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Integrated Qos Enhanced Differentiated Mac Model For Manets

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Abstract: Quality of Service (QoS) enhancement, often require fair scheduling algorithms and efficient MAC protocols. At times, MAC protocols are unable to meet the required QoS due to few reasons such as; starvation, packet drops due to unpredictable channel conditions and malicious behavior of certain nodes.To overcome these issues, an Integrated QoS enhanced differentiated MAC model(IQ-MAC) is proposed. The contribution is twofold. First, a composite prioritization and hybrid scheduling model based on Queue length, channel condition and life time of packets is proposed. Secondly, a misbehavior diagnosis model based on methods from statistics to enhance bandwidth utilization is proposed. The model is simulated with NS-2. Results show that on an average, the proposed model gives 15% more average throughput, 21% less packet drops and 17% less delay compared to the existing DWFQ architecture.

Keywords: MAC Layer, Misbehavior, Priority, Scheduling, QoS, Differentiated Services.

1. Introduction

Efficient bandwidth allocation in the MAC Layer has already been addressed in the earlier works[1]. However, there are other issues that have not been discussed exhaustively such as i) the fairly relative bandwidth allocation with avoidance of starvation and priority reversal for differentiated services, ii) dynamic scheduling model to avoid stale messages especially for urgent messages with short life time, iii) Technique to enhance throughput and reduce packet drops during collision and congestion in a differentiated services environment and iv) quantitative methods to diagnose and mitigate misbehavior at the MAC layer to preserve bandwidth.To reduce starvation and to identify and penalize misbehaving nodes, thereby to increase QoS, IQ-MAC model is proposed. The model providesdifferentiated services and ensures packet delivery before its lifetime. It further takes care of misbehavior diagnosis, mitigation and a method to build trust.

2. Related Work

IEEE 802.11e EDCF [2] is the widely used MAC protocol in Mobile Ad Hoc Networks. This protocol supports differentiated services and favors real-time applications. It supports four Access Categories (AC) which are Voice, Video, Best effort and Background. It uses four parameters to achieve differentiation. They are Transmission Opportunity (TXOP), Arbitrary Inter Frame Space (AIFS), Minimum Contention Window (CWmin) and Maximum Contention Window (CWmax). These parameters vary for the four ACs.

Any node that uses IEEE 802.11e should abide by the protocol standard and use the value of the parameter settings in the protocol. Since a MANET is formed dynamically and operates without a central supervising entity, no level of trust can be expected from the nodes and they are susceptible to attack by their peers [3]. A node is considered malignant if it cheats its neighbors by pretending to be following the protocol standard but actually wastes resources or utilizes excess resources than assigned. Since all the nodes in a network share a common communication channel, using extra bandwidth or not cooperating in forwarding packets leads to degradation of network performance [3]. Hence enhancing and equipping MAC protocols to diagnose and mitigate misbehavior becomes indispensable.

Authors in [4] propose the multiple flows Distributed Weighted Fair Queuing (DWFQ) architecture to provide fair queuing in IEEE 802.11e. With multiple flows DWFQ, bandwidth is distributed in proportion to the flow's weight. By assigning higher weight to packet with higher priority, multiple flows DWFQ can also support QoS requirements of priority application. The major drawbacks of this architecture are i) Starvation of the low priority traffic due to its lower weight ii) Improper bandwidth utilization due to static weights. iii) Probability of node misbehavior by gaining higher weights. Thus designing a MAC to support composite prioritization based on lifetime and traffic type of the data packet with dynamic MAC parameters becomes essential.

Authors in [5] propose differentiation based on user profiles and scheduling based on Dynamic proportional static weights. Drawback is that, since MANETs operate without a central entity, differentiation based on user profile paves way for nodes to disguise themselves as high profile user and misuse channel access. In [6], a complex method to derive dynamic urgency index is proposed. Further, priority is given for nodes seeking urgency. Drawback is that, any selfish node may request for urgency.In [7] an elaborate statistical method to diagnose misbehavior is proposed. In [8], authors propose a nonparametric cumulative sum (CUSUM) model to diagnose misbehavior. They use an Access Point (AP) to record all the received/sent packets and detect the node that received/sent more packets. Such detected node is considered as a misbehaving node. MANETs have critical battery power, no central coordinator and are temporarily connected only for a short duration of time. Literature deals with prioritization, scheduling and misbehavior detection separately. No works have been done to produce a wholesome architecture. Hence IQ-MAC is proposed to integrate and develop a wholesome protocol that can produce better QoS for the various types of traffic and overcome the challenges in [4-7].

3. Integrated QoS Enhanced Differentiated MAC Model (IQ-MAC)

The main objective of the proposed IEEE 802.11e based Integrated QoS Enhanced Differentiated model (IQ-MAC) is to define a model incorporating a scheduling algorithm and a MAC protocol that supports QoS based bandwidth utilization, considering the challenges in a MANET. It encompasses the following changes to the existing MAC protocol.

1. Composite Prioritization
2. Hybrid Scheduling Mechanism
3. Dynamic Differentiated MAC Parameters
4. Diagnosing and Mitigating MAC Misbehavior

3.1 Composite Prioritization

Prioritization is achieved in two phases. The first level of prioritization is based on the traffic class. The data is categorized into four Access Categories (AC) in the order of their priority as Voice (AC1), Video (AC2), Best effort (AC3) and Background (AC4). This prioritization is Fixed Priority (FP).

The second level of prioritization is at the packet level. Packets are dynamically prioritized at every hop based on their life time and number of hops. This is achieved by calculating Dynamic Priority (DP).The dynamic priority is assigned based on the probability of a packet reaching its destination on time.The concept of Bernoulli probability [7] is applied to find the dynamic priority. Themass function is the density function of a discrete random variable *X* having 0 and 1 as its only possible values; it originates from the experiment consisting of a single Bernoulli trial. A sequence of n independent Bernoulli trials is considered with the probability of success equal to *'p'* on each trial. The probability of '*k'* successes in *'n'* trials can be calculated as in Eq.(1) [9].

$$\Pr(X = k) = \binom{n}{k} * p^k * q^{n-k} \qquad (1)$$

The time at which the packet has to reach the next hop is estimated with its life time and number of hops needed to reach the destination. This is called the threshold. If the packet reaches on estimated time, then it is considered as *success*. If the packet does not reach on time then it is considered as *failure*. This is can be modeled as a Bernoulli trial. At every hop estimated time is calculated and arrival time is noted. Then either success or failure is computed. Thus it becomes a sequence of Bernoulli trials where each trial is independent of the other. The probability*'p'* of a node reaching its destination, on or before its lifetime,is calculated as the ratio of the number of times a packet has kept its time (Hit) to the total number of hops using Eq.(2) and 'q' is calculated using Equation 3.3. Substituting *'p'* and *'q'* in Eq.(3), the urgency of a packet to reach its destinationwith remaining 'n' hops with 'k' hitsis calculated. This value is considered as the DP. Lower the DP, higher the priority.

$$p = \frac{\text{numberofHits}}{\text{numberofHops}} \qquad (2)$$

$$q = 1 - p \qquad (3)$$

When a packet is generated at source, an additional field is added to the header of every packet to store the DP.

3.2 Hybrid Scheduling Mechanism

The Access Category based priority FP and the dynamic priority DPare considered for scheduling. At every node four separate queues are maintained for the four traffic classesAC1, AC2, AC3, and AC4. The packets are enqueued according to their classes in their respective queues.

There may be situations when an packet requiring urgency gets backlogged at the tail end of the queue and may result in dropping due to delay. To avoid this, the Queues are ordered based on the increasing order of DP. The urgent packet is given priority and if there is a priority collision, it is resolved based on FP. Thus higher priority is given to the urgent packets of AC1 than the urgent packets of AC4. Thus priority reversal is also avoided.

3.3 Dynamic Differentiated MAC Parameters

IEEE 802.11e supports service differentiation at the MAC layer by using EDCA for contention and HCCA for polling. Service differentiation is achieved through variable IFS and contention window sizes. The AIFS is a prioritized static entity which is assigned for the four ACs. Lower the AIFS higher the priority. The CW is also a static entity with variable window sizes varying between CWmin and CWmax for the various ACs. Lower the CW size, higher the priority. Standard TXOP is new to IEEE 802.11e, which allows a burst of packets, till the $\text{TXOP}_{\text{limit}}$, which is also a static differentiated parameter. TXOP is set long enough for a burst of a MSDU limited to a static parameter that is predefined, such that the TXOP of AC1> AC2>AC3> AC4. Drawback is that, when collision occurs and there is need to resend packets, the window size cannot compensate for the packets lost leading to packets backlogging in the queue. This is overcome by dynamically differentiating them.

3.3.1Dynamic Differentiation using TXOP

It is proposed to compute $\text{TXOP}_{\text{limit}}$ based on access ratio(*AR*), which gives the number ofpackets to be dequeued based on queue length and average collision ratio of each AC discussed in Algorithm 1.This compensates for the delay caused by resending packets due to collision. If there are no packets waiting in the higher priority AC queues, then the $TXOP_{limit}$valueof the higher priority AC is assigned to the lower priority ones, to increase the throughput of the low priority ACs. Algorithm 1,is a modified version of the algorithm discussed in [5].

Algorithm 1. Calculation of $TXOP_{limit}$

```
Step 1:   $x_j = \frac{ql_i}{\sum_{j=0}^{3} ql_j}$ , i=0 to 3
Step 2:   $P_{col}^{j}[i] = (1 - \alpha) * P_{curr}^{j}[i] + \alpha * P_{col}^{j-1}[i]$ , i=0 to 3
Step 3:   $cx_i = (x_i * (1 + P_{col}^{j}[i])) * 100$ , i=0 to 3
Step 4:   If ($cx_0$<Av) then $cx_0$ = Av
Step 5:   If (($cx_1$>$cx_0$) or ($cx_1$<$cx_2$) or ($cx_1$<$cx_3$)) then
          $cx_1$= Av
Step 6:   If (($cx_2$>$x_0$) or ($cx_2$>$x_1$) or ($cx_2$<$cx_3$)) then $cx_2$= Av
Step 7:   If (($cx_3$>$cx_0$) or ($cx_3$>$cx_1$) or ($cx_3$>$cx_2$)) then
          $cx_3$= Av
Step 8:   $AR_i$=$cx_i$, i=0 to 3
Step 9:   Tr =$T_{data}$+2 * SIFS +$T_{ACK}$
Step 10:  $TXOP_{limit}$ [i] = ($AR_i$ * Tr) - SIFS,  i=0 to 3
Step 11:  If $x_{i-1}$=0 then $TXOP_{limit}$ [i]=$TXOP_{limit}$[i-1], i=1 to 3
```

Where *Tr* is the total time required to transmit one data packet, $T_{data}$is the time required to transmit one data packet, SIFS is the short inter frame space and T_{ACK} is the time required to transmit ACK, which are PHY dependent. Percentage of queue length (x_i) is calculated based on individual queue length (ql_i). $P_{col}^{j}[i]$is the collision ratio for each AC calculated for the jth update period. Access ratio (AR_i) for each class is calculated as cx_i based on their average queue length$x_i$and Collision rate$P_{col}^{j}[i]$.

3.3.2 Dynamic Differentiation using CW

Priority in granting a TXOP to a queue is achieved through backoff timers. There are two waiting stages during contention, the AIFS and the backoff stage. IEEE 802.11e EDCF uses prioritized differentiated contention window sizes for the four classes of traffic identified as CW[i]. Drawback is that the values are static. The shorter window sizes, may lead to increased packet drops because at every collision the contention window doubles. Hence dynamic window sizes based on the congestion and collision are proposed. CW[i] is a random integer value uniformly taking values in the range (0, CW[i]) inclusive. The initial value of CW[i] is set to CWmin[i]. At every collision, the CW[i] doubles and the maximum value it can take is CWmax[i].

To overcome the limitation of small window size during collision that causes packet drops, differentiated contention window sizes are proposed based on the collisions calculated. The average collision rate is found by summing the individual collision rates divided by number of classes. This is done because collision of any packet in the network will lead to further collisions with the same CW[i]. To set the CW[i] based on collision, a collision threshold is assigned based on the collision tolerance.It is carefully chosen in such a way that the CW[i] size increases only if average collision is greater than collision threshold. The size of the CW[i] is increased to avoid further collision and packet drop. If the collision rate is within the threshold, then the CW value is not altered. Further, if there is no packet waiting in the higher priority queues, then, the lower priority ACs are assigned small CW sizes to increase the throughput of the low priority ACs. Algorithm 2, explains the procedure.This algorithm is adapted from [6] and tailored to suit this model.

Algorithm 2. Calculation of CW

```
Step 1:   If ($x_{i-1}$=0) then
           { $CWmin_{new}[i] = CWmin_{old}[i-1]$,
          $CWmax_{new}[i] = CWmax_{old}[i-1]$
          } i=1 to 3

Step 2:   $A_{col}=\sum_{i=0}^{3} P_{col}^{j}[i]$

Step 3:   if ($A_{col} \geq T_{col}$) then
          { {
          $CWmax_{new}[i] = 2 * (CWmax_{old}[i] -$
          $CWmin_{old}[i])$,
          $CWmin_{new}[i+1] = CWmax_{new}[i]$
           }  i=0 to 2
          $CWmin_{new}[0] = CWmin_{old}[0]$
            $CWmax_{new}[3] = CWmax_{old}[3]$
               }
           Else
          {
          $CWmin_{new}[i] = CWmin_{old}[i]$,
          $CWmax_{new}[i] = CWmax_{old}[i]$
          }    i=0 to 3
```

3.4 Diagnosing and Mitigating MAC Misbehavior

Diagnosing MAC misbehavior in an unmonitored decentralized network such as MANET though difficult, is necessary. IEEE 802.11e is more susceptible to attack because of its varying parameters used to achieve differentiation. The protocol defines a longer $TXOP_{limit}$for high priority AC traffic and a shorter one for low priority ACs. A node can behave malignant using $TXOP_{limit}$ to favor low priority AC4 traffic by assigning a longer $TXOP_{limit}$. To resolve priority at contention, AC1 traffic is allotted shorter contention window sizes than the AC4 traffic. Similarly, the protocol defines shorter CW for AC4 traffic and Longer CW for AC1 traffic. A selfish node for its own benefit can assign longer Backoff to AC1 forwarded packet, thus can delay the channel acquisition of AC1 traffic class. This leads to QoS degradation. Misbehaviors using TXOP and CW are diagnosed and mitigated to improveQoS.

3.4.1 Calculation of Expected Values of TXOP and CW

To identify deviation, the expected values of TXOP and CW are collected. Similarly, the observed values are also collected. In the earlier D4M model[7], a certain procedure is proposed to collect values of the QoS parameters; CWmin from the beacon frames and priority values from the priority field and TXOP from the duration field of RTS frames. In the proposed model,$TXOP_{limit}$ [i] is calculated as in Algorithm 1 and the expected TXOP (ETXOP[i]) is calculated as in Eq.(4).

$$ETXOP[i]=TXOP_{limit}[i], i=0 \text{ to } 3 \quad (4)$$

The duration field of RTS frame is updated with *ETXOP[i]* according to the priority value. Generally for nodes under EDCA, the duration value is set to the remaining duration of the TXOP. The duration value is reassigned with the TXOP calculated using Algorithm 1. All the nodes in the neighborhood can listen to the RTS and they take the expected value of TXOP from the duration field of the RTS. Expected CW value can be obtained from the QoS parameter set specified in the “EDCA parameter set element” of the beacon frames. Since CW is recalculated based on collision, expected CW(ECW) is calculated as in Algorithm 2, and values of $CWmin_{new}$[i] are assigned to ECW[i] where i=0 to 3.

3.4.2 Calculation of Observed Values of TXOP and CW

The observed duration of the TXOP can be calculated as the duration of time when the transmission started by initiating a RTS (RTS_{start}) and the time of arrival of the last ACK frame ($Last\_ACK_{arr}$). If there are more data frames, the waiting time after ACK is SIFS. If it is the last ACK frame, then it waits for AIFS+Backoff for the next contention. Thus, it is assumed that the current TXOP has ended. The following Algorithm 4, depicts the calculation of observed TXOP and CW.

Algorithm 4. Calculation of Observed TXOP & CW

```
Step 1:  $TXOP_{start} = RTS_{start}$
Step 2:  If waiting_time>SIFS then $TXOP_{end} = Last\_ACK_{arr}$
Step 3:  $TXOP_{dur} = TXOP_{end} - TXOP_{start}$
Step 4:  $Backoff = RTS_{start} - Prev\_ACK_{arr} - AIFS$
```

3.4.3 Misbehavior Diagnosis

At every node two lists are maintained; one is the Behavior list (B-list) and another is the Enhanced Neighbor List (eN-List) [7]. B-list stores data collected about the neighbors such as, the neighboring node’s identity, Access category, Expected and Observed TXOP and Expected and Observed CWmin. If a node misbehaves in the current diagnostic period, then status is set to 1, default is 0. Misbehavior Status (MS) is calculated as in Eq.(5).

If ((ETXOP=OTXOP) and (ECW=OCW)) then M_{curr}=0
Else M_{curr}=1 (5)

TABLE1. Behavior List (B-List)

S.No	Node ID	Access Category (AC)	Expected TXOP (ETXOP)ms	Observed TXOP (OTXOP)ms	Expected CW (ECW)ms	Observed CW (OCW)ms	Current Misbehavior Status (M_{curr})
1	1	1	.003264	.003264	7	15	1
2	2	2	.006016	.003264	15	15	1
3	3	4	0	0	1023	1023	0

The neighbor node id, current misbehavior status and Misbehavior Index are stored in the eN-list. At the beginning of every diagnostic period, status is initialized to default first. At the end of every diagnostic period, it is updated based on Eq.(5). Further, based on the status, the misbehaving node is penalized by denial of service to that node for one diagnostic period.The probability of misbehavior $P^{j}_{mis}$of every node is calculated as the number times the node misbehaved to the total number of observations of that node during the diagnostic period ‘*j*’.

TABLE 2. Enhanced Neighbor List (eN-list)

Node id	$\mathbf{P^{j-1}_{mis}}$	$\mathbf{P^{j}_{mis}}$	**MI**
1	0.2	0.3	0.25
2	0.1	0	0.5
3	0	0	0

The Misbehavior Index (MI) is calculated to estimate the trust of a node as in Eq.(6). It is calculated based on the current and previous probability [9] of misbehavior of a node.

$$MI = (1-\alpha)*P^{j-1}_{mis} + \alpha * P^{j}_{mis} \quad (6)$$

$\propto$is considered as the smoothing factor. Lower the misbehavior index, higher the trust. The misbehavior index ranges from 0 to 1.

4. Simulation and Results

The model IQ-MAC is validated using NS-2 simulation platform. For the simulation, two different scenarios are considered with varying parameters as shown in Table 3. IQ-MAC model is compared with DWFQ[4] architecture.

TABLE 3. Simulation Parameters

Parameter	**Scenario 1**	**Scenario 2**
Collision rate	< 0.5	> 0.5
Percentage of misbehavior	< 50%	> 50%
Percentage of AC4 nodes	< 50%	> 50%
Number of Nodes in the MANET	100	
Data Rate	10 Mbps	
Network Area	500 x 500 m^2	
Mobility Model	Random Way point	
Traffic Model	CBR	

From the simulation study under these scenarios, performance metrics, namely, packet delivery ratio and delay of the DWFQ[4]is compared with the proposed IQ-MAC model.

4.1 Packet Delivery Ratio

Packet loss may be due to selfish nodes dropping forwarded packets purposely to conserve their battery power in a Multihop environment, or packets may be dropped because of waiting in the queue and not serviced before the packet's time to live or dropped due to collision.

Scenario 1

Figure 1, depicts the result of Scenario 1. It shows that the packet delivery ratio of IQ-MAC is marginally better than DWFQ because of less collision and misbehavior. The marginal improvement of IQ-MAC is because of the Dynamic Scheduling which prioritized the packets based on their lifetime.

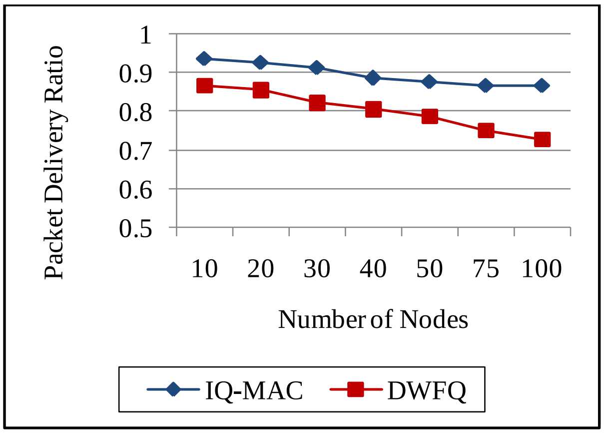

Figure 1.Comparative analysis of Packet Delivery Ratio – Scenario 1.

Packet drops in DWFQ increases with increase in number of nodes. Packet drops in IQ-MAC slightly drops with the increase in number of nodes, because of collision then becomes stable even when the number of nodes increases. This is because of the varying TXOP and CW proposed to avoid packet drops.

Scenario 2

Figure 2, depicts the result of Scenario 2. It shows that the packet delivery ratio of the proposed model is higher even if the collision and misbehavior ratio are more. This is because, the dynamic MAC parameters reduces packet drops during collision. The misbehavior mitigation also reduces intentional packet drops, in so doing improves overall packet delivery ratio.

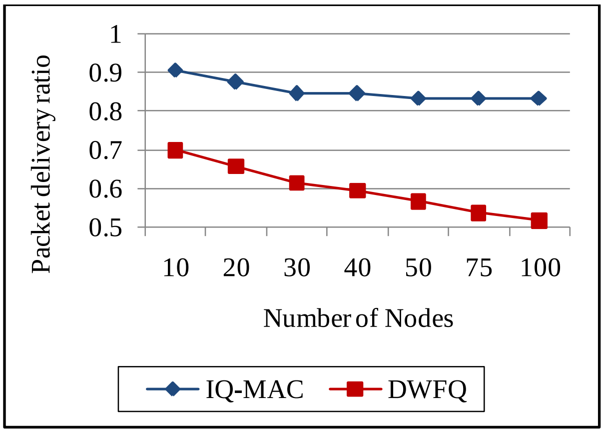

Figure 2.Comparative analysis of Packet delivery ratio – Scenario 2.

4.2 Throughput

Throughput is calculated as the total number of bits received at the destination divided by the total transmission time. The average throughput of both the models are compared under two scenarios one with low collision and misbehavior and another with high collision and misbehavior.

Scenario 1

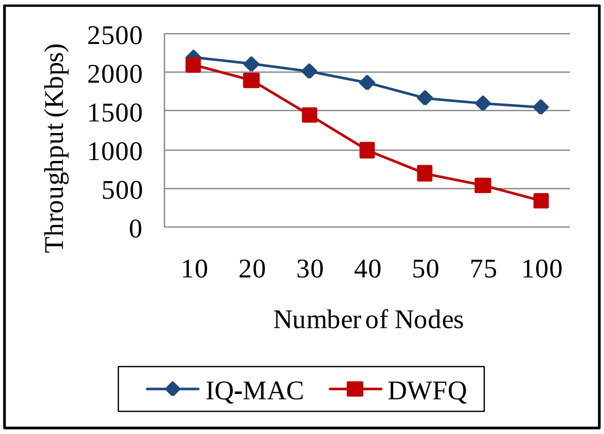

Figure 3.Comparative analysis of Throughput – Scenario 1.

Figure 3, shows the average throughput of Scenario 1. The throughput of IQ-MAC is better than DWFQ for the varying number of nodes. This is because of the dynamic MAC parameters. The minor drop off in throughput in IQ-MAC is becauseof control packets overhead which is mandatory in MANETs. It increases with the increase in number of nodes. But the increased TXOP reduces this to an extent. Throughput falls steadily in DWFQ, as the number of node increases. This is because, the collision increases with the increase in number of nodes leading to retransmissions.

Scenario 2

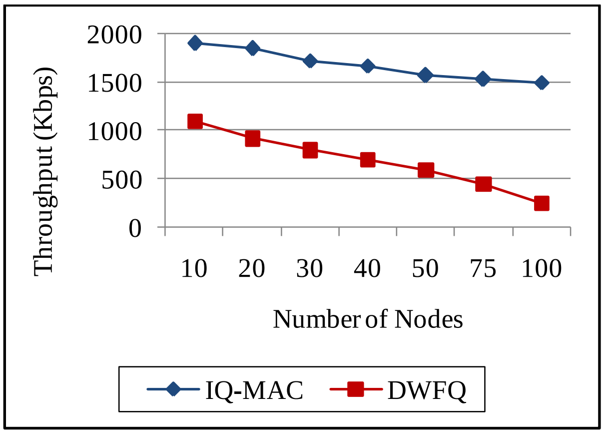

Figure 4.Comparative analysis of Throughput –Scenario 2.

Figure 4, shows the average throughput of Scenario 2. The throughput of IQ-MAC is much higher than DWFQ. Throughput ofDWFQ drops with the increase in the number of nodes.This is because of the increased collision and misbehavior which causes improper utilization of bandwidth. The throughput in IQ-MAC is retained because of the varying contention window and transmission opportunity based on collision. The mitigation of misbehaving nodes has also complemented to the better performance of the proposed model.

4.3 End to End Delay

End to End delay includes, all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, and propagation and transfer times. Average delay is calculated as, the average of the difference between the time when the packet is received by the destination, and the time it has been sent from the source.

Scenario 1

Figure 5, depicts results of Scenario 1, where the delay occurred by IQ-MAC is lower compared to DWFQ. DWFQ faces the maximum delay when the number of nodes is more in the network. In IQ-MAC average delay is reduced because of the dynamic prioritization, dynamic adjustments of contention window and transmission opportunity. The increase in delay beyond 30 nodes is because of the control overhead inherent to MANETs. But in the proposed model, control packets are reduced by increasing the TXOP, which is calculated based on the Queue length. Thus delay is maintained at a minimum even when the number of node increases.

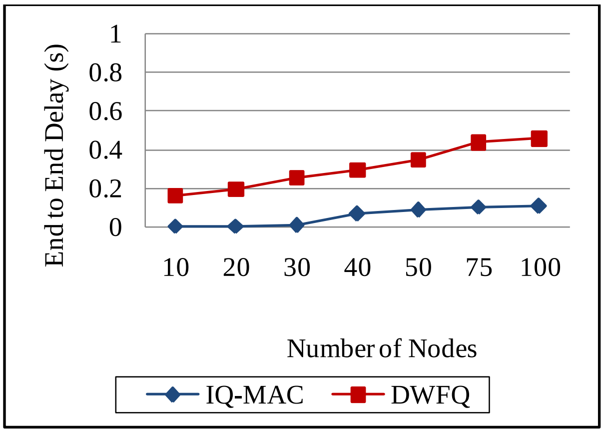

Figure 5.Comparative analysis of End to End Delay – Scenario 1.

Scenario 2

Figure 6, depicts results of Scenario 2, where the delay occurred by IQ-MAC is very less compared to IEEE 802.11e. IEEE 802.11e faces the maximum delay even when the number of nodes is less. This is because of the increased collision and misbehavior. In IQ-MAC average delay is reduced because of the dynamic prioritization and dynamic adjustments of contention window and transmission opportunity. Further, the undue delay that is caused by malicious nodes by increasing contention window sizes is also diagnosed and mitigated. A marginal increase in the delay with the number of nodes is inevitable because of the bandwidth constraint inherent with MANETs.

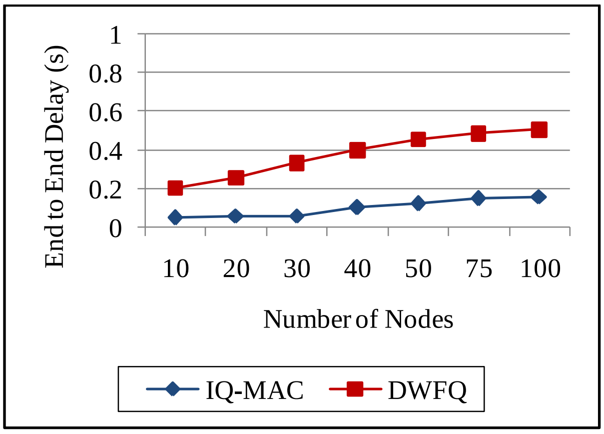

Figure 6.Comparative analysis of End to End Delay – Scenario 2.

5. Conclusion

The main objective of this proposed work is to design an IntegratedQoS enhanced differentiated model to differentiate traffic dynamically thus reducing starvation of low priority AC packets even during collision, alleviate misbehavior and improve throughput and reduce delay and packet drops. The proposed work encompasses Composite prioritization, Hybrid scheduling mechanism, Dynamic differentiated MAC Parameters and Diagnosing and Mitigating MAC Misbehavior. Results show that on an average, the proposed model gives 15% more average throughput, 21% less packet drops and 17% less delay.

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