Queue Management Algorithm for Multi-rate Wireless Local Area Networks

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Abstract— **Wireless local area network(LAN) has become popular due to the capability of supporting high data rates in ubiquitous computing. These high data rates are possible through new modulation schemes that are optimized for channel conditions. Especially, IEEE 802.11b supports the various data rates, 11Mbps, 5.5Mbps, 2Mbps and 1Mbps according to the channel conditions between the access point(AP) and the mobile station. The coverage area supported by the high data rate such as 11Mbps is very small. However, the lower data rate increases the coverage area, thus the change of data rate can overcome this coverage problem of the high data rate. There are many wireless packet scheduling and buffer management algorithms, but they assume an wireless channel supporting only single base-rate and hardly take advantage of high data rate when multiple data rates are possible. In this paper, we propose the new queue management algorithm in order to utilize high data rate efficiently in the current wireless LAN. Basically, the proposed queue management algorithm manages the priority queue of packets, where packet with shorter transmission time has higher priority, since the transmission time is highly dependent on the available data-rate to the mobile station. We show our suggested algorithm achieves high throughput through the simulation in based in wireless LAN environments based on the IEEE 802.11b.**

I. INTRODUCTION

The IEEE 802.11a and IEEE 802.11b media access control(MAC) protocols provide a physical-layer multi-rate capability [1]. The original IEEE 802.11 protocol supports single base rate, typically 2Mbps. With multi-rate enhancement, data transmission can take place at various rates according to channel conditions. Higher data rates than the base rate are possible when the signal-to-noise ratio(SNR) is sufficiently high. Consequently, with IEEE 802.11a the set of possible data rates includes 6, 9, 12, 18, 24, 36, 48 and 54 Mbps whereas for IEEE 802.11b the set of possible data rates includes 1, 2, 5.5 and 11 Mbps. As the multi-rate enhancements are physical layer protocols, MAC mechanisms are required to exploit this capability. The auto rate fallback(ARF) protocol was the commercial implementation of a MAC that utilizes this feature [2]. With ARF, senders attempt to use higher transmission rates after consecutive transmission successes and revert to lower rates after failures. Under most channel conditions, this multi-rate enhancement using ARF provides a performance gain over pure IEEE 802.11 single base rate.

In this paper, we propose a new approach to management of queue for multi-rate wireless LAN. The key motivation of this paper is based on the following observations. IEEE 802.11a and IEEE 802.11b MAC protocols provide high data rates, up to 54Mbps and 11Mbps respectively. But data rate of each mobile station is decided according to the channel condition of each, such as SNR. The whole mobile stations in basic service set(BSS) share the same wireless channel by using Carrier Sense Multiple Access-Collision Avoidance(CSMA-CA) MAC protocol. In this environment, the bottleneck points of wireless system are the lowest data rate connections between AP and mobile stations. When more packets are transmitted to mobile host with 1Mbps data-rate, worse throughput, delay and packet loss probability are come up with, from those in case more packets are transmitted to mobile host with 11Mbps, even the total amount of transmitted traffic is same in both cases. To achieve high throughput, we need to consider the data-rates between the AP and mobile stations and the packet size.

Fig. 1 shows the overall framework of AP extended with our proposed queue management algorithm. When the network layer has a packet to transmit, it calls the enqueue function of our queue management system. In the enqueue function, if the queue is full, we choose the packet which has the longest transmission time based on the channel state monitor information, such as data-rate of each mobile station and then drop it. When the MAC protocol wants to transmit a packet, it calls the dequeue function of our queue management system. In this case, dequeue operation prefers the packet of the shortest transmission time as the enqueue operation drops the packet of the longest transmission time based on the reason.

Although there are some proposed packet scheduling algorithms in wireless packet networks, such as CDMA and wireless LAN, these algorithms are all built on the assumption of single data rate. In this paper, we propose a new queue management algorithm in the environments where multi-rate data transmission is supported such as IEEE 802.11a or IEEE 802.11b, which consequently guarantees higher throughput. The reminder of this paper is organized as follows. We start in Section II by giving some background on the IEEE 802.11 and some queuing algorithms in single rate wireless networks. The proposed queuing algorithm is described Section III. Section IV presents the results of simulation experiments. Finally, we summarize and conclude the paper in Section V.

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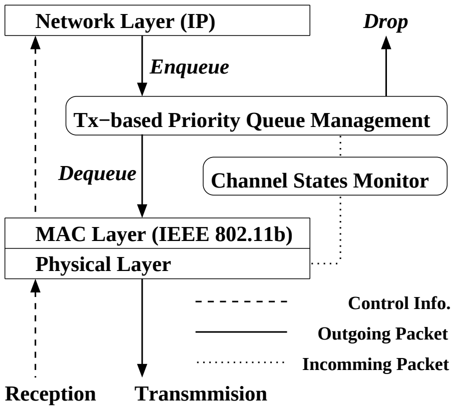


Fig. 1. Architecture of the proposed queue management algorithm

II. Related Work

A. Review of IEEE 802.11

We briefly review the IEEE 802.11 Distributed Coordinated Function(DCF). As described in [1], a transmitting mobile station must first sense an idle channel for a time period of Distributed InterFrame Spacing(DIFS) after which it generates a random backoff timer chosen uniformly from the range $[0,\ w-1]$, where w is referred to as the contention window. At the first transmission attempt, w is set to CW_{min}(minimum contention window). After the backoff timer reaches 0, the mobile station transmits a short request-to-send(RTS) message. If successfully received, the receiving mobile station responds with a clear-to-send(CTS) message. Any other mobile stations which hear either the RTS or CTS packet uses the data packet length information to update its Network Allocation Vector(NAV) containing the information of the period during which the channel will remain busy. Thus, all mobile stations including hidden node can defer transmission suitably to avoid collision. Finally, a binary exponential backoff scheme is used such that after each unsuccessful transmission, the value of w is doubled, up to the maximum value $CW_{max} = 2^m CW_{min}$, where m is the number of unsuccessful transmission attempts.

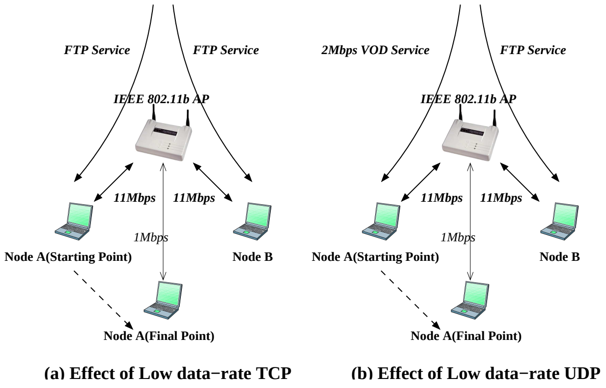
B. Some Queuing Algorithms in Wireless Networks

There have been some proposed several packet scheduling algorithms in wireless packet networks. Idealized wireless fair queuing (IWFQ) [6] and channel condition independent packet fair queuing (CIF-Q) [7] have been proposed for wireless packet fair queuing. Because of location-dependent errors in wireless channels, each mobile station experiences different interference and fading patterns depending on its position. These paper proposed the packet scheduling algorithm to achieve the throughput fairness over all mobile station. Distributed fair scheduling (DFS) [5] presented a general mechanism for translating a given fairness model into a corresponding per-node backoff-based collision resolution algorithm. Using this translation, [5] proposed the backoff algorithm for achieving proportional fairness in wireless shared channels. These papers assumed that the wireless network can transmit or receive the packet by using the only single base-rate. In the multi-rate wireless network, previously proposed queuing algorithms hardly take advantage of high data rate. In the following section, we explain the problem definition and the our new queue management algorithm in multi-rate wireless LAN.

III. Proposed Queue Management Algorithm in Multi-rate Wireless Networks

A. Problem Definition

Here, we present the proposed queue management algorithm in multi-rate wireless LAN, such as IEEE 802.11a and IEEE 802.11b. The key observation is that the achievable maximum throughput of wireless LAN is determined by the total traffic to the mobile stations which have the lowest data-rate link. In the IEEE 802.11b case, when the amount of traffic to mobile stations which have link capacity of 1Mbps exceeds 1Mbps, no more traffic can be delivered.



(a) Effect of Low data−rate TCP (b) Effect of Low data−rate UDP

Fig. 2. Simulation scenario using IEEE 802.11b

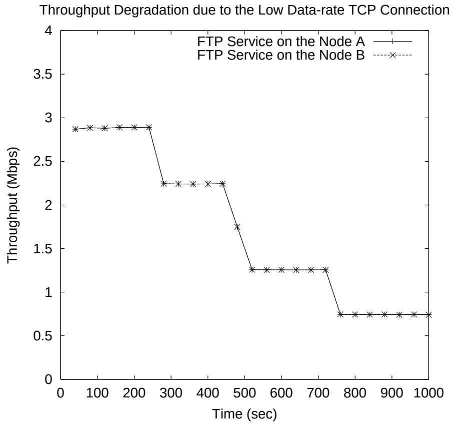


Fig. 3. Throughput effect between low data-rate TCP and high data-rate TCP

To clearly show that this problem is due to the heterogeneous link characteristic, we carry out the following simulation. In Fig. 2 (a) and (b), two mobile stations are close enough to AP that both mobile stations can be served with 11 Mbps data rate from AP. When the simulation starts,

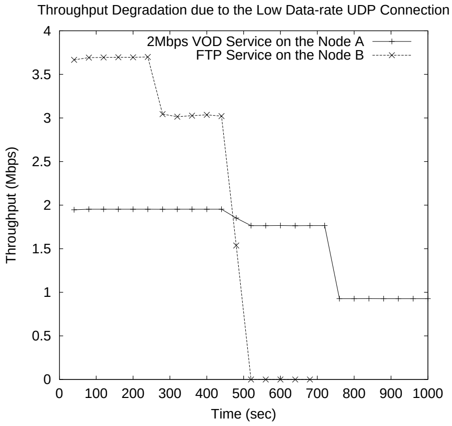


Fig. 4. Throughput effect between low data-rate UDP and high data-rate TCP

only *node A* begin to move away from the AP with 0.5 m/s. Thus, *node A*'s data rate reduces from 11 Mbps to 5.5 Mbps, 2 Mbps and finally down to 1 Mbps. In Fig. 2 (a), both mobile stations are served with the FTP service using TCP, and the throughput of each mobile station is shown in Fig. 3. As $Node\ A$'s data rate reduces, the throughput of $Node\ A$ is decreased. However, the problem is that the throughput of $Node\ B$ is also decreased together. Even though the data-rate of *node B* is high enough, the throughput of $Node\ B$ is effected by the data-rate of $Node\ A$ because the wireless channel is shared media. In Fig. 2(b), moving mobile station $Node\ A$ is served with the 2Mbps VOD service using UDP and $Node\ B$ is served with the FTP service using TCP. As shown in Fig. 4, the FTP throughput of $Node\ B$ is changed to zero and FTP connection is disconnected after 500(s), when the data-rate of $Node\ A$ is changed to 2Mbps.

If we limit the traffic of such mobile stations, we can achieve higher system throughput with the same resource because mobile stations which have the relatively higher data-rate can be used more efficiently. Recently, more Internet Service Providers(ISPs) are interested in the public area service of wireless LAN(e.g., NetSpot in Korea). In this situation, the pricing of wireless LAN is dependent on the number of transmitted packets. Therefore, the goal of proposed queue management algorithm is to obtain both the number of transmitted packets for the revenue of ISPs and the number of transmitted bytes for the resource utilization. The following sub-section explains algorithms using the notation shown in Table I.

B. Enqueue Problem

Here, we present the enqueue problem of the proposed queue management algorithm in multi-rate wireless network, such as IEEE 802.11a and IEEE 802.11b. The enqueue operation of this paper is described in Algorithm 1. Algorithm 1 operates when a new packet (P) arrives at its queue (Q). The queue management module inserts the arriving packet (P) into the queue (Q). If the queue is full, we decide a packet to be dropped according to the following rules. The overflow of queue means that the number of incoming data packets of wireless system is more than that of outgoing packets. Therefore, we choose the packet which have the longest transmission time to be dropped so that we can reduce the packet drop probability. Since the upper bound of queue length commonly uses the the number of packets instead of the number of bytes, the reduction of average packet transmission time results in the increase of the available queue space. Lines 5-13 in Algorithm 1 shows the way to look for the packet which has the longest transmission time ($P.Size()/Data\_Rate(k)$) in the queue Q. After we decide the packet (P_{victim}) to be dropped, we remove the packet in the queue (Q). This priority queue management algorithm based on the transmission time of packet gives the lower priority to mobile station with the lower-data rate, when the queue is full. However, the packets with small size, such as in voice or interactive application, get high priority for transmission although the data rate of them is low, since it takes little time for transmitting small-sized packets even in low data rate.

TABLE I

NOTATIONS FOR ALGORITHM DESCRIPTION

Notation	Description
$Q.Length()$	return the queue length (*packets*)
$Q.Insert(P)$	insert the *packet P* into the queue
$Q.Lookup(i)$	return the *i'th packet* in the queue
$Q.Remove(P)$	delete the *packet P* in the queue
$P.Size()$	return the size of *packet P*
$P.NextHop()$	return the next hop address of *packet P*
$Data\_Rate(k)$	the host k's data rate

Algorithm 1 *Enqueue*(P) P : newly arriving packet

```
1:  $Q.Insert(P)$;
2:  if $Q.Length() \geq QueueLimit$ then
3:      $i \leftarrow 1$;
4:      $Max\_TxTime \leftarrow 0$;
5:      while $i \leq Q.Length()$ do
6:          $P_{tmp} \leftarrow Q.Lookup(i)$;
7:          $TxTime \leftarrow$
                $P_{tmp}.Size()/Data\_Rate(\ P_{tmp}.NextHop()\ )$;
8:          if $TxTime > Max\_TxTime$ then
9:              $Max\_TxTime = TxTime$;
10:             $P_{victim} \leftarrow P_{tmp}$;
11:         end if
12:         $i \leftarrow i + 1$;
13:     end while
14:     $Q.Remove(P_{victim})$;
15:     $Drop(P_{victim})$;
16: end if
```

C. Dequeue Problem

The proposed dequeue operation is described in Algorithm 2. The basic dequeue operation is nearly the same as the enqueue operation. When the dequeue function is called and the queue is not empty, we find the packet with the shortest transmission time(Lines 6-14 in Algorithm 1). This selected packet (P_{prefer}) is removed in the queue. In this proposed queue management, the primary objective of the queue management algorithm is to achieve high throughput. This dequeue operation make the queue length to be short as fast as possible. The combination of both transmission time based enquque and dequeue operations improve the throughput of wireless LAN, but the enqueue operation mainly contributes to the improvement of the throughput. Since the average transmission time of the packets in the queue is reduced mostly by priority enqueue based on transmission time, the reduction of it by dequeue operation may be small. However, in the extreme case where the traffic of mobile station with lowest data-rate is heavily overloaded, this dequeue operation take important role of improving the throughput of wireless LAN. In Section IV, we show the benefits of proposed queue management algorithm through the various simulation results.

Algorithm 2 *Dequeue*()

```
1:  if $Q.Length() = 0$ then
2:      $return$;
3:  end if
4:  $i \leftarrow 1$;
5:  $Min\_TxTime \leftarrow \infty$;
6:  while $i \leq Q.Length()$ do
7:      $P_{tmp} \leftarrow Q.Lookup(i)$;
8:      $TxTime \leftarrow$
            $P_{tmp}.Size()/Data\_Rate(\ P_{tmp}.NextHop()\ )$;
9:      if $TxTime < Min\_TxTime$ then
10:         $Min\_TxTime = TxTime$;
11:         $P_{prefer} \leftarrow P_{tmp}$;
12:     end if
13:     $i \leftarrow i + 1$;
14: end while
15: $Q.Remove(P_{prefer})$;
16: $Transmit(P_{prefer})$;
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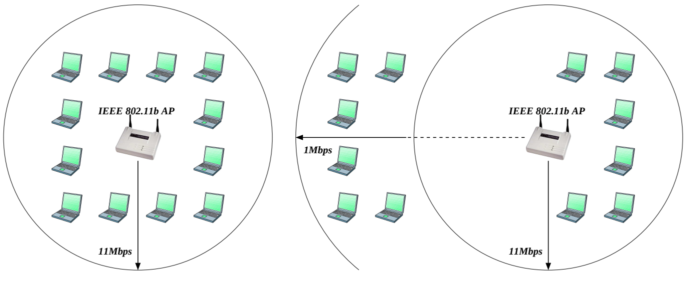
IV. Simulation Experiments

A. Simulation Environment



(a) initial network topology (b) final network topology

Fig. 5. Simulation scenario

The simulation results in the paper were generated using the $ns-2$ network simulator, with extensions from NOAH, a wireless routing protocol that supports direct communication between access point and mobile stations. In this simulation, the available data rates are based on IEEE 802.11b and are set to 1 Mbps, 2 Mbps, 5.5 Mbps, and 11 Mbps. Especially, the values for data rates were chosen based on the distance ranges specified in the $Orinoco^{TM}$ 802.11b card data sheet [8]. Fig. 5 (a) represents the initial network topology. It is composed of one access point(AP) and 12 mobile stations. In Fig. 5, all mobile stations are close enough to AP that they all can be served with 11 Mbps data rates from AP. When the simulation starts, half of the 12 mobile stations begin to move away from the AP with 0.5 m/s. So their data rates reduces from 11 Mbps to 5.5 Mbps, 2 Mbps and finally down to 1 Mbps. Fig. 5 (b) shows 6 mobile stations moved and the other 6 mobiles stations stayed in place, served with 1 Mbps and 11 Mbps, respectively.

We simulated with 3 different applications(Video, Audio, and Data traffic) to show the various internet traffic characteristics. Each of the application has 4 connections, 2 of them are connected to moving mobile stations, and the other 2 are connected to stationary mobile stations. So we have 6 moving and 6 stationary nodes, each of them is composed of 2 Video, 2 Audio, and 2 Data traffic applications. The video traffic is CBR generating 1.5 Mbps with packet size of 1400 bytes. The audio traffic is exponential On/Off, which can be configured to behave as Poisson process, generating 256 Kbps with packet size of 128 bytes. And the data traffic is Pareto On/Off generating 512 Kbps with packet size of 512 bytes.

B. Simulation Result

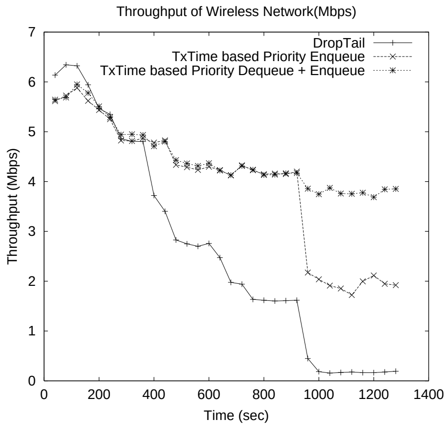


Fig. 6. Total throughput of wireless LAN (Mbps)

Fig. 6 shows throughput, the amount of data bytes successfully transmitted from AP to all mobile stations per second. The x-axis is time ranging from 0 to 1400 seconds and y-axis is throughput(Mbps). In this graph, we show 3 queue management algorithms, DropTail, Tx Time based Priority

Enqueue (TTPE) which implements Algorithm 1 only, and Tx Time based Priority Dequeue and Enqueue (TTPDE) which implements both Algorithm 1 and Algorithm 2. Up to around 300 seconds, these three algorithms show high throughput over 5 Mbps with no difference, since all of them are close to AP, so are served with high data rate, 11 Mbps. As 6 mobile stations are moving further away from the AP, the difference of throughput between these algorithms gets apparent. This is because, as we pointed earlier, mobile stations away from AP will be served with lower data rates than the maximum data rates. TTPE and TTPDE algorithms show better throughput than DropTail algorithm. Especially, 1000 seconds later, TTPDE algorithm guarantees 4 Mbps, meanwhile DropTrails only around 0.2 Mbps. The reason why TTPE and TTPDE algorithms show such difference in throughput especially after 1000 seconds will be explained next figures.

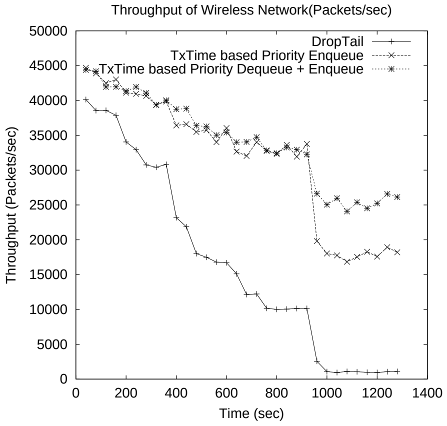


Fig. 7. Total throughput of wireless LAN (packets/sec)

Fig. 7 shows the throughput from the aspect of the number of successfully transmitted packets per second from AP. The result is similar to that in the prior graph, Fig. 6. The overall performance enhancement, in terms of the number of successfully transmitted packets, due to the suggested priority queue management algorithms shows that our queue management algorithms outperform the DropTail queue management algorithm. This results also mean that the wireless LAN Internet Service Providers(ISPs) which price each packet can achieve greater profit.

Fig. 8 represent the throughput(Mbps) of the 6 stationary mobile stations with 11 Mbps data rate. With TTPDE algorithm, we see that the throughput is over 3 Mbps all the time. As the 6 mobile stations are moving away from the AP, the difference in the amount of total served traffic between the suggested algorithm and DropTail algorithm is growing. This is because the 6 stationary mobile stations with high data rate, are guaranteed high data rates regardless of the moving mobile stations with low data rates. It means the efficient usage of the wireless resources since the suggested algorithm shows high throughput of the stationary mobile stations.

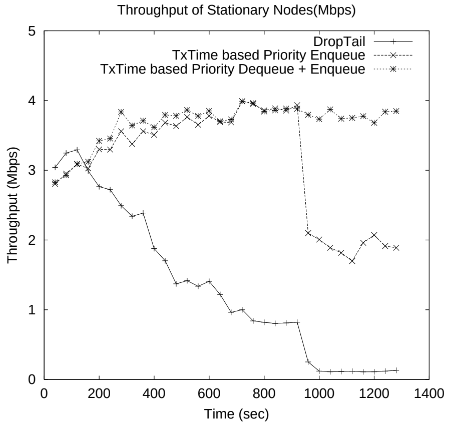


Fig. 8. Throughput of stationary mobile stations (Mbps)

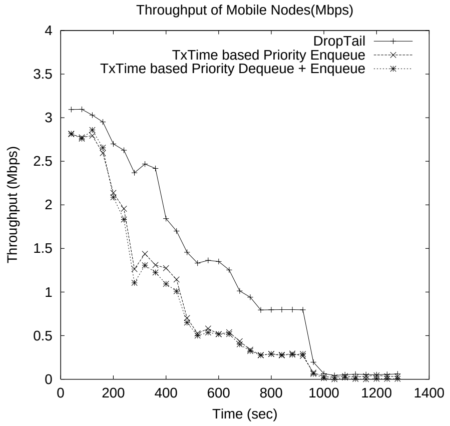


Fig. 9. Throughput of moving mobile stations (Mbps)

Fig. 9 represents the throughput(Mbps) of the 6 moving mobile stations. This graph shows that the amount of served data traffic is going down in all algorithms, because the available data rates between the 6 moving mobile stations and AP go down as they move further away from the AP. Especially only about 0.1 Mbps traffic is served after 1000 seconds later. We see that the DropTail algorithm outperforms the suggested priority queue management algorithms. However, the difference in throughput between the DropTail algorithm and the suggested algorithms is so subtle, under 1 Mbps, that it is a trifle compared to the high throughput increase of the stationary mobile stations by the suggested algorithms.

Fig. 10 shows the total amount of traffic transmitted to the four video applications. When we analyze the simulation results by the application, the video applications gain most benefits from the TTPDE algorithm. The rest two applications do not have many performance gains with the inclusion of dequeue algorithm. This is because the video applications has lower priority than audio or data traffic, so drops of video packets happen more frequently.

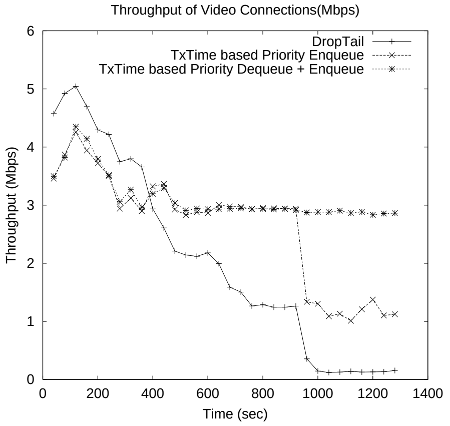


Fig. 10. Throughput of video application (Mbps)

But with dequeue algorithm applied, we can have more queue space so that the packets of video applications have lower chance to be dropped than without dequeue algorithm, consequently leading to performance gains. As we mentioned earlier, the reduction in the average transmission time with the inclusion of dequeue algorithm is trivial, however, when the network is highly loaded (after 1000 seconds) it has great effect on performance. Now we see that the performance gains of the overall throughput we have seen so far are mainly due to the increase of throughput in the the video traffic applications.

V. Conclusion

In this paper, we proposed a priority queue management algorithm which can provide both efficient wireless resources utilization in multi-rate Wireless LAN environment , IEEE 802.11a, IEEE 802.11b. Basically the link quality of mobile station has heterogeneous characteristics that are highly affected by channel states. In other words, some mobile stations can communicate in high data rates and others in low date rates. With this characteristics, the traffic communicated with low data rates have a great influence on the overall performance of the Wireless LAN. Our proposed priority queue management algorithm which considers both the size of packet and the data rates of link works independently of such heterogeneous characteristics and achieves higher throughput (Mbps, packets/sec). We simulate with $ns-2$ simulator and it shows the expected results. The proposed algorithm contributes to the efficient resource utilization and to the high profit for the wireless LAN Internet Service Providers(ISPs).

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