Adaptive Mac Layer Techniques to Support Multiple Priorities in MANETs

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ABSTRACT
Mobile Ad Hoc Networks (MANETs) are self-configured and are formed by autonomous mobile nodes to exchange various types of data such as video, voice, best effort and background or access different application. Further, MANETs are used by various profiles of users. Hence providing differentiated services becomes mandatory for MANETs. Literature provides various research results on different number of priorities to support differentiated services. In this paper we propose a proportional bandwidth sharing model which supports multiple priorities, takes care of scheduling and MAC layer prioritization (N-MAC). Multiple Priority model is simulated in ns2. Results show that 16% of starvation is reduced in our proposed scheme than the existing scheme. Proportional bandwidth sharing is verified analytically using Jain's Fairness Index and the waiting times are evaluated using Queuing theory. It is also observed that the overhead of differentiated services increases by 7.5% and overall throughput decreases by 7% with the increase in number of priorities.

Keywords
Jain's Fairness Index, MAC protocol, MANET, Multiple priorities, Proportional-share.

1. INTRODUCTION
MANET is an emerging technology which has received the attention of many researchers today. Conventional cellular wireless mobile networks rely on extensive infrastructure to support mobility whereas MANETs do not need expensive base stations or wired infrastructure [1]. Due to the limitation of radio transmission range, mobile computers may not be able to communicate with each other directly. Therefore, every mobile computer in MANETs relies on other mobile computers for multi-hop message transmissions and in the mean time provides message-forwarding services for others [2].

Neither wired infrastructure nor expensive base stations are required for formation of MANETs. They provide users with more flexible and cheaper ways to access and exchange information. For example, an ad hoc wireless network could be rapidly deployed to broadcast information for special events such as conference and seminars on a campus. A set of laptop computers with wireless transmission cards is enough to construct such a network [3].

However, the promising application market of MANETs may be compromised due to the difficulty of providing services in MANETs. First, due to mobility, wireless links among the mobile hosts can change very quickly, resulting in dynamic changes in network topology, message forwarding routes, and available bandwidth [3]. Second, MANETs are power-constrained because mobile hosts usually rely on battery power. Third, the difference of transmission power in different mobile hosts may result in asymmetric links among the network nodes. Fourth, radio transmission is not reliable, considering the effects of multiple access, fading, noise, and interference etc. Finally, a MANET may be large, including thousands of mobile hosts. This makes network control difficult.

Generally, QoS for a network is measured in terms of guaranteed amount of data which a network transfers from one place to another during a certain time. In order to achieve the goal of providing high quality to real-time traffic, it will be necessary to implement new techniques that can guarantee QoS while accounting for the limited bandwidth and the delay and error characteristics of the MANETs. This requires a differentiated services architecture that can offer multiple service levels, each with a different QoS guarantee [4]. The growing civilian and military interest in these networks has made the Quality of Service increasingly important.

Literature suggests prioritization based on user profile or the role of the user in an organization. This is because generally MANETs find its application in conference, meeting and military operation where hierarchical structure of organization is followed [1]. These applications require expedited forwarding of high priority packets such as a command from a higher authority or an instruction from a conference chair. Any message that arrives later than its life time is considered stale and needless. Further the profile of the user sending the message is also important because many applications require hierarchical prioritization [5].

This paper proposes a user profile based multi priority proportional share scheduling and MAC protocol model (N-MAC) for MANETs. The model incorporates, dynamic proportional share queues, adaptive rationed dequeuing algorithm, variable inter frame space, proportionate prioritized backoff timers and adaptive RTS/CTS control packets to support priority.

The paper is organized as follows. Section 2 presents review of literature; Section 3 explains the proposed model, followed by simulation results in Section 4; Section 5 elaborates on the analytical verification of the model and Section 6 gives conclusion and future directions.

2. REVIEW OF LITERATURE
Desired QoS can be achieved by deploying a suitable scheduling algorithm. The need to minimize delay, increase throughput and achieve fairness are some of the primary motives behind selection of a particular scheduling algorithm.

Different scheduling algorithms use different metrics for setting priorities [6]. Some follow static priority scheduling and others dynamic priority scheduling. Algorithms that follow static priority scheduling are Priority Queuing (PQ), Weighted Fair Queuing (WFQ) and Round Robin (RR), Examples of dynamic priority scheduling algorithms are shortest-remaining processing-time (SRPT), earliest deadline first (EDF), minimum laxity first (MLF) and zero laxity first (ZLF) [7].

WFQ offers fair queuing that divides bandwidth across queues of traffic based on weights. WFQ ensures that all traffic is treated fairly, given its weight. Given the weight of the queues, WFQ ensures satisfactory response time to critical applications, such as interactive, transaction-based applications, that are intolerant of performance degradation [8].

Busy tone priority scheduling (BTPS) [6] in multi-hop networks uses two narrow-band busy tone signals BT1 and BT2 to ensure medium access for high priority source stations. Low priority source stations determine the presence of high priority packets by sensing the carrier on the busy tone channels. Drawback is that the BTPS scheme does not account for maximum bandwidth utilization among nodes in the network. Secondly, though it eliminates hidden terminal and exposed terminal problems and also deals with priority reversal issue, it does not efficiently solve the starvation issue that may arise among low priority nodes [9].

There are few scheduling algorithms that set priority in data traffic. IEEE 802.11e follows a data type based priority queue model where, only when the high priority queue is empty, the next higher queue is dequeued [10]. This creates starvation among the low priority queues[5]. In [11] a scheduling algorithm similar to IEEE 802.11e is proposed, where the buffer space allotted to the low priority is restricted, which leads to starvation of low priority traffic and unfairness. Though in recent times number of protocols has been proposed to support QoS, fairness has not been considered [12].

This paper proposes a user profile based proportional share scheduling and MAC protocol model for MANETs. The model incorporates, dynamic proportional share queues, adaptive rationed dequeuing algorithm, variable inter frame space, proportionate prioritized backoff timers and adaptive RTS/CTS packets to support priority. The model is verified with Jain's Fairness Index for fairness and waiting times are also evaluated.

3. PROPOSED MODEL - N-MAC

To meet the user's service requirements, we propose to classify the users into 'n' number of classes, based on the requirement of the application such as $U_0, U_1,...U_{n-1}$. U_0 is the highest profiled user with maximum Quality of Service followed by U_1, then U_2 up to U_{n-1}, which is the lowest profile user with Best effort service. Every node of the user is assigned a static priority according to the classification based on user profile. We add an additional field to the header of every packet that is generated at the source to store the priority of the node [13]. The codes *0, 1,.., n-1,* representing the priority of users $U_0, U_1, ...U_{n-1}$ are stored in the priority field.

3.1. Adaptive Rationed Dequeuing Algorithm

Channel contention within a node can be resolved using robust scheduling technique that decides who acquires the channel next. Our objective is to allocate proportional share of bandwidth among the contending nodes. To achieve this, at every node we maintain separate queues $Q_0, Q_1, ...Q_{n-1}$ for the various classes of users. The packets are enqueued in their respective queues according to their priority mentioned in the Priority Field. The packets are dequeued from the queues proportionally based on their weights and the percentage of packets waiting in their respective queues. Here the weights are constant and the percentage of queue length is dynamic. The Queue length for the queues $Q_0, Q_1, ...Q_{n-1}$ are $QL_0, QL_1, ...QL_{n-1}$ respectively and the percentage of queue length $x_0, x_1 .... x_{n-1}$ is calculated as in Equation (1).

$$x_i = \frac{QL_i}{\sum_{j=0}^{n-1} QL_j}\ , i = 0\ to\ n - 1 \qquad (1)$$

The number of packets to be dequeued from the queues is calculated based on their access ratios given in Equation (2).

$$w_0 x_0 : w_1 x_1 : ..... : w_{n-1} x_{n-1} \qquad (2)$$

Where, w_0, $w_{1....}$, w_{n-1}, w_{n-1} are the user defined weights assigned for every class of user $U_0, U_1, ...U_{n-1}$ respectively, such that $w_{max} > w_0 > w_1 > ... w_{n-1} > 0$. Where, w_{max} is the maximum weight that can be assigned [14]. Every user is assigned a proportional weight to meet their service requirements. This proportional weight favors fairness among the competing nodes in a differentiated services environment. $x_0, x_1, ..., x_{n-1}$ are the percentage of packets waiting in their respective queues.

When the traffic is dominated by low priority packets, the access ratio of High Priority packets may fall below the low priority ones. Hence to ensure the priority of the High Priority nodes, we propose to maintain the percentage of Higher Priority packets at an average such that, *Av=100/n*, when the percentage of Higher Priority packets falls below the average percentage. Thus at any point of time, for any random data flow, the priority of Higher Priority packets is ensured. The following Algorithm 1 achieves this.

Algorithm I – Adaptive Rationed Dequeuing Algorithm

```
Step 1:    for i = 0 to n-1
           {
           If x_i > any one of {x_o ..... x_{i-1}} or
                x_i < any one of {x_{i+1} ..... x_{n-1}} then
                x_i = Av
           }
Step 2:    Access ratio= w_0 x_0 : w_1 x_1 : ..... : w_{n-1} x_{n-1}
```

Calculating access ratio based on percentage of Queue length, introduces a level of dynamicity to the scheduling model.

3.2. Prioritization at the MAC Layer

Once the packet is dequeued and ready for transmission, the next step is to acquire channel access. IEEE 802.11 DCF[15] for wireless LANs is the widely used MAC protocol. There are two waiting stages during contention, the Inter Frame Space(IFS) and the Back-off stage. The priority at the channel contention is achieved at the IFS by Equation (3) adapted from the IEEE 80211e.

$$IFS_i = SIFS + AIFSN_i * slot\ time;\ i=0\ to\ n-1 \qquad (3)$$

Where, SIFS is the Short Inter frame space, AIFSN is the Arbitrary Inter Frame Space Number. We propose to differentiate the AIFSN proportionally based on their weights. It is calculated using formula (4). The higher the weight assigned to a node, the lower will be the AIFSN. The minimum value of AIFSN is maintained at 2[10]. Hence, the IFS will be shorter and thus the priority will be higher.

$$AIFSN_i = integer\left(\frac{\sum_{j=0}^{n-1} w_j}{w_i}\right) \; ; \; i=0 \text{ to } n-1 \quad (4)$$

The next stage is the Back-off stage. IEEE 802.11 DCF is a random access mechanism, where a node selects a backoff value based on the formula (5).

$$Backoff = integer(2^{2+i} * random() * slot\text{-}time) \quad (5)$$

Where random() is the random number evenly distributed between 0 and CW, where CW is the Contention Window which varies between minimum(CW_{min}) and maximum contention window (CW_{max}) and *i* is the number of attempts made for transmission.

To further support prioritization and to reduce collision, differentiated backoff timers are proposed, proportionate to their access ratios, using formula (5) as in the following Equation (6) adapted from [16].

$$Backoff = integer(PF_k^{\,2+i} * random() * slot\text{-}time) \quad (6)$$

Where, PF_k is the Priority Factor of the k^{th} class of user. [16] proposes user defined priority factor. Since we already have user defined weights, we calculate PF proportionate to the weights[17]. The higher the weight assigned, greater will be the share of bandwidth allocated. The lower the PF, lower will be the waiting time. Hence, PF should be calculated such that $0<PF_0<PF_1<\ldots\ldots<PF_{n-1} < 1$. The following formula (7) calculates the PF for the various priorities proportional to their weights.

$$PF_k = 1 - \frac{w_k}{\sum_{j=0}^{n-1} w_j} \; ; \; k=0 \text{ to } n-1 \quad (7)$$

3.3. Adaptive RTS/CTS

Once, the backoff reaches 0, RTS-CTS-DATA-ACK transmissions takes place. To achieve prioritization, [18] proposes AT-ST scheme to support two priorities, where, the high priority nodes send AT packet to inform the neighboring nodes about the high priority packet transmission. The node that receives the AT packet, checks the backoff value and compares with its own. If the receiver is of high priority and with a certain priority threshold, it will immediately send a ST packet to suspend transmission to the source node. This above mentioned scheme does not support more than two priorities, since priority is assigned only through backoff and variable backoff are designed only for two. Hence we modify this scheme to support three priorities. Further our scheme also avoids the extra control packet overhead caused by the AT and ST packets. We propose to integrate the packet priority along with the Request To Send (RTS) packet. We add an additional *priority field* to the RTS packet and store the packet priority analogous to [19]. The *priority field values* 0,1, … ,n-1 are used to represent the various classes of users, $U_0, U_1, \ldots U_{n-1}$ respectively. Similarly, an additional *flag field* is added to every Clear To Send (CTS) packet [19]. *The flag values* 0 and 1 are used to represent 'clear to send' and 'suspend transmission' respectively. When the backoff of a node reaches zero, RTS packet is transmitted. The node receiving the RTS packet follows three steps: 1) it forwards the RTS packet to its neighbors. 2) Checks for the priority of the packet of the sending node in the priority field. 3) If the priority of the sending node is greater than or equal to its own packet priority, it sends a CTS with flag value 0, thus informing to proceed with data transmission. If otherwise, it sends a CTS with flag value 1, thus informing that a priority reversal has occurred, hence defer transmission. Thus the node receiving CTS follows two steps: 1) if a node receives CTS-0, it continues transmission with DATA and if a node receives CTS-1 defers transmission. 2) If a neighboring node, overhears CTS-0 defers transmission and if it overhears CTS-1 resumes its state. Thus the priority reversal problem is avoided.

4. SIMULATION AND RESULTS

Similar to wired networks, QoS in MANET can be measured in terms of throughput, delay, packetloss, jitter, packet delivery ratio etc. We implemented our proposed model N-MAC and IEEE 802.11 DCF in ns2. The test network included a minimum of 10 and a maximum of 50 nodes. The experiment was conducted with two, three and four priorities. The priorities for the nodes were assigned randomly.

The transmission range of each node is defined as 250m and the bandwidth of the channel is 2 Mbps. The DSR protocol is used for routing. For the purpose of simulation, in Scenario I, we have tested with two classes of users, assigning the following weights w_0= 2, w_1=1. In Scenario II, we have tested with three classes of users, assigning the following weights w_0= 3, w_1=2, w_2=1. In Scenario III, we have tested with four classes of users, assigning the following weights w_0= 4, w_1=3, w_2=2, w_3=1. Weights are chosen such that they maintain relative fairness according to Jain's fairness index discussed in Section VI. MAC parameters CWmin is chosen as 32, CWmax as 1023, slot- time as 20 µs and SIFS as 10 µs were taken. We have evaluated our model based on throughput. Five simulations were run with varying access ratios. The simulation results were recorded and analyzed. Further comparative throughput and control overhead analysis for two, three and four priorities were also done.

4.1 Throughput

Throughput is calculated as the total number of bits received at the destination divided by the total transmission time. We observed throughput for the following three scenarios.

4.1.1 Scenario I

In Scenario I, simulation was done with two priorities HP-High priority, LP - Low Priority with access ratios calculated with Algorithm 1 and tabulated in Table 1[20]. We ran the simulation ten times and aggregated the results.

Table.1. Access Ratio – Scenario I

% of HP	% of LP	Access ratio
90	10	18:1
70	30	14:3
50	50	10:5
30	70	10:5
10	90	10:5

Figure 1, shows that, the throughput of HP increases with the increase in percentage of HP packets. The throughput of HP packets does not drastically decrease lower than LP even when the percentage of HP packets is less than the LP packets. This is because of our Algorithm 1, where we maintain the access ratio of the HP packets even when it drops below 50%. Similarly the throughput of LP does not drop very low, even if their percentages are less; because of their fair share allotted through their weights. This avoids extensive starvation of LP nodes.

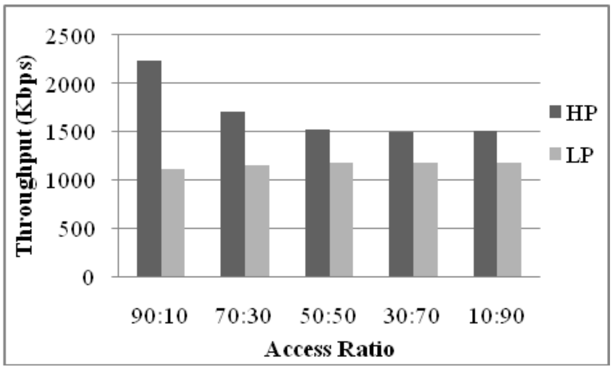

Figure.1. Throughput for HP and LP users

4.1.2 Scenario II

In Scenario II, we simulated three priorities such as HP- High priority, MP - Medium Priority and LP – Low Priority, with access ratios calculated with Algorithm 1 and tabulated in Table 2[14]. The simulation was run ten times and the results were averaged.

Table.2. Access Ratio – Scenario II

% of HP	% of MP	% of LP	Access ratio
80	10	10	24:2:1
50	30	20	15:6:2
33	33	33	10:7:3
30	50	20	10:7:2
10	10	80	10:7:3

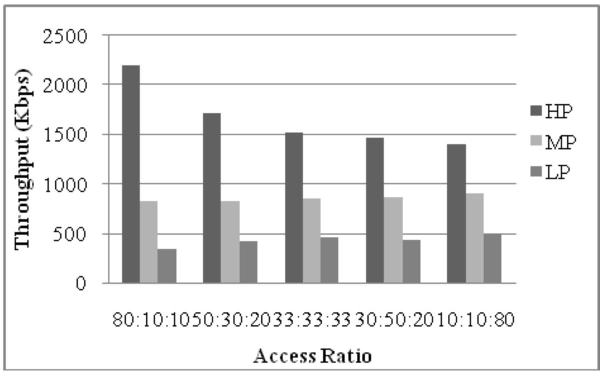

Figure.2. Throughput for HP, MP and LP users

Figure 2, shows that, the throughput increases with the increase in percentage of packets in the queue. The throughput of HP packets does not drastically decrease lower than MP and LP, when the percentage of HP packets is less than the MP and HP packets. This is because of our Algorithm 1, where we maintain the access ratio of the HP packets even when it drops below 33%. Similarly the throughput of MP and LP does not drop very low, even if their percentages are less because of their fair share allotted through their weights. This avoids extensive starvation of MP and LP nodes.

4.1.3 Scenario III

In Scenario III, we simulated Four priorities such as VHP - Very High Priority, HP – High Priority, MP - Medium Priority and LP – Low Priority, with access ratios calculated with Algorithm 1 and tabulated in Table 3. We ran the simulation ten times and the results were averaged.

Table.3. Access Ratio – Scenario III

% of VHP	% of HP	% of MP	% of LP	Access ratio
70	10	10	10	28:3:2:1
50	20	10	10	20:6:2:1
25	25	25	25	10:8:5:3
20	20	30	30	10:8:5:3
10	10	10	70	10:8:5:3

Figure 3, shows that, the throughput increases with the increase and decreases with the decrease in the percentage of packets in the queue. The throughput of HP packets does not drastically decrease lower than LP, when the percentage of HP packets is less than the LP packets. This is because of our Algorithm 1, where we maintain the access ratio of the VHP packets even when it drops below 25%. Similarly the throughput of LP does not drop very low, even if their percentages are less because of their fair share allotted through their weights.

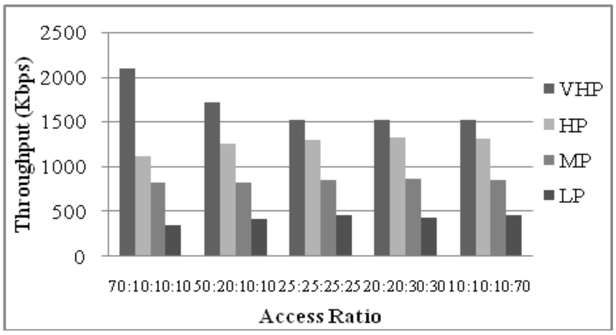

Figure.3. Throughput for VHP, HP, MP and LP users

4.2 Comparison of Throughput

We compare the throughput of two, three and four priorities and IEEE 802.11 DCF, when the number of nodes belonging to various priorities are equal. We cummulate the average throughput of all users and compare the throughput of IEEE 802.11 DCF with no priority(DCF), Two priority(2P), Three Priority(3P) and Four Priority(4P). Figure 4, consolidates the results of throughput. Results show that the throughput of IEEE 802.11 DCF is low compared to other priorities. When the number of node increases, the throughput is very low, which leads to starvation possibly because of the large CW size during collision and congestion.

The throughput of other three prorities are almost the same. The throughput of 4P is 7% lower. Further it can be observed that the starvation of our model is reduced by 16% compared to IEEE 802.11 DCF. This is because of the small AIFSN and CW for high priority nodes, the entire throughput increases. The throughput may start to deteriorate with increase in priority because of the increased AIFSN and CW Size. More the number of priorities, larger will be the AIFSN and CW, thus increase in delay. If they are made shorter for more priorities, it may result in collisions. Hence results show that limited number of priorities would yield better results.

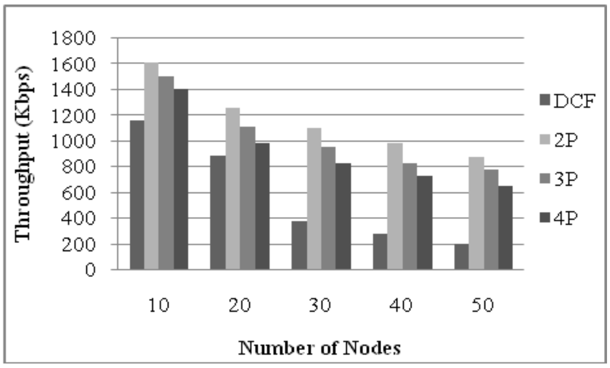

Figure.4. Comparative throughput

4.3 Comparison of Control Overhead

The control packet overhead is calculated as the total number bytes used as control packets to the total number of bytes used for data packets. We compare the control overhead of IEEE 802.11 with no priority(DCF), Two priority(2P), Three Priority(3P) and Four Priority(4P). Figure 5, consolidates the results of Control Overhead. Results show that the control overhead increases with the increase in number of priorities and number of nodes. Control overhead increases by 7.5% for 4P compared to DCF.

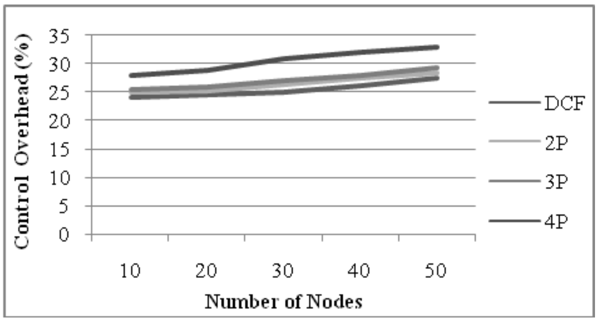

Figure.5. Comparative Control Overhead

5. ANALYTICAL MODEL

5.1 Evaluation of Fairness

Fairness in sharing the bandwidth is generally appreciable where we do not favor any kind of traffic. But in reality, it is generally not applicable because different types of traffic would demand different QoS. Traffic such as Voice and Video require more bandwidth than the data. Fairness is a broad concept. Fairness can be categorized as absolute and relative fairness. Absolute fairness refers to a scenario where all the traffic types are allotted exactly the same bandwidth. Relative fairness takes into account how much of the individual requirements are being fulfilled. Relative fairness is a better way of measuring fairness[5]. A well-known index of fairness was proposed in [21] known as Jain's Fairness Index. It is a very general definition and states that, If the number of contending users is *n* and the i^{th} user receives an allocation x_i then Jain's fairness index *f(x)* is given as in Equation (8).

$$f(x) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n \sum_{i=1}^{n} {x_i}^2} \qquad (8)$$

The result is the measure of equality of the allocation of values. The f(x) values range between 0 and 1. When there is absolute fairness then, f(x) is 1. As fairness decreases, f(x) decreases until it reaches 0. We verify relative fairness of our model with respect to throughput. We compute x_i in Equation (8) as in Equation (9), where '*a*' is the observed throughput and '*e*' is the expected throughput.

$$x_i = \begin{cases} \frac{a_i}{e_i}, if \;\; a_i < e_i \\ 1, if \;\; a_i \geq e_i \end{cases} \qquad (9)$$

The observed throughput a_i is obtained from simulation and the expected throughput e_i with proportional share can be calculated as in Equation (10) where *TB* is the total bandwidth for allocation and w_i is the weight.

$$e_i = w_i * \frac{TB}{\sum_{i=0}^{n-1} w_i} \qquad (10)$$

The results of Equation (8) is depicted in Figure 5, for varying number of nodes with three priorities and the number of nodes in all priorities are the same. (Scenario II). Results show that our model ensures 95% overall relative fairness.

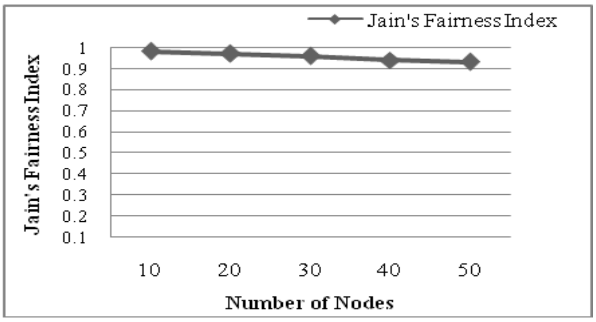

Figure.5. Fairness of throughput

5.2 Evaluation of Waiting times

A single server proportional-share scheduling system fed by multiple Poisson streams with arrival rates λ_1, λ_2 .. λ_n for various queue is considered. The cumulative arrival rate is denoted as λ. The service time is denoted by 1/μ. The utilization of each queue is denoted as λ_k/μ_k. The utilization ρ of the output link is given by λ/μ. A packet has to wait until the residual transmission *R* of current packet and the number of packets N_k ahead of it in the k^{th} queue. Further, if some other queue is being serviced, it has to wait for the other packets in other *j* queues to be serviced is denoted by P_j . Thus the mean packet delay W_k of the i^{th} packet in the k^{th} queue of n total queues is calculated as in Equation (11).

$$W_k = R + \frac{1}{\mu}\left[N_k + \sum_{\substack{j=1,\\ j\neq k}}^{n} P_j\right] \qquad (11)$$

The mean residual time R, by the evidence in [22] can be written as in Equation (12).

$$R = \frac{\lambda\overline{T^2}}{2} \tag{12}$$

Where $\overline{T^2}$ is the second moment of the mean service time $\overline{T}$. According to Little's formula,

$$N_k = \lambda_k W_k \tag{13}$$

Since the scheduling algorithm follows proportional share scheduling, P_j can be substituted by the Access Ratios AR_j, that determines the number of packets. Substituting Equation (12) and (13) in (11), Equation (11) can be written as in Equation (14).

$$W_k = \frac{\lambda\overline{T^2}}{2} + \frac{1}{\mu}\left[\lambda_k W_k + \sum_{\substack{j=1,\\ j\neq k}}^{n} AR_j\right] \tag{14}$$

Further reducing yields Equation (15),

$$W_k = \frac{\frac{\lambda\overline{T^2}}{2} + \frac{1}{\mu}\sum_{\substack{j=1,\\ j\neq k}}^{n} AR_j}{1-\rho_k} \tag{15}$$

Equation (15) gives the upper bound of the mean packet delay. The AR is calculated as in Algorithm 1 where, $AR_0 > AR_1 > AR_2 > \ldots > AR_{n-1}$. Hence, the mean packet delay is such that $W_0 < W_1 < W_2 < \ldots < W_{n-1}$. When the packet arrives during the current service interval, packet delay is minimum. The lower bound of mean packet delay can be given as in Equation (16).

$$W_k = \frac{\frac{\lambda\overline{T^2}}{2}}{1-\rho_k} \tag{16}$$

Thus it is analytically proved that prioritization is achieved and starvation is also avoided.

6. CONCLUSION

In this paper, we propose a novel scheduling model that supports multiple priorities which provides prioritization and differentiation based on user profiles. It provides prioritization at three levels. First, it assigns node priority and stamps the packets accordingly and maintains distinct queues. Secondly, it uses adaptive rationed dequeuing algorithm to dequeue the packets so that, starvation is avoided for Low priority nodes. Finally prioritization is achieved at the MAC layer through proportionally differentiated IFS, backoff timers and Adaptive RTS-CTS frames. Simulation was done in ns2 with two, three and four priorities. Results show that differentiated services have been achieved for the different profiles of users. The average throughput of DCF was compared with various priorities and result shows that our model achieves 16% less starvation than DCF. To analytically prove our model, we calculated relative fairness with Jain's fairness index and evaluate waiting times. It is observed through simulation that the throughput decreases and control overhead increases with the number of priorities.

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