fairness Index of the multi flows

The degree of fairness of the multiple flows using IEEE 802.11b and QU-EAIFS MAC is calculated using Jain's fairness index as shown in Figure 10. The average degree of fairness of IEEE 802.11b is 98% and that of QU-EAIFS is 99.00%.

V. CONCLUSION AND FUTURE DIRECTION

The new MAC, Queue Utilization with Hop based Enhanced Arbitrary Inter Frame Spacing (QU-EAIFS) designed for a saturated Ad hoc networks is based on enhancing arbitrary IFS and providing priority during contention. In a simulation using 5-hop chain topology, the new protocol QU-EAIFS MAC have a performance gain of approximately 40%, 75%, 87% over the standard IEEE 802.11b, IEEE 802.11e (Lowest priority), IEEE 802.11e (Highest priority) respectively in a saturated region. Further increase of path length to 6 hops achieves a performance gain of approximately 34% in QU-EAIFS over IEEE 802.11b, approximately 87% over IEEE 802.11e (Lowest Priority), and 160% over IEEE 802.11e (Highest priority). The paper also concludes that IEEE 802.11e performs worse than the IEEE 802.11b. Additional experiments conducted with shorter path length, smaller packet size and random network topology validates the robustness of the performance gain of the proposed new protocol QU-EAIFS MAC.

The future work will be based on intelligently coordinating the nodes, by knowing the current network resources like the queue utilization, bandwidth availability, and hop travelled by the packets by exploring the effect of contention, hidden nodes, transmission range and its interference range at large.

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