On Flow Reservation and Admission Control for Distributed Scheduling Strategies in IEEE802.11 Wireless LAN

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ABSTRACT

Providing service differentiation in IEEE802.11 Wireless LANs [3] has been investigated by many researchers ([2], [5], [6], [7], [9], [13]). It has been shown [1] that some distributed schedulers such as DFS [9] and EDCF [5] can achieve high throughput and certain service differentiation comparing to DCF and PCF provided that the traffic load in the system is low or medium. However, those strategies do not support flow reservation and thus cannot guarantee QoS requirements of high priority real-time flows under overloading network traffics. In this paper, we present a MAC layer flow reservation and admission control scheme for distributed scheduling strategies in the aim of achieving QoS guarantee in IEEE802.11 wireless LANs. Our approach has several desirable features: (1) It can work with most of the distributed scheduling strategies like DCF, DFS, EDCF without modification of the underlying scheduling mechanism. (2) A dynamic priority re-allocation method is integrated with the admission control to further improve system throughput. (3) Misuse of priority can be easily handled. Simulation of our proposed reservation scheme upon various distributed scheduling strategies has been conducted, and results show that this scheme can achieve low collision rate, high throughput, and less delay.

Categories and Subject Descriptors

C.2.2 [Computer - Communication Networks]: Network Protocols – protocol architecture.

General Terms

Algorithms, Performance, Design.

Keywords

IEEE 802.11 Wireless LAN, admission control, reservation, QoS.

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1. INTRODUCTION

Providing service differentiation in IEEE802.11 wireless LANs has been of a lot of interest in recent years. Simulations [1] have been conducted for comparing different scheduling strategies in IEEE802.11, including PCF, DCF, DFS [9], and EDCF [5]. Results show that EDCF makes good improvements over PCF and DCF in that it is a distributed scheme and can differentiate traffics by their priority values. DFS ensures better service for high-priority flows and does not starve low-priority flows even under high traffic load. However, results [1] also show that when the traffic is heavy, the performance of these scheduling strategies deteriorates very quickly and becomes intolerable. Also, for EDCF, when the bandwidth demands of high priority flows are large, low priority flows are almost starved, which is not acceptable for most applications. Adaptive EDCF [4] makes further improvement on EDCF, but it still suffers seriously when the traffic load is heavy.

Actually, the common idea of the above scheduling strategies is to minimize packet transmission collision either by varying the contention window size for different traffic categories, or by employing appropriate backoff interval calculation methods to control the channel access of wireless stations. Under light or medium load, these strategies are efficient in the sense that all flows should backoff for a different period of time after collision and thus the likelihood of colliding again is rare. However, when the traffic load increases, without flow admission control, collision rate cannot be significantly reduced by only adjusting backoff intervals, i.e., collision rate increases with the increase of the traffic load. This increasing collision rate is very harmful for system performance and may yield low throughput and large packet delays. Therefore, in order to avoid the severe performance degradation under high traffic load, flow reservation and admission control become critical.

Furthermore, all the distributed schedulers assume that flows are one-directional, i.e., the sender and receiver are fixed. However, in peer-to-peer communications, both communication parts can be either sender or receiver and in some interactive communication scenarios, flows of requests and responses are synchronized. If those requests and responses are reserved as independent flows, it is possible that a request is accepted but the response from the counterpart is rejected, making no QoS guarantee for the interactive session. Therefore, supporting per-session reservation is desirable.

It should be observed here that reservation at the MAC level has been used in wireless ATM networks [8]. Also, the current trend in design and implementation of MAC protocols is to adopt cross-layer interaction [12]. By looking up upper layers, MAC protocols can obtain per-flow information and handle both request and response as two packets of one same flow. In this way, per-flow reservation in MAC layer can be straightforward and efficient.

Proposed Approach: In this paper, a MAC layer flow reservation and admission control scheme for distributed scheduling strategies in IEEE802.11 wireless LANs is presented. This scheme can work in both infrastructure and Ad-hoc models and support per-session reservation. For priority-based scheduling strategies such as EDCF, an efficient priority re-allocation algorithm is proposed for improving QoS. This priority re-allocation algorithm can easily handle misuse of priority. In order to accommodate all kinds of MAC schedulers, an experiment-based bandwidth estimator is used for flow admission control. By enforcing admission control, the unnecessarily severe channel contention between real-time flows can be significantly reduced.

It is noted that for contention-based channel access, collision is inevitable, so it is impossible to guarantee bandwidth reservation for any flow. Therefore, what our scheme offers is not guaranteed service, but controlled load service, or soft-QoS. Simulation results show that this scheme can achieve low collision rate, high throughput, and less delay.

Contributions: The contributions of this paper are as follows:

- A per-flow reservation scheme for soft-QoS guarantee in IEEE802.11 wireless LAN is provided.
- A priority re-allocation based dynamic admission control strategy is proposed, which is effective in handling misuse of priority and providing protection for other flows.
- The proposed scheme is compatible with the IEEE802.11 standard and can work with most of the existing distributed schedulers.
- Our scheme also supports resource reservation for peer-to-peer sessions.

Organization of the paper: Section 2 reviews the related work. Section 3 introduces the proposed flow reservation scheme in details, which includes a priority re-allocation algorithm, a dynamic admission control algorithm, and a flow reservation protocol. Section 4 discusses the performance evaluation of this scheme for various scheduling strategies such as DCF, DFS, and EDCF. Section 5 concludes this paper.

2. RELATED WORK

DCF (Distributed Coordinator Function) is the basic medium access mechanism in IEEE802.11 [3]. DCF is contention-based and it uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) algorithm to coordinate the access to the wireless channel. To resolve the hidden terminal problem, a RTS/CTS handshaking procedure is required to detect the transmission collision. Before a station (STA) sends out a data frame, it first senses the channel. If the channel is idle for at least a DCF interframe space (DIFS), the frame is transmitted. Otherwise, a backoff time slot is chosen randomly in the interval [0,CW), where CW is the contention window. The contention window is incremented exponentially with the increase of the number of attempts to retransmit the frame. During the backoff period, the backoff timer is decremented by one each time the channel is determined to be idle for at least a DIFS period. When the backoff timer reaches zero, the data frame is sent out. If collision occurs, a new backoff time slot will be chosen and the backoff procedure starts over until some time limit is exceeded. After the successful transmission, the contention window is reset to CW_{min}. DCF suffers from collision seriously under high loads, and it does not provide any traffic differentiation.

PCF (Point Coordinator Function) is an optional mechanism for IEEE802.11. PCF coexists with DCF by providing a CFP (Contention Free Period), during which the PC (Point Coordinator) polls high priority STAs and allocates time slots for them to transmit data frames. A STA is not allowed to transmit data packet without the permission from the PC. PIFS (PCF Interframe Space) is defined to make sure that low priority STAs do not interfere PCF operation. Also, DCF is supported in this case to prevent low priority STAs from being starved. PCF is designed to offer QoS for real-time applications. But it is an centralized approach and suffers from location-dependent errors.

EDCF [5] (Enhanced Distributed Coordinator Function) is the newly proposed medium access mechanism by task group E of IEEE802.11 working group. EDCF is an extension of IEEE802.11 standard. The goal of this extension is to provide differentiated DCF access to the wireless medium for prioritized traffic categories. EDCF makes two improvements for providing differentiation. First, it includes a QoS parameter set element which sets the contention window values and AIFS (Arbitration Interframe Space) values for prioritized EDCF channel access during the contention period. Classes with smaller AIFS have higher priority. Second, to achieve better medium utilization, packet bursting is used, i.e., when a STA has gained access to the medium, it can be allowed to send more than one frame without contending for the medium again. EDCF provides good traffic differentiation, but it causes starvation of low priority flows under high traffic load.

DFS [9] (Distributed Fair Schedule) is proposed for achieving fairness in IEEE802.11. DFS borrows the idea of SCFQ but is a distributed approach. The basic idea of DFS is that the backoff interval of flows with larger weight should be smaller. The result shows that DFS can achieve very good fairness while improving the performance of DCF.

Some other QoS schemes for IEEE802.11 have been proposed. In A-EDCF [4], the contention window of each flow is adapted according to the estimated collision rate in attempt to improve the performance of EDCF in heavy load. However, A-EDCF is just better than EDCF and it still suffers in overloading network condition. In PCC [13], an admission control strategy similar to PCF is provided. Also, contention windows are dynamically changed in the same way as DFS. A desirable feature of PCC is that it reduces the overhead to minimum by embedding flow information in MAC frames. Further enhancement on EDCF has been made in TCMA [6] and several per-flow differentiation methods are discussed by Aad [2].

RSVP (Resource Reservation Setup Protocol) ([10], [11]) is designed to provide integrated service for packet-switched network such as IEEE802.3. However, because of the scarcity of bandwidth and high link error in wireless network, directly applying RSVP may lead to high overhead and instable performance. In [12], an application level flow reservation scheme is proposed for max-min fairness scheduling in a single-hop IEEE802.11 wireless network. This scheme can guarantee each admitted flow receives at least the minimum required bandwidth. In [7], Virtual MAC is proposed for channel monitoring and estimation of achievable service levels. However, this approach requires modification of MAC protocol and is not as flexible as measurement-based approaches.

3. FLOW RESERVATION SCHEME

3.1 System Model

The architecture of the proposed scheme is depicted in Figure 1. The reservation scheme resides between higher layer and the MAC layer. But essentially, it's a sub-layer of the MAC layer. This sub-layer is transparent to both the upper and lower layers since it can be seamlessly integrated such that both higher layer and lower MAC layer (CSMA/CA channel access mechanism) are not aware of the existence of flow reservation. Thus, implementation of this scheme does not require any modification of the underlying scheduling mechanisms.

This scheme is designed to work together with distributed scheduling strategies. For centralized approaches such as PCF, this scheme is not very meaningful since PCF already implements admission control by polling some of the high-priority stations.

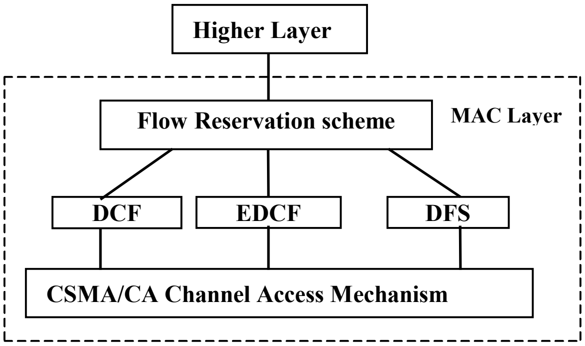

Figure 1. Architecture of flow reservation scheme

3.2 Assumptions

Before the introduction of the proposed scheme, several assumptions are made as follows:

- It is assumed that all nodes in a WLAN are within the broadcast region of each other and all nodes share a single channel.
- A Wireless Bandwidth Manager (WBM) is specified for admission control and flow reservation. This WBM may be "fixed" (for infrastructure, Access Point is the ideal candidate) or "arbitrary" (for Ad-hoc network, it needs to be specified or voted by any popular voting protocol), depending on the model of the network.
- In peer-to-peer communications, both communicating parts, initiators and receivers, know their own QoS requirements such that their communication session can be reserved.
- Flows are not guaranteed to be well-behaving, i.e, a flow may set their priority to be much higher than necessary, or a flow can generate packets at a rate faster than the reserved one.

3.3 Priority Setting and Re-allocation

Basically, there are two classes of scheduling approaches, priority based approaches such as EDCF, TCMA, and PCC, and non-priority based approaches such as DCF and DFS. As a weighted fair scheduler, DFS is not considered as priority-based scheduling approach. Usually, the priorities of flows are set by applications according to Table 1. In EDCF, at most eight traffic category queues can be maintained. So, this table can be directly mapped to EDCF. It is noted that traffic types with priority values from 0 to 3 are basically best-effort flows, while those whose priorities are from 4 to 7 are real-time flows.

Table 1. Priority assignment of traffic types

User priority	Traffic type
7	Network Control
6	Voice
5	Video
4	Controlled Load
3	Excellent Effort
2	Spare
1	Background
0 (default)	Best Effort

For priority-based schedulers, priorities are involved in computing backoff intervals such that flows of higher service classes have more chances to access channel than flows of lower service classes. Ideally, different flows should choose different backoff intervals in order to avoid possible collisions. However, it is possible that all flows are of very high priorities and they may have higher probability of choosing same backoff intervals and thus collide more frequently. In this case, simply making the scheduling with user-specific priorities may lead to serious performance. A-EDCF [4] proposes to dynamically change contention windows of flows to alleviate serious flow contention and achieve high performance. However, this approach requires modification of the standard. Notice that changing flow priority actually changes the contention window distribution of flows. Therefore, it is equivalently effective to assign a new priority appropriately for an incoming flow. In order to reduce serious channel contention in the network while providing QoS guarantee for high priority flows, we propose to evenly distribute priorities among all flows. The algorithm is described in Figure 2.

We classify flows into two classes, *high priority*[1] *class*, and *low priority*[2] *class*, which have priorities from 4 to 7, and 1 to 3, respectively. Correspondingly, flows are called high priority flows and low priority flows, respectively. Two flows are said to be of *the same class* (higher or lower) if they are in the same range specified. Also, *Flow_length* of a priority *p*, *Flow_length*(*p*), is defined as the total bandwidth demands of all the flows of priority *p* in the network. When an incoming flow arrives, its priority is reassigned according to the following rules:

- **A flow is assigned a priority of the same class with the smallest *Flow_length*.**
- **Among all the priorities satisfying the above condition, the one closest to the original priority is chosen.**

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[1] We use high priority flow and real-time flow exchangeably.

[2] We use low priority flow and best-effort flow exchangeably.

Algorithm: Priority Re-allocation

```
int Reallocate_priority (flowid, priority, rate)
List: flow_list;
if flowid is not found in flow_list
    if $4 \le priority \le 7$
        find priority p ($4 \le p \le 7$) with the smallest Flow_Length;
        new_priority = p;
    if $0 \le priority \le 3$
        find priority p ($0 \le p \le 3$) with the smallest Flow_Length;
        new_priority = p;
    insert flowid, priority, new_priority, rate in flow_list;
    return new_priority;
else
    if the transmitted packet is the last flow packet
        delete the flow from flow_list;
        assign the priority to a flow whose old priority is closest;
        return priority;
    else
        new_priority is obtained from flow_list;
    return new_priority;
end
```

Figure 2. Algorithm of priority re-allocation

If all flows have the same bandwidth demand, then *Flow_length(p)* is equivalent to the total number of flows with priority *p*. In order to make sure that the performance of an individual flow does not decrease significantly after priority re-allocation, the new priority should also be of the same class as the original one. For example, if the original priority of an incoming flow is 7, *Flow_length*(1)=*min*{*Flow_length(p)*, $0 \le p \le 7$ }, and *Flow_length*(5)=*min*{*Flow_length(p)*, $4 \le p \le 7$ }, then we should assign the flow new priority 5, instead of 1, since 1 and 7 are not of the same class. By setting the boundaries for priority re-allocation, we can ensure the overall performance of real-time flows.

In low or medium traffic load, assigning a lower priority does not decrease the received throughput of a flow because of enough idle slots in the channel. In high traffic load, our algorithm can effectively improve the overall throughput of the network by minimizing the collision rate. Another desirable feature of this algorithm is that it can easily punish misbehaving flows by assigning a very low priority to them and protect other flows. The effectiveness of this algorithm is demonstrated in section 4.4.

3.4 Dynamic Admission Control Algorithm

The objectives of our admission control strategy are as follows.

- It provides good quality of service for high priority flows.
- It prevents starvation of low priority flows.
- It is general and can work with most of the scheduling algorithms.
- It should help handle misuse of flow priority.

In IEEE802.11 Wireless LANs, because of the CSMA/CA mechanism, the channel utilization is not 100%. As a result of this, the aggregate received throughput never reaches the channel capacity. Therefore, reserving channel capacity for all real-time flows is not reasonable since when the total load gets close to the channel capacity, the network is already overloaded. To accommodate this fact, we introduce concepts of *Achievable Bandwidth, Reservation capacity, and Available Bandwidth.*

Definition 1: The *Achievable Bandwidth* is the maximum possible aggregate throughput received by all flows in the network.

Definition 2: The *Reservation capacity* is the maximum bandwidth that can be reserved for real-time flows, which cannot be greater than the achievable bandwidth.

Definition 3: The *Available Bandwidth* is the amount of bandwidth which is available for reservation, i.e., reservation capacity minus the allocated bandwidth.

It can be seen that achievable bandwidth is a function of scheduling algorithm and network configuration. For example, the achievable bandwidth of DCF with the packet size of 1024 bytes is different from that of DFS with packet size of 400 bytes. In [12], a measurement based approach for estimating bandwidth in MAC layer is proposed and the following formula is given for estimating the total throughput of the network.

$$TP = \frac{S}{T_r - T_s} = \frac{S}{D}$$

Where, S is the packet size. T_s and T_r are the timestamps that packet is ready at the MAC layer and the timestamp that an ACK has been received for the same packet. $D = T_r - T_s$ is called renewal period, which is also the MAC delay of the packet transmission at a station. The renewal period depends on how fast a station can access the channel. If the backoff counter a station chooses is larger, then *D* is correspondingly larger. If the traffic load of the network is larger, *D* is also larger. And, during the renewal period of a low priority flow packet, packets of higher flows may have been successfully transmitted, which should also be counted in the throughput calculation. For DCF, each station contends the channel at equal opportunity, so this estimation yields small inaccuracy when the network is not congested. However, for priority based schedulers such as EDCF, stations may perceive dramatically different renewal period and thus the estimated throughput is far different. This discrepancy leads to inaccurate estimation of the available bandwidth and seriously affects the success of the admission control. Considering the difficulty of obtaining accurate bandwidth estimation for *arbitrary* schedulers, we choose to obtain the average achievable bandwidth by simulation. The measurement of achievable bandwidth is described in section 4.1.

In our scheme, flows are reserved according to the standard FCFS (First Come First Serve) admission control policy until the new bandwidth request cannot be satisfied. To avoid the starvation of best-effort flows, it is fair to reserve only a certain portion of the achievable bandwidth for real-time flows. Of course, this is not only a technical issue, but also an administrative issue. It is up to the administrator of the service provider to decide how much bandwidth real-time flows may reserve.

Then we come up with the following dynamic admission control strategy:

Rule 1: For real-time flow reservation, standard FCFS admission control policy is applied; for best-effort flows, no reservation is made.

Rule 2: Real-time flows may reserve up to a certain portion of the achievable bandwidth.

Rule 3: It is assumed that the portion in rule 2 can either be fixed by the system administrator or be modified dynamically according to the number of best-effort flows in the system.

Rule 4: For priority based schedulers, if a flow is admitted, it is assigned a new priority according to the proposed priority re-allocation algorithm.

If the portion in rule 2 is to be dynamically modified, more information from the senders needs to be collected at the WBM such that it can make better estimation on how much bandwidth should be allocated for real-time flows. This can be done by including those information in reservation request messages.

3.5 Flow Reservation Setup Protocol

As we have mentioned in section 2, it is not appropriate to apply RSVP in IEEE 802.11 WLANs. Therefore, we adopt a simple request/response pattern for flow reservation and admission control, and no re-negotiation is necessary because we are offering soft-QoS. Since each wireless station does not have global information of the LAN, in order to request for bandwidth reservation, some centralized approach is needed. In our approach, a Wireless Bandwidth Manager (WBM) is specified for admission control and flow reservation. Every high priority mobile stations, before data transmission, must send their QoS requirements to WBM, which will accept/reject the requests according to the availability of the bandwidth in the wireless LAN.

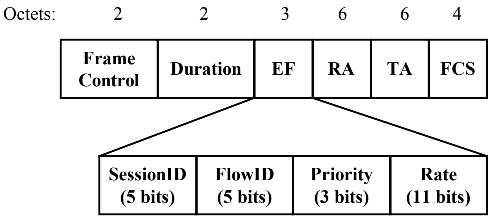

Figure 3. Frame Format of flow reservation request

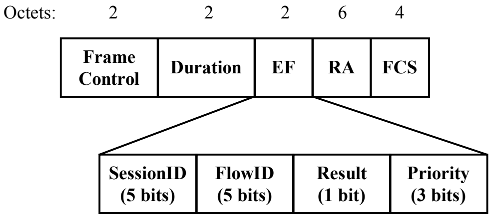

Figure 4. Frame format of flow reservation response

The flow reservation request can be either sent as a new control message like RTS, or piggybacked with RTS. Likewise, the result can also be sent as an explicit message like CTS, or piggybacked with CTS. The former approach leads to extra overhead of message passing, but it is only per-flow. If the QoS information is embedded in RTS, then the overhead of longer frame header is involved in all packet transmissions. Also, since we intend to support session reservation, reservation can only be sent back until the results for both directions are known. Thus, the session reservation result may not be ready when CTS is to be sent back. Therefore, we argue that although extra overhead is involved, it is only per-flow basis and is still efficient. Also, to support session reservation, we need explicit signaling for flow reservation.

The frame formats for the flow reservation request and response messages are designed in Figure 3 and Figure 4, respectively. This frame format is based on RTS and CTS, respectively. An additional field called *Extensible Field* (EF) is inserted. For request message, EF contains session id, flow id, flow priority, and rate demand. For response message, EF contains session id, flow id, flow priority, and reservation result. The remaining 2 bits are undefined. The Rate field is 11 bits, which corresponds to maximum of 2047. So a flow can request up to 2Mbps bandwidth, which is large enough for almost all cases.

Now we explain the flow reservation procedure as follows. Before transmitting RTS, each flow sends its traffic information (embedded in flow reservation request) to WBM, which obtains the traffic information in the EF field, and checks if the bandwidth demand can be accepted according to the admission control algorithm proposed. Once admitted, the new flow is added to the reserved flow list and allocated bandwidth is updated. Then AP sets the result and the new re-allocated priority in the EF field of the response message, and sends it back to the sender. If the result is 1, then the flow is accepted and it will contend the channel with the new priority, otherwise, the flow is dropped and may try again as a new flow in the future. When a reserved flow finishes, it sends release message to AP, which will remove it from the reserved flow list. For best-effort flows, no admission control is enforced. However, it is beneficial to provide their traffic information such that WBM can make good estimation on how much bandwidth it should allow for real time flow reservation.

Session reservation is similar to normal flow reservation. However, difference happens when WBM decides to send back the result. When WBM finds that a node is reserving a session, it will look up the session id and see if the reservation of the same session from the counterpart has been admitted/rejected. If the result is known, then the result is set to 1 only when both reservations succeed. Otherwise, WBM waits until the decision can be made. Of course, here we assume that both peers of a session have agreement on when to make the reservation request so that the result can be obtained as soon as possible.

4. PERFORMANCE EVALUATION

ns-2 network simulator is used to simulate the proposed scheme on Linux machines. The standard IEEE802.11 module is modified to integrate the flow reservation protocol. The physical channel bandwidth is set to be 2 Mbps, and it is assumed that a STA only initiates one flow at a time and all stations are stationary.

The major performance metrics measured in our simulations are:

- **Normalized throughput** is the percentage of demanded throughput received by an individual flow or all flows. It reflects the degree of flows' throughput requirements getting satisfied.
- **Collision rate** is the number of collisions per second. It is used to show the seriousness of collisions in the network.
- **Mean delay** is the average packet delay incurred for an individual flow.

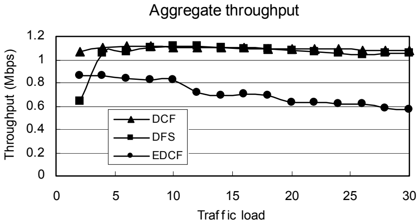

Figure 5. Aggregate throughput (DCF, DFS, and EDCF)

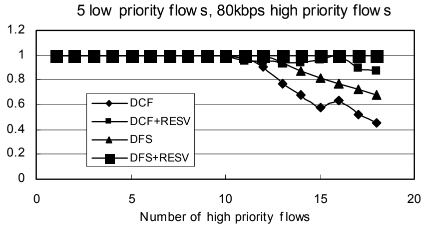

Figure 7. Normalized throughput (5 low priority flows)

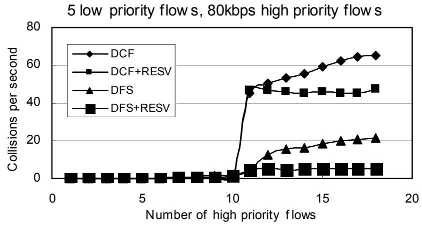

Figure 9. Collision Rate (5 low priority flows)

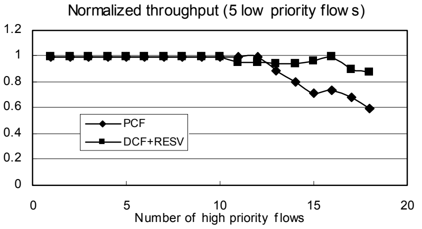

Figure 6. Normalized throughput (PCF and DCF+RESV)

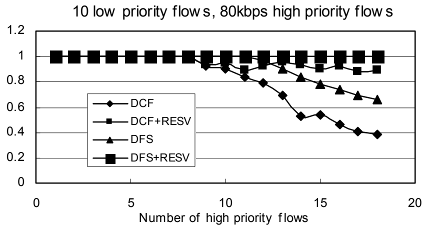

Figure 8. Normalized throughput (10 low priority flows)

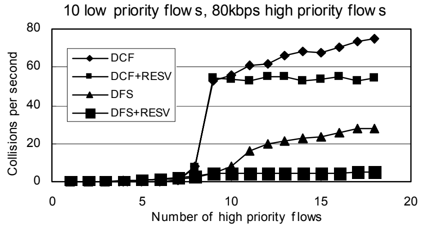

Figure 10. Collision Rate (10 low priority flows)

In all simulations, we have n+1 number of nodes and $n/2$ number of flows. Without loss of generality, a flow i $(1 \le i \le n/2)$ is setup from node 2i-1 to 2i and node 0 is specify as the WBM. The duration of the simulation is set such that the measured metrics converge to the fixed value. The parameters for each individual scheduling algorithm are the default values except for the following. In DFS, *Scaling_Factor* is 0.02 and *CollisionWindow* is 4 slots. The reservation capacity is tuned according to the traffic load of low priority flows and usually it is 70%-80% of the corresponding achievable bandwidth. For the simulation of DCF and DFS, the network configuration is ad-hoc model, while in PCF and EDCF, it is infrastructure model.

4.1 Achievable Bandwidth

The achievable bandwidth of DCF, DFS, and EDCF is depicted in Figure 5. In order to obtain the achievable bandwidth, we vary the number of flows but always make the total traffic to be the bandwidth capacity of the wireless channel, which is 2 Mbps. It can be seen that the aggregate throughput of DCF and DFS is higher than EDCF since in EDCF there are actually two hops involved for each data transmission. From this result, we estimate the average achievable bandwidth of DCF and DFS as 1.1Mbps. For EDCF, the average achievable bandwidth is about 0.8Mbps.

4.2 Comparison with PCF, DCF, DFS, EDCF

For convenience, when our reservation scheme is integrated with DCF, DFS, and EDCF, we call the corresponding approach DCF+RESV, DFS+RESV, and EDCF+RESV, respectively.

First, simulations are conducted for comparing the performance of PCF, DCF and DFS with our scheme. The packet size is 400bytes. Bit rates of high and low priority flows are 80Kbps, and 40Kbps, respectively. We fix the number of low priority flows to 5 and increase high priority flows gradually. Reservation capacity is set as 880Kbps to avoid starvation of low priority flows.

Figure 6 shows the normalized throughput of flow 1 in the case of DCF+RESV and PCF. It can be seen that when the system traffic load is high, PCF experiences serious performance degradation while DCF+RESV still receives high throughput. Thus, our admission scheme takes advantage of distributed pattern while providing good QoS for supporting real-time flows.

The normalized throughput and collision rate are depicted in Figure 7 and Figure 9, respectively. We can see that the normalized throughput is higher for DCF+RESV and DFS+RESV when compared with DCF and DFS respectively. This is because in the case of with reservation, when the traffic load is high, new high-priority flows are rejected because of the unavailability of enough resources. Therefore new high-priority flows do not affect the performance of existing flows in the network and reserved flows can continue to receive the same quality of service. However, without reservation, more and more flows are competing for channel access and the system quickly gets saturated. Also, we can see that the collision rate is much smaller in the case of with reservation. We also conduct simulations for the same scenario but change the number of low priority flows to 10 and the correspondingly adjust the reservation capacity to 720Kbps. The results are depicted in Figure 8 and Figure 10. It is obvious that in this scenario, low priority flows consume more bandwidth and thus the performance of high priority flows is relatively worse. However, with reservation, soft-QoS is still guaranteed. Also, results show that DFS outperforms DCF, which is consistent with the results in [1].

Table 2. $CW_{\min}$ of different priorities in EDCF

Priority	0	1	2	3	4	5	6	7
$CW_{\min}$	512	512	255	127	63	31	15	7

Then, the performance of the proposed reservation scheme with EDCF is evaluated. The contention window values for different priorities are listed in Table 2. Packet size is 800bytes and all flows have the same rate of 80Kbps. The priorities of flows are initially specified as 6 and then re-allocated by the proposed priority re-allocation algorithm. Flows are added from the total number of 0 to 24, to gradually increase the traffic load in the network. Also, we set the reservation capacity to be 0.8Mbps and 1Mbps, respectively. The normalized throughput received by a specific flow (with priority of 7) under different traffic load is depicted in Figure 11. It can be seen that without reservation, when the number of flows is greater than 16, the received throughput decreases significantly. However, with reservation, the received throughput is always kept and a gain of around 40% is achieved when the number of flows is 24.

The average normalized throughput received by all flows in the network is depicted in Figure 12. As expected, under low and medium traffic load, there is no need for reservation, so almost all flows receive 90% of their demanded rate for both cases of with and without reservation. However, when the traffic load increases, the average normalized throughput with EDCF becomes lower while EDCF+RESV still receive almost the same amount of bandwidth. When the number of flows is 24, the average normalized throughput is increased by two times. Also, we find that setting the reservation capacity of 0.8Mbps leads to better result than 1Mbps, in term of the average normalized throughput. However, considering that the rejection rate can be further reduced by setting higher reservation capacity, we prefer to choose reservation capacity of 1Mbps. Of course, higher values such as 1.2Mbps can also be used, but some performance degradation should be expected. We also measure the mean delay (Figure 13) and collision rate (Figure 14). It can be seen that EDCF+RESV always achieve lower collision rate and mean delay. When the number of flows is 24, the mean delay is reduced by almost 50% and the collision rate is reduced by about 60%.

4.3 Dynamic Priority Re-allocation

In this section, the effectiveness of our dynamic priority re-allocation is shown by another simulation. Here we do not enforce admission control and just assign the priority according to our proposal. We fix the number of high priority to be 10 with the bandwidth demand of 80Kbps each and flow priority of 6, and then gradually increase the number of low priority flows (with priority 1) from 0 to 20. The average normalized throughput of high priority flows is depicted in Figure 15. With the increase of number of low priority flows, only 60% of the requested bandwidth are received for high priority flows, on average. Note that in the previous simulation, we use 800Kbps for reservation capacity. Thus, without priority re-allocation, the QoS of the reserved flows cannot be guaranteed. However, with priority re-allocation, more than 80% of the bandwidth request can be offered, which is quite good for soft-QoS guarantee. We also monitor the number of dropped packets and the result is shown in Figure 16. It can be seen that using our proposed algorithm, the number of packets being dropped is much smaller. The reason is that in priority re-allocation, sacrificing a small number of high priority flows by re-allocating lower priority can lead to stable high performance for all others.

4.4 Dynamic Flow Arrival

In order to illustrate how this scheme works for dynamic flow arrivals, we simulated a simple scenario with EDCF as the scheduler. In this scenario, a flow of rate 600Kbps (we call it "main flow") starts at time *t*=1sec and lasts until *t*=101sec. Then from t=5sec, every 10 seconds, packets of flows with rate of 200Kbps (we call it "disturbing flow") arrive and the duration of each flow is 15 seconds. The reservation capacity is set to 800Kbps. The throughput of the main flow over time is shown in Figure 17. It can be seen that with reservation, 92.8% of the demanded rate of main flow is received. However, without reservation, this figure is only 72.7%.

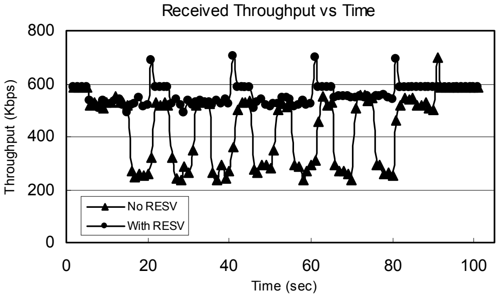

Figure 17. Received throughput of the main flow

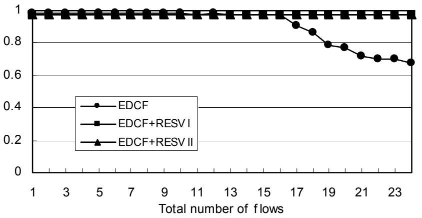

Figure 11. Normalized throughput

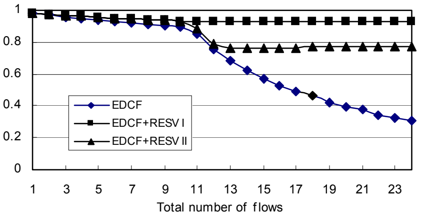

Figure 12. Average normalized throughput

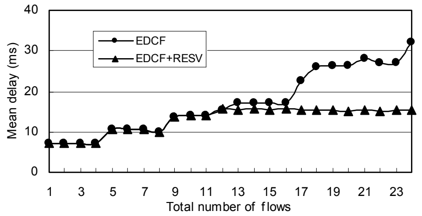

Figure 13. Mean delay

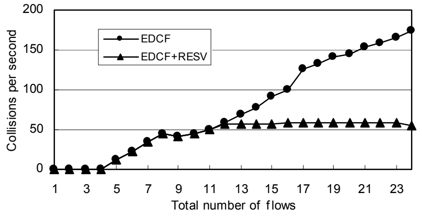

Figure 14. Collision rate

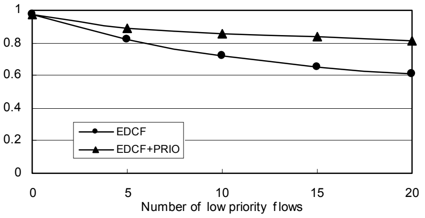

Figure 15. Average Normalized throughput of high priority flows

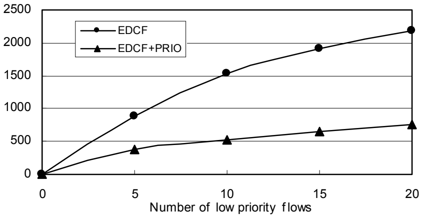

Figure 16. Number of dropped packets

Table 3 gives the statistics about the throughput comparison of EDCF and EDCF+RESV. With reservation, although 50% of the disturbing flows are rejected, their total received throughput is only reduced by about 24%. However, the throughput of main flow is increased by around 28% and the overall throughput is increased by around 15%. Since we focus on the QoS guarantee of the main flow, this performance degradation experienced by disturbing flows is actually paid off. Therefore, reservation effectively avoids serious degradation of the main flow.

Table 3. Throughput results of dynamic flow arrivals

Throughput (Kbps)	No RESV	With RESV
Overall Throughput	578.5	663.6
Main Flows	436.24	557.36
Disturbing Flows	922	700.5

4.5 Control over Misbehaving Flows

Because of the scarcity of the bandwidth in wireless networks, misbehaving users should be effectively handled to ensure the stable performance. Note that misbehaving users may or may not be authorized. Here, we focus on authorized users who abuse priority setting by requesting much higher service class than necessary. With our proposed priority re-allocation algorithm, only minimum amount of work is needed to deal with this situation. If a flow is found on abusive priority setting by checking its QoS requirements, its priority can be modified appropriately according to Table 1, or the flow can be punished by assigning it a very low priority. Even if it's not possible to distinguish misbehaving flows and honest ones (scenario in section 4.3), a new flow's priority may still be re-allocated such that the presence of a misbehaving flow does not necessarily affect the overall performance of the network. Therefore, misuse of flow priority can be easily handled by our priority re-allocation algorithm.

5. CONCLUSION

In this paper, a flow reservation and admission control scheme for distributed scheduling strategies in IEEE802.11 wireless LANs is presented. As a part of our admission control strategy, a priority re-allocation algorithm is proposed for QoS guarantee of priority based schedulers such as EDCF. With this algorithm, misuse of flow priorities can be handled with minimum work. Also, in our scheme, resource reservation of peer-to-peer communication session is supported. Our reservation scheme does not modify the underlying MAC access mechanism. Therefore, it can be easily implemented to be compatible with the current IEEE802.11 standard. Simulation results show that with the proposed flow reservation and admission control scheme, the traffic load in the system is stable and reserved flows can continue to receive same quality of service once accepted, this is a very desirable feature.

We are currently working on the following topics:

- Investigation of measurement based approaches for bandwidth estimation with arbitrary schedulers.
- Integration of our scheme with standard RSVP protocol is also of our interest.
- Efficient flow reservation approach for Mobile Ad-hoc Network (MANET).

6. REFERENCES

[1] Anders Lindgren, Andreas Almquist and Olov Schelén, "Evaluation of Quality of Service Schemes for IEEE 802.11 Wireless LANs". In Proceedings of the 26th Annual IEEE Conference on Local Computer Networks, Tampa, Florida, pp. 348-351, Nov. 2001.

[2] I. Aad and C. Castelluccia, "Remarks on per-flow differentiation in IEEE 802.11". In EuropeanWireless 2002, Florance, Italy, February 2002.

[3] IEEE, "IEEE std 802.11 – wireless LAN medium access control (MAC) and physical layer (PHY) specification", 1997.

[4] Lamia Romdhani, Qiang Ni, and Thierry Turletti, "Adaptive EDCF: Enhanced Service Differentiation for IEEE 802.11 Wireless Ad Hoc Networks". IEEE Wireless Communications and Networking, New Orleans, USA, Vol. 2, pp. 1373 –1378, March 2003.

[5] M. Benveniste, G. Chesson, M. Hoeben, A. Singla, H. Teunissen, and M. Wentink, "EDCF proposed draft text", IEEE working document 802.11-01/13lrl, March 2001.

[6] M. Benveniste, "Tiered contention multiple access' (TCMA), a QOS-based distributed MAC protocol". The 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, Lisboa, Portugal, , Vol. 2, pp. 598-604, September 2002.

[7] Michael Barry, Andrew T. Campbell, Andras Veres, "Distribued Control Algorithms for Service Differentiation in Wireless Packet Networks". In Proceedings of IEEE INFOCOM, Vol. 1, pp. 582-590, April 2001.

[8] N. Passas, L. Merakos, D. Skyrianoglou, F. Bauchot, G. Marmigere and S. Decrauzat, "MAC Protocol and Traffic Scheduling for Wireless ATM Networks", ACM Mobile Networks and Applications Journal, Vol. 3, 1998.

[9] Nitin H. Vaidya, Paramvir Bahl, Seema Gupta, "Distributed Fair Scheduling in Wireless LAN". In Proceedings of ACM MOBICOM, Boston, MA, pp. 167-178, August 2000.

[10] R. Braden, etc, "Resource Reservation Protocol (RSVP)-Version 1 Functional Specification", RFC 2205, September 1997.

[11] R. Yavatkar, etc, "SBM (Subnet Bandwidth Manager):A Protocol for RSVP-based Admission Control over IEEE 802-style networks", RFC2814, May 2000.

[12] Samarth H. Shah, Kai Chen and Klara Nahrstedt, "Dynamic Bandwidth Management for Single-hop Ad Hoc Wireless Networks". In Proceddings of 1st IEEE International Conference on Pervasive Computing and Communications, Dallas-Fort Worth, Texas, pp. 195-203, March 2003.

[13] W. T. Chen, Yu-Ming Lin, and Shou-Chih Lo, "Priority-Based Contention Control in IEEE 802.11 Wireless LANs". In 16th International Workshop on Communications Quality & Reliability, Okinawa, Japan, March 2002.