Dynamic Queue Utilization Based MAC for Multi-Hop Ad Hoc Networks

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***Abstract* – The end-to-end throughput in single flow multi-hop Ad Hoc networks decays rapidly with path length. Along the path, the success rate of delivering packets towards the destination decreases due to higher contention, interference, limited buffer size and limited shared bandwidth constraints. In such environments the queues fill up faster in nodes closer to the source than in the nodes nearer the destination. In order to reduce buffer overflow and improve throughput for a saturated network, this paper introduces a new MAC protocol named Dynamic Queue Utilization Based Medium Access Control (DQUB-MAC). The protocol aims to prioritise access to the channel for queues with higher utilization and helps in achieving higher throughput by rapidly draining packets towards the destination. The proposed MAC enhances the performance of an end-to-end data flow by up to 30% for a six hop transmission in a chain topology and is demonstrated to remain competitive for other network topologies and for a variety of packet sizes.**

***Index Terms* – Ad-Hoc, MAC, Queue, QoS, Network Saturation.**

I. INTRODUCTION

Quality of Service (QoS) provisioning in Ad Hoc networks remains a challenging issue despite substantial research undertaken over the past decade [1]-[5]. Seminal papers have considered the capacity of a wireless network subject to multiple flows [6] but in this paper attention is restricted to a single multi-hop flow in the saturated region (a point where increasing the input data rates in the network does not enhance the performance further). Even in this case, due to high interference and limited bandwidth, network environments self-generate bottlenecks along multi-hop paths. The network saturates rapidly and end-to-end throughput decays rapidly with path length [7]-[8].

For a single multi-hop flow in an Ad Hoc wireless network, a node is considered to be active if it is a source node, a relay node, or a receiving node. In standard IEEE 802.11DCF, all active nodes have equal probability of accessing the medium, and a node with i active nodes in its interference range may gain access to the medium with a probability of $1/i$. In a linear chain topology, per node access probability decreases as the hop count rises and the interfering nodes increases. For a long chain topology, the highest degree of interference occurs around the centre of the chain and is lower towards either the source or the destination ends of the chain. So, for a single flow along a chain, the queue utilization pattern will vary with the hop count. This motivates the design of a medium access mechanism that dynamically depends on the queue utilization of the participating nodes.

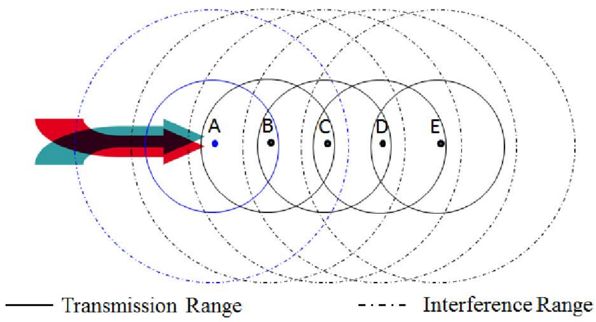

Figure 1. A chain topology with four hop network

In the given figure 1, if node A wants to send data to node E, as the number of hop increases, the degree of interference and the number of contenders also increases, so it gets harder to push the packets forward towards the destination. When node A uses the channel, node B and C has to differ, because node B is with the transmission range of node A and node C is within an interference range of node A. In such a distributed network with a shared channel mechanism, if a real time traffic with a high data rate of constant bit rate is generated at node A or node A acts as a gateway of the inflow traffics, the chances of buffer overflow is high since the access of the shared channel by node B or C would force node A to differ accessing the channel. Thus a ripple effect of differing upto two hop neighbours is formed when a node becomes active as a sender or as a relay node in a shared channel of multi hop network. So, achieving high end to end throughput is limited by the nature of the network.

In the condition of network saturation, losses of data in the network are mainly due to the queue being full, no route availability or retry count exceeded. Other kinds of drops are due to collision and packet error, but such packets are retransmitted if the TTL (Time To Live) and retry count are still valid. Problems induced by physical limitations like

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bandwidth, transmission range and interference range cannot be resolved easily, but the MAC algorithm can be adjusted to control the access mechanism in such a way that overall packet drop is reduced and the network performance is elevated, which is the aim of this paper.

II. PERFORMANCE OPTIMIZATION IN AD HOC NETWORKS

In order to improve the performance of resource constrained Ad Hoc networks, a number of protocols have been proposed by different authors: challenges and prospects of bandwidth allocation are discussed in [9] and a method of predicting the available bandwidth for optimizing per node performance is proposed in [10].

Significant efforts have focused on optimizing the performance in multi-hop wireless Ad Hoc networks by controlling congestion and by designing efficient MAC protocols. The IEEE 802.11DCF specification provides fairness across the active contending nodes within its transmission range [11], but in order to differentiate services both in terms of throughput and delay and provide QoS, IEEE 802.11e was introduced with some variations in [12]-[14]. In order to enhance the performance of IEEE 802.11e, [15] discusses a technique to avoid unnecessary polling of a silent station which generates voice traffic. In order to elevate the end-to-end throughput, hop-by-hop congestion control is discussed in [16] and an end-to-end congestion control is also proposed in [17]. The authors of [18] describe a throughput-oriented MAC by controlling the transmitting power of the nodes based on game theory, to achieve concurrent transmission, [19] describes a method to optimize the sensing thresholds of the CSMA receiver and the transmitter by minimizing the outage probability by using SINR (Signal to Noise Ratio). A distributed contention window adaptation technique to adjust the incoming and the outgoing traffic is proposed in [20]. The authors of [21] describe an interesting MAC protocol that allows a concurrent transmission among the neighbours. In order to optimize the contention window usage, the authors of [22] also proposed a backoff generator based on contention level and the channel BER (Bit Error Rate) status.

The remainder of the paper is structured as follows. The proposed MAC is described in detail in Section III. Section IV provides the evaluation of the results, and then Section V concludes the paper by proposing a number of future directions.

III. PROPOSED MAC

A. Proposed Exponential Backoff Mechanism

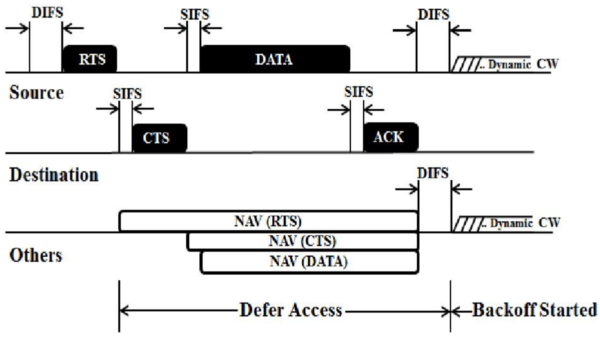

Figure 2 :Medium Access Control Operation.

The proposed MAC, named Dynamic Queue Utilization Based MAC (DQUB-MAC), is derived from the original IEEE 802.11 specification and operates within the context of the RTS/CTS mechanism shown in figure 2. The new protocol dynamically adjusts the probability of accessing the medium according to the buffer utilisation of active nodes. It does this by varying the [CWMin; CWMax] interval used in the backoff phase of the IEEE 802.11 protocol. As such, this protocol is explicitly cross-layer and the information concerning the queue utilization (q_u) is passed to the MAC layer with the help of a new 16-bit field in the IP packet header as shown in figure 3. Although not used in this paper, this information embedded in the packet header could also be useful at the next hop as it makes the node aware of the buffer status of the preceding node.

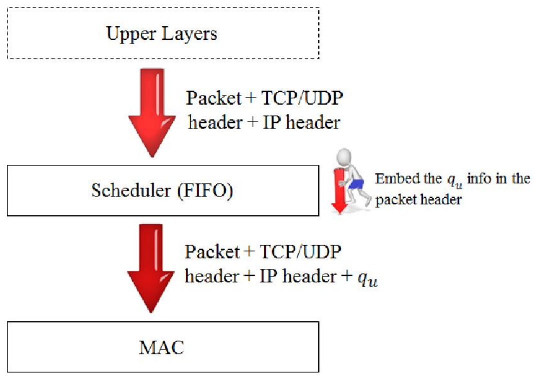

Figure 3: Embedding the Queue Utilization info in the Packet.

The DQUB-MAC assigns higher medium access probability to nodes with a higher queue utilisation. A node with full or already overflowing queue has the greatest likelihood of accessing the medium and a node with an almost empty queue has low probability of accessing the channel. This differentiation increases the probability of frames progressing to the next hop should that node have an emptier queue. This optimizes the utilization of the queues and reduces the packet drop along the path and leads to higher end-to-end network throughput.

A node running the DQUB-MAC protocol is initialised in the usual way with [*CWMin;CWMax*] =[0:8]. When the node becomes active either in sending, receiving or relaying, the CW range depends linearly on the remaining space in the queue according to (1).

$$[CWMin, CWMax] = \begin{cases} \left[2^{\alpha}\frac{Q-q_u}{\psi}; 2^{\alpha}(\frac{Q-q_u}{\psi}+1)\right], & r=0 \\ \left[2^{\alpha}\left(\frac{Q-q_u}{\psi}+1\right)(\gamma);\ 2^{\alpha}\left(\frac{Q-q_u}{\psi}+2\right)(\gamma)\right], & r>0 \end{cases} \quad (1)$$

In (1), Q denotes the maximum size of the queue, and the current utilization of the queue is denoted by q_u, so $Q - q_u$ represents the remaining number of empty slots of the queue. There are two adjusting parameters, α and ψ; and they control the width of the range of the contention window and the number of the priority levels respectively. In the present work, Q =100 and the adjusting parameters are set to α= 3, so that the contention window range grows/shrinks with a factor of 8 for different priority levels and with ψ= 30 in (1) to generate four different priority levels, namely: low, fair, high and very high when the queue utilization is between 0-29%, 30-59%, 60-89% and >=90% respectively. So, a fuller queue has a higher probability to access the channel compared to the emptier queue. The retry count of a packet is denoted by *r* and when the data packet is to be retransmitted (*r*>0) then a new contention window (CW) range interval is calculated as shown in (1). This depends linearly on the remaining number of retries given by γ, which is computed as the difference between the retry limit of retransmission, and the current retry number of retransmission. This factor γ helps a packet which has attempted a higher number of retransmission to get higher degree of access probability to that of a fresher one when the queue utilizations (q_u) of the nodes are similar. The maximum number of retransmissions takes the same value as used in IEEE802.11 following the work of [23], so that packets which are too old are discarded after several unsuccessful attempts.

IV. EVALUATION

The new algorithm has been tested and benchmarked against both IEEE802.11 and IEEE802.11e standards in a variety of simulation environments. The purpose of the tests is to evaluate the efficiency in distributing the traffic and queue utilisation, as well as to determine the resulting packet loss in saturated network scenarios. Moreover, some tests of the robustness of the algorithm under less favourable circumstances are also performed.

All simulations are carried out with NS2, version 2.35 according to the network parameters listed in Table 1. Each simulation lasts for 800 seconds and each result is an average value of 10 rounds of simulations. The majority of simulations are performed using 1000 byte packet size.

A. *Six-hop chain topology:*

Most of the simulations use a regular chain topology based on the node arrangement shown in figure 4 and later a rigorous random topology simulations are considered to validate the testing. Different length chains will be considered but the first sets of simulations are based on a six hop chain. Node 0 and node 6 act as the source and the destination respectively for a UDP connection supporting a CBR application with a packet size of 1000 bytes.

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, 1500 bytes

Table 1: Simulation Setup.

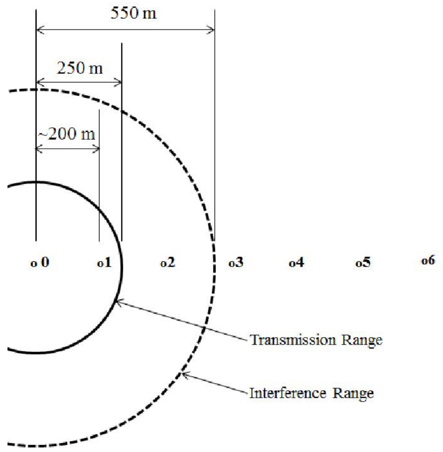

Figure 4: Chain Topology settings of the Ad Hoc Network

The first set of simulations measure the throughput as the offered load is increased on the 6-hop chain. Figures 5, 6, and 7 show the results for IEEE802.11 DCF, IEEE802.11e and DQUB-MAC respectively.

In the experiment of figure 5, using IEEE 802.11 DCF the MAC layer contention among the competing nodes is fair, but interference along the transiting path is different, 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 5 shows that end-to-end throughput starts to saturate when the source node generates data at approximately 290kb/s in IEEE802.11DCF. The performance deteriorates as the offered load increases, but stabilizes at around 400kb/s and upwards. The graph also shows the data rates in each node in order to display the bottlenecks. The graph confirms that loss of packets along the route is not uniform and neither is the utilization of each queue along the path. The end-to-end throughput at the point the network becomes saturated is approximately 200kb/s.

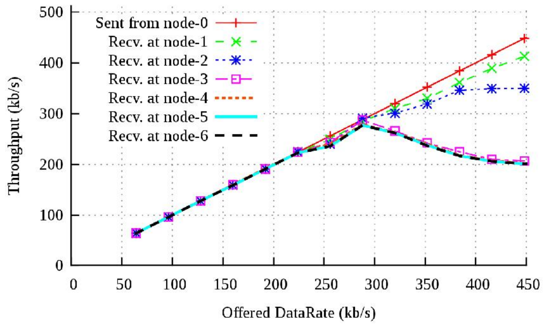

Figure 5: Throughput per Hop Vs Offered DataRate, IEEE802.11DCF on a 6-hop Chain.

Figure 6 shows that the performance of IEEE 802.11e is worse than IEEE 802.11DCF despite setting the data flow to the highest priority. This is due to the fact that the CW window range for this highest priority is only (7,15) which is too narrow for a saturated network. The end-to-end throughput starts to saturate only at around 200kb/s, a traffic load much lower to that of IEEE802.11DCF. Since, the network becomes saturated much earlier, the experiment reveals that there is a heavy loss of packets in an around the source node. This result also shows that the distribution of the queue utilization is non-uniform along the high hop communicating path. The end-to-end throughput after network saturation is approximately 130kb/s, a value which is approximately 35% lower than IEEE 802.11DCF.

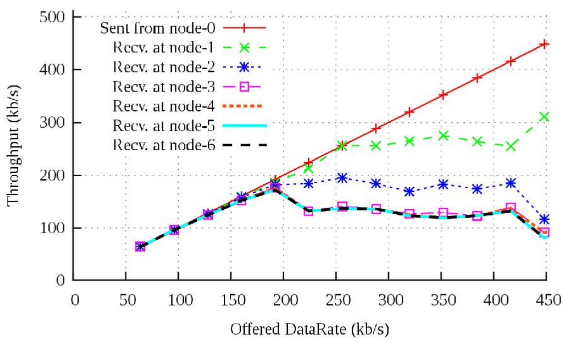

Figure 6: Throughput per Hop Vs Offered DataRate, IEEE802.11e on a 6-hop Chain.

The experiment of figure 7 shows that the saturation point of the offered load of DQUB-MAC is similar to that of IEEE 802.11DCF protocol. However, as the offered load is further increased, the performance does not sink like IEEE 802.11DCF and IEEE802.11e. Instead, as the queue utilization along the path is distributed more uniformly in comparison with IEEE 802.11DCF or IEEE 802.11e, the resulting data rates continue to increase when the offered data rate increases. This is due to the fact that the nodes with heavily utilized queues are given higher probability to access the channel than the ones that are less utilized. As a queue fills up, more packets are forwarded towards the nodes with underutilised queues. Those nodes with similar queue utilization are hereby each share the same CW range. Nodes with fewer packets wait longer than the ones that are overflowing, therefore the overall packet drop is greatly reduced and in turn the network performance is enhanced. The network becomes saturated with a high end-to-end throughput of approximately 270kb/s. The end-to-end throughput of DQUB-MAC is approximately 35% and 107% higher than that of IEEE802.11DCF and IEEE802.11e respectively in network saturation.

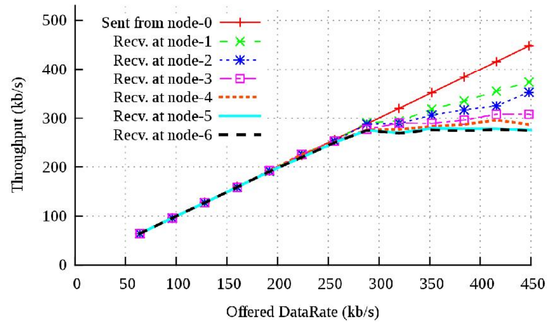

Figure 7: Throughput per Hop Vs Offered DataRate, DQUB-MAC on a 6-hop Chain.

Figure 8 shows the throughput achieved per hop along with the error bar for a specific offered data rate of 416kb/s along the 6-hop chain. This represents the packet arrival rate at each intermediate node. In the case of IEEE 802.11DCF, the data rate is halved after three hops; IEEE 802.11e halves the data rate after only two hops from the source. In the case of DQUB-MAC, the overall arrival rate at each intermediate node is much higher than for the IEEE802.11 standards and the data rate never drops by half. This improvement is due to the fact that queues that are either full or highly utilised (in this case queues on the source and the following few nodes) will dynamically receive higher access probability to push the packets forward, compared to those nodes whose queues are less populated and are situated closer towards the destination. Since no priority of any form is assigned to IEEE 802.11 DCF, the impact of hidden nodes and buffer overflow degrades the performance of the network after third hop and similar is the case for IEEE 802.11e.

The error bar is too small to be visible as shown in the figure 8. During network saturation, the average delay between two successive packet arrivals of a packet size of 1000 bytes at the destination when DQUB-MAC, IEEE

802.11 DCF, and IEEE 802.11e MAC are used are 28.8569ms, 29.3185ms and 60.411ms respectively, when the packet generating interval at the source is 19.2307ms. At a low data rate when packets of 1000 bytes are generated with an interval of 62.5ms at the source i.e. during unsaturated network, the average delay between two successive packet arrivals are 62.5131ms, 62.5046ms, and 64.102ms while using DQUB-MAC, IEEE 802.11 DCF, and IEEE 802.11e MAC respectively. During network saturation, the overall average arrival rate is higher for DQUB-MAC, due to the use of fast forwarding technique when queue utilization is high, unlike IEEE 802.11 DCF or IEEE 802.11e MAC where heavy loss of packets occurs due to buffer overflow.

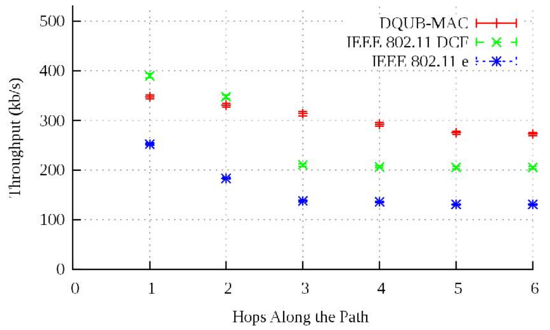

Figure 8: Avg. Throughput Vs Hops along the Path.

The way in which DQUB-MAC improves the queue utilisation distribution is shown in figure 9 which presents the per-hop packet loss distribution with an offered load of 416kb/s. The maximum loss rate at any hop along the route for DQUB-MAC is only 15% whereas IEEE802.11DCF and IEEE802.11e have maximum loss rate approaching 40%. In DQUB-MAC, the loss rate is distributed uniformly along the route while IEEE 802.11DCF and IEEE 802.11e, display an irregular pattern of loss.

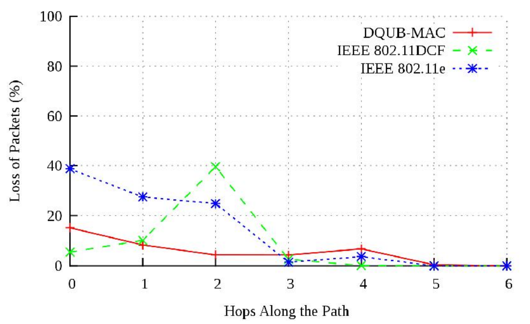

Figure 9: Per-hop Packet Loss Distribution.

B. End-to-End Delay Analysis:

Using the chain topology of figure 4 and the network parameters listed in table 1, the average end-to-end delay of a packet with a short path length of 2 hops and a long path length of 6 hops are calculated with an increasing offered load as shown in table 2. The average end-to-end delay is the average time taken by a packet between its delivery time at the destination and the time when it was generates at the source's application. The main factors contributing to the end-to-end delay of a packet are processing delay, queuing delay and transmission delay; among all these factors, the queuing delay has the highest impact on delaying the end-to-end delivery of a packet. In a shared channel environment, higher number of active nodes led to a higher degree of contention which enhances the queuing delay.

Source Data Rate kb/s	Average End-to-End delay in sec			
	2 hops		6 hops	
	IEEE 802.11 DCF	DQUB-MAC	IEEE 802.11 DCF	DQUB - MAC
32	0.010914	0.011452	0.03315	0.034774
96	0.01091	0.011451	0.033141	0.034775
160	0.01091	0.01145	0.033154	0.034825
224	0.01091	0.01145	0.033153	0.034776
288	0.01091	0.011452	0.191107	0.233461
352	0.01091	0.011451	3.457812	2.939796
416	0.01091	0.011451	4.854712	4.986854
480	0.01091	0.01145	6.025652	5.738954
544	0.010912	0.011452	6.403192	5.85696
608	0.010909	0.011453	6.427407	6.086968
672	0.010897	0.011502	6.294373	6.065397

Table 2: Average End-to-End Delay of a Packet.

Here in analysing the delay, instead of testing with different packet sizes, the end-to-end delay is evaluated using different data rates with a fixed packet size of 1000 bytes, so that the rate of generation of packet varies. For a short distance communication like two hops, the end to end delay is not much affected by the increasing data rate of the source in both the medium access control protocols, IEEE 802.11 DCF and DQUB-MAC when tested with an offered load of upto 672 kb/s. But in case of long path length like 6 hops, where the degree of contention is higher, DQUB-MAC performs better in terms of average end-to-end delay in comparison to IEEE 802.11 DCF when the offered load of the source is high; it is due to the fast forwarding technique used in DQUB-MAC when the queue utilization is higher. When the data rate is low, the end-to-end delay is small because there is sufficient bandwidth to share among the contending nodes and the queue hardly gets full to introduce a long queueing delay, but when the offered data rate is high, more packets are generated with a faster rate at the source than the capacity of the shared channel, so the queuing delay increases, resulted in higher end-to-end delay in both the IEEE 802.11 DCF or the DQUB-MAC.

C. Shorter chains:

Since the end-to-end performance of IEEE 802.11e is not competitive, comparison of the proposed protocol is done only with IEEE 802.11DCF hereafter. Two-hop and four-hop chain topologies are tested and compared with the outcome scenario of the six-hop chain topology. In order to cause network saturation, the offered data rates are 768kb/s, 585kb/s and 416kb/s respectively.

Table 3 compares the three different scenarios and confirms that the longer the path length, the larger is the performance improvement from using the new algorithm. However, there is a discernible advantage even for short chains. The reason for small improvement for shorter chain in DQUB-MAC is due to similar queue utilization pattern (similar priority) among the nodes, since the nodes are exposed within the vicinity of each other's interference ranges. When the path length is high, the degree of contention and interference density vary, resulted in higher degree of variation in queue utilization pattern, highest around the source.

MAC Type	Chain throughput (kb/s)		
	2-hop	4-hop	6-hop
IEEE 802.11 DCF (A)	715	324	208
DQUB – MAC (B)	726	334	271
Percentage improvement	1.5%	3.1%	30.3%

Table 3: Saturation Throughput of Shorter Chains.

D. Flows with opposite directions:

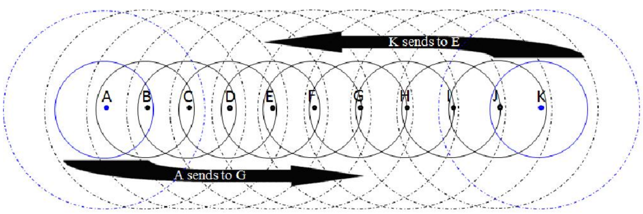

Figure 10: A chain topology with 11 nodes, with two flows from Opposite Direction.

Here in figure 10, eleven different nodes are arranged in a chain topology. Two sources of the extreme end points of figure 10 are selected as the sources, where node A sends to node G and node K sends to node E, so that the two traffics crosses each other with a crossover of two hops and each flow has to move six hops to reach their respective destinations. The graph of figure 11 provides the network performance of the network for an increasing data rate of per flow offered load of the network topology of figure 10, which is tested with a network parameters listed in table 1. In a system using IEEE 802.11 DCF medium access control mechanism, the total network throughput peaks when the offered per flow load is 250kb/s to 350kb/s, but thereafter despite increasing the per flow offered load of the network, the total end-to-end network throughput drops drastically and saturates with a total network throughput of around 325kb/s. In case of DQUB-MAC, the network saturates with a higher network throughput of around 375kb/s. It shows that there is a performance gain of 15% during network saturation in case of DQUB-MAC over the standard IEEE 802.11 DCF medium access control protocol. In such case where one traffic flow crosses other traffic flow in an opposite direction with a 6 hop communication, the peak network throughput is achieved when the per flow load supply is between 250kb/s - 350kb/s and 250kb/s - 420kb/s in case of IEEE 802.11 DCF and DQUB-MAC respectively. Increasing per flow load does not increase the overall network performance after the peak, but the DQUB-MAC performs better and handles saturated region more efficiently to that of IEEE 802.11 DCF as shown in figure 11.

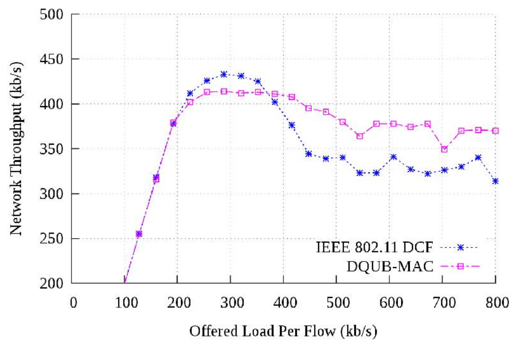

Figure 11: Network performance, with two flows running from opposite direction

E. Other packet sizes:

So far, all simulations have taken place with 1000 byte packets. Under the same network scenarios and the same network parameters, it is observed that for smaller 500 byte packets the performance gain is not as large. This is due to the fact that the control overhead (RTS-CTS-ACK) increases substantially. The gain of DQUB-MAC over IEEE802.11DCF for high hop count is approximately 16%. When the hop count between the communicating nodes is two and four, then the performance gain of DQUB-MAC over IEEE802.11DCF is approximately 2.5% and 3.2% respectively.

For larger packets, beyond the Maximum Transfer Unit (MTU) of a link, the packet is fragmented. However, even with a 1500 byte packet and 1000 byte MTU the performance gain of DQUB-MAC over IEEE802.11DCF over two hops, four hops and six hops is approximately 5.0%, 12.0% and 18.0% respectively.

F. Random topology:

In order to validate the results are not an artefact of artificially arranged networks, a random placement of 40 nodes is considered as shown in figure 12, by dividing the area into three zones, namely AREA 1, AREA 2 and AREA 3. AREA 1, AREA 2 and AREA 3 are randomly placed with 10 nodes, 20 nodes and 10 nodes respectively. Sources and destinations are also randomly selected from AREA1 and AREA 3 respectively. Potential source zone and destination zone are separated by at least 1000m with a consideration that source and destination are at least multiple hops apart. A fixed data rate of 416kb/s is offered to the network and tested with 1000 byte packets of real time data like CBR traffics. The same network parameters listed in Table 1 are used during the simulation. The actual path taken depends on the routing algorithm, DSDV. Two different sets of simulations are considered: firstly, with a single flow with a random selection of source from AREA 1 and a random selection of destination from AREA 3. Secondly, 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. A total of 200 different random topologies are considered with a fresh random selection of source and a destination pair(s) at each turn in both the cases. Ignore all those simulations, if path could not be established between the source and destination pair.

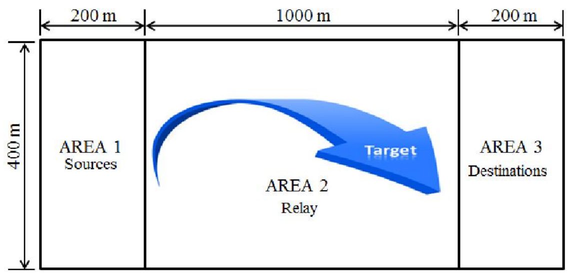

Figure 12: Random Topology

Since the node placement is defined and the simulation is ran extensively, an average value is considered for simplicity in analysis. In the first case with a single flow, the correlation coefficient of the end-to-end performance of IEEE 802.11 DCF and DQUB-MAC is +0.78, showing a strong uphill (positive) linear relationship. In this case DQUB-MAC yields a performance gain of approximately 42kb/s, which is a gain of 22% over IEEE 802.11 DCF. The error bar of IEEE 802.11 DCF is 1.043 and that of DQUB-MAC is 1.127 which shows that both the protocols are consistent and performance does not fluctuate much. In a multiple flow scenarios, the total network performance gain of DQUB-MAC is approximately 37kb/s, which is a gain of 20% over IEEE 802.11 DCF. The average degree of fairness among the flows in DQUB-MAC and IEEE 802.11 DCF are 97.51% and 97.60% respectively, using Jain's fairness index.

The random topology setup of figure 12 is also tested with an exponential traffic generator with multiple sources. During an exponential traffic generation there are different durations called the burst period and the idle time. The burst period is the time when network traffic is generated and idle time is the period when the application goes silent. The system is tested with a network parameters listed in table 1 with a 1000 bytes packet size and a multiple flows of 416kb/s per flow offered load in the network. Table 4 shows that whether the idle time is smaller or greater than the burst time, the overall network performance gain of DQUB-MAC outperformed the standard IEEE 802.11 DCF. When the burst time is greater than or equal to the idle time, the overall network performance gain of DQUB-MAC is over 16% compared to the IEEE 802.11 DCF.

Burst Time (s)	Idle Time (s)	IEEE 802.11 DCF (kb/s)	DQUB-MAC (kb/s)	Gain %
1.0	0.5	193.96	226.66	16.85
0.5	1.0	209.74	218.08	03.97
0.5	0.5	204.84	242.02	18.15

Table 4: Network Performance using Exponential Traffics.

V. CONCLUSION AND FUTURE DIRECTION

This paper has proposed a new MAC protocol, called Dynamic Queue Utilization Based (DQUB) MAC, which adjusts the contention window range based on the current utilization of the queue. As a result, a node with higher utilisation queue will be prioritised over a node whose queue is less utilized. Moreover, during packet retransmission, the protocol also ensures that packets with higher retransmission count will take priority over packets with lower retransmission count.

In simulations using a long 6-hop chain topology, the proposed DQUB-MAC demonstrated a performance gain of up to 30% over IEEE 802.11DCF when a CBR traffic is considered. Despite employing the highest priority, IEEE 802.11e performs even worse than IEEE 802.11DCF. Additional experiments also showed that these performance gains are robust with respect to varying the length of the chain, adjusting the packet size, considering random topologies and DQUB-MAC also works well with exponential traffic applications with a performance gain of over 16% when a burst time is greater than or equal to the idle time. There is a high degree of stability and consistency in DQUB-MAC even with random topologies. The degree of fairness of DQUB-MAC is equally compatible with the standard MAC with a higher degree of overall network performance gain.

Future work will be based on testing the protocol by introducing exponential back off instead of using a linear backoff when the packet retries, so that the protocol can withstand and accommodate high degree of contention. It shall also focus on using hop count values in designing the inter frame spacing to prioritize those packets travelled with higher hops.

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