# End-to-end QoS Guarantee in Heterogeneous Wired-cum-Wireless Networks

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***ABSTRACT***— *With information access becoming more and more ubiquitous, there is a need for providing QoS support for communication that spans wired and wireless networks. For the wired side, RSVP/SBM has been widely accepted as a flow reservation scheme in IEEE 802 style LANs. In this paper, we investigate the integration of RSVP and a RSVP-like flow reservation scheme in wireless LANs, as an end-to-end solution for QoS guarantee in wired-cum-wireless networks. We propose WRESV, an RSVP-like flow reservation and admission control scheme for IEEE 802.11 wireless LAN. Using WRESV, wired/wireless integration can be easily implemented by cross-layer interaction at the Access Point. Main components of the integration are RSVP-WRESV parameter mapping, and the initiation of new reservation messages, depending on where senders/receivers are located. In addition, we also propose various optimizations for supporting multicast session, mobility management, and admission control.*

**Keywords**: Interoperability, Flow Reservation, QoS, IEEE 802.11, RSVP.

## 1 INTRODUCTION

IEEE 802.11 wireless LANs are being successfully used as the last-mile technology in the present-day pervasive computing environments. In many instances, mobile users access/exchange information in wired networks. Considering that information being accessed or exchanged comprise multiple media formats, supporting QoS across wired and wireless networks becomes important. While the QoS support has been extensively studied in wired networks, current IEEE 802.11 standard does not support QoS very well. This makes end-to-end QoS guarantee of wireless Internet quite challenging. Although many optimizations have been proposed to improve QoS support by providing service differentiation in IEEE 802.11 wireless LANs, they have two major disadvantages. First, most schemes do not provide explicit flow reservation and admission control. Without this, it is impossible to guarantee QoS of real-time flows when network traffic becomes heavy. Second, most schemes only consider QoS support in WLAN and are not interoperable with QoS schemes in wired networks. These two disadvantages make existing QoS schemes incomplete and inefficient in practice. Better schemes that provide flow reservation and seamlessly integrate with wired QoS schemes will gain more popularity.

RSVP/SBM has been widely accepted as a reservation scheme for flow reservation in IEEE 802 style LANs to support Integrated Service (IntServ). However, in IEEE 802.11 wireless LAN, no such flow reservation and admission control scheme exists. A good idea would be the integration of RSVP in wired infrastructure and RSVP-like flow reservation protocol in wireless LAN. Advantages of this approach are: (1) Reservation based schemes can provide better ensured QoS guarantee than service differentiation. [1] (2) Choosing RSVP-like flow reservation protocol in wireless LAN makes message mapping between itself and RSVP more efficient. (3) The message mapping is only needed at the access point, which has more computational power. (4) The overhead of the integration can be minimized by cross-layer interaction between MAC layer and IP layer.

In this paper, we propose Wireless Flow Reservation Protocol (WRESV), an efficient RSVP-like flow reservation and admission control scheme for QoS guarantee in IEEE 802.11 wireless LAN. Because of the overhead of signaling and higher link error in wireless LANs, this scheme is designed as a light-weighted version of RSVP. With the integration of WRESV and RSVP, end-to-end quality of service can be guaranteed. The major components of this integration are RSVP-WRESV parameter mapping, and initiation of new reservation messages at the boundary of the wired and wireless network, depending on the location of the sender/receiver. In addition, various optimizations are proposed on supporting multicast session, mobility management, and admission control.

This paper is organized as follows. Section 2 reviews the related work. Section 3 briefly introduces the proposed WRESV. Section 4 discusses the details of the protocol integration between WRESV and RSVP. Section 5 discusses the integration with Differentiated Service and Section 6 concludes this paper.

## 2 RELATED WORK

Integrated Service (IntServ) model [1] is proposed as an extension of Internet architecture to support real-time as well as non-real-time applications of current IP network. The major components of the framework to implement IntServ are the packet scheduler, the admission control routine, the classifier, and the resource reservation setup protocol. As the most popular resource reservation setup protocol, resource ReSerVation Protocol RSVP [2, 3] is designed to meet the requirements of IntServ model in multicast, heterogeneous network environment. Further, Subnet Bandwidth Manager (SBM) [3] is proposed for RSVP-based admission control in IEEE 802-style networks. Finally, a framework [4] is designed to support IntServ over shared and switched IEEE 802 LAN technologies.

Several admission control schemes have been proposed in order to guarantee QoS in wireless LANs. Barry et al. [6] propose a Virtual MAC algorithm that passively monitors the channel by using virtual MAC frames and estimates local service level (i.e. throughput and delay) by the measurement of virtual frames. Valaee and Li [8] propose another measurement based admission procedure using a sequence of probe packet for ad hoc networks. Instead of using probe packets, Shah et al. [7] propose a measurement based admission control scheme using data packets to measure the network load. Banchs and Pérez [5] propose ARME, an extension of DCF, that uses a token bucket based algorithm to detect whether the network is in a overloaded condition, and thus improve the performance of system by adjusting contention appropriately. All these schemes only consider the QoS guarantee within wireless networks and no attempt is made for the more challenging problem of supporting QoS over wired-cum-wireless networks.

In recent years, cross-layer interaction [7][15] has gained more attentions for protocol design in wireless network because of its efficiency. In these protocols, cross-layer interaction is implemented for different layers to share same useful information such as flow characteristics, node location and network topology so that they can cooperate closely to meet applications' QoS requirements.

Integrating Differentiated Service (DiffServ) [10] with IEEE 802.11 WLAN has been studied. Park and Kim [12] propose a QoS architecture between DiffServ and IEEE 802.11e [11] by mapping priorities with IEEE 802.1D/Q. In order to support QoS and Mobility for wireless Internet, Antonio and Rousseau [16] present a hierarchical QoS architecture to extend DiffServ to WLANs with flexible mobility management. Regarding integration with RSVP, Shankar and Choi [13] propose a MAC-level QoS signaling for IEEE 802.11e WLAN and addresse its interaction with RSVP and SBM. However, this approach is based on centralized Hybrid Coordination Function (HCF) with a complex signaling procedure.

In [9], we proposed a general flow reservation and admission control scheme for QoS guarantee in IEEE 802.11 wireless LANs. This scheme can work with most existing scheduling strategies such as DCF, EDCF, and DFS [20] seamlessly. In this scheme, a simpler request/response pattern for flow reservation and admission control was adopted in the aim of providing soft-QoS guarantee in wireless LANs.

## 3 WRESV – WIRELESS LAN FLOW RESERVATION PROTOCOL

RSVP [2] is designed to provide integrated service for packet-switched network such as IEEE802.3. However, several issues need to be considered on the design of signaling protocol in WLANs. For example, the frame length of the reservation messages should not be too large to avoid high collision rate. Also, complexity of explicit signaling should be reduced such that the overhead of extra packets is the minimum. Therefore, directly applying RSVP in WLAN is not an appropriate approach. Since each wireless station does not have global information of the WLAN, a Wireless Bandwidth Manager (WBM) is used in our approach for admission control and flow reservation. Before data transmission, every high priority mobile station must send its QoS requirements to the WBM, which will accept/reject the requests according to the availability of the bandwidth in the wireless LAN. Our approach is based on the scheme proposed in [9]. For convenience, we call this proposed flow reservation scheme in IEEE 802.11 WLAN Wireless LAN Flow Reservation Protocol (WRESV).

In our approach, we adopt explicit signaling for request/response reservation messages. The frame formats for the flow reservation request and response messages are designed in Figure 1 and Figure 2, 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. In addition to the request and response message, we define ERROR message, which just indicate whether the bandwidth requirement of a flow can be granted.

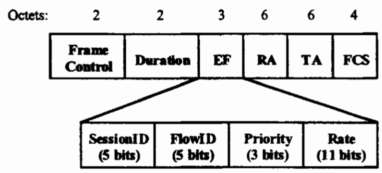


Figure 1. Frame format of flow reservation request

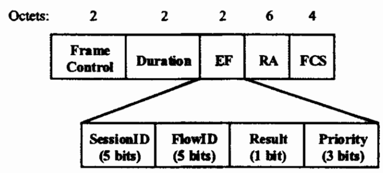


Figure 2. Frame format of flow reservation response

The flow reservation procedure of WRESV works as follows. Before transmitting RTS, each flow sends its traffic information (embedded in REQUEST message) 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, the 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, the sender it notifies AP, which will remove it from the reserved flow list.

## 4 RSVP/WRESV INTEGRATION

The architecture of wireless Internet is depicted in Figure 3. Mobile Hosts (MHs) can roam between different broadcast regions (cells), which are connected to a wired backbone (infrastructure). The wired infrastructure can be an IEEE 802 style Ethernet LAN or other IP network, and it is connected to Internet through a gateway router. Wired and wireless networks are inter-connected via Access Point (AP), or base station, which is capable of both wired and wireless routing. All MHs within a cell can only access the infrastructure through AP. Due to the node mobility, end-to-end QoS guarantee in the context of wireless Internet also means that if a MH moves between different cells, its bandwidth should be allocated in the new cell and freed from the old cell, making the end-to-end QoS guarantee even more challenging.

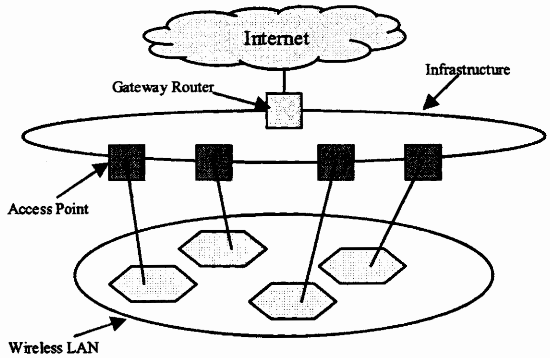


Figure 3. Architecture of Wireless Internet

In WRESV, it is assumed that all MHs are within the broadcast region of the AP (If two MHs can sense each other, packets are sent directly to each other without being relayed through AP). If a self-organized ad hoc network is attached to the wired infrastructure through the AP, in order to make bandwidth reservation, a MH may have to send RESPONSE message to AP with several hops, incurring larger signaling overhead and higher probability of reservation failure due to the considerable wireless link error. Therefore, our model is more appropriate for infrastructure based WLANs. QoS for Mobile Ad Hoc Networks (MANETs) is more related to routing issues and thus out of the scope of this paper.

RSVP is the leading standard for implementing IntServ over Internet. And, SBM is applied to support reservation of LAN resources for RSVP-enabled data flows and operations of RSVP-enabled hosts/routers and switches/bridges. Hence, flow reservation in the wired network can be managed by RSVP/SBM. For the wireless side, WRESV can work as the framework for making flow reservation and enforcing admission control. Therefore, our main work focuses on the interoperability of wired and wireless network, i.e., the integration of RSVP/SBM and WRESV. Some other IP reservation protocols (e.g., ST-II [19]) contain some other noteworthy architectural differences from RSVP such as the use of hard-state and sender-initiated reservations. However, we focus on RSVP only and we believe that the design issues discussed in our approach are general and thus applicable to the integration with other protocols too.

### 4.1 End-to-End Reservation

As a receiver-initiated protocol, RSVP has primarily two messages, i.e., Path message and Resv message. Firstly, Path message is sent from a sender to receivers for the purpose of installing reverse routing state in each intermediate router along the path and providing sender-specific traffic characteristics. With information carried in the Path message, receivers can initiate reservation requests by sending Resv message. On the other hand, WRESV is a sender-initiated protocol, leading to difficulties of straightforward integration with RSPV. However, it is noted that in WRESV, AP is actually the proxy of all receivers in the same cell. Then, the RESPONSE message can be thought of as from the receivers (or from proxy of receivers), which is similar to Resv message in RSVP. With this analogy, good matches can be made between the reservation messages of Path/Resv of RSVP, and REQUEST/RESPONSE of WRESV, respectively. Therefore, WRESV is basically a light-weighted version of RSVP in IEEE 802.11 wireless LANs.

The end-to-end reservation setup procedures for downlink (wired-to-wireless) and uplink (wireless-to-wired) flows are depicted in Figure 4 and Figure 5, respectively. Since admission control decisions of MHs are delegated by WBM, reservation setup procedures for uplink and downlink flow work differently and they are described in detail as follows.

(1) Downlink (Sender is in wired network)

When RSVP_Path message from the sender arrives, AP needs to enforce admission controls for both WLAN and wired network. Based on the available bandwidth of the wireless channel (with the admission control algorithm proposed in WRESV), WBM admits the flow by allocating bandwidth for the flow, or rejects the reservation because of the unavailability of the resources. If the flow can not be satisfied in WLAN, AP just gives up the reservation. Otherwise, AP checks whether the outgoing link supports the requested rate. AP initiates reservation request and sends RSVP_Resv to the sender only when admission controls in both WLAN and wired network succeed. If all the intermediate routers along the path from AP to the sender approve the reservation, sender sends RSVP_ResvConf back to AP, indicating the success of the whole reservation procedure. If RSVP_ResvConf has not been received after a certain time period, AP times out and frees the bandwidth allocated to the flow. An interesting feature of this procedure is that since WBM delegates all admission control decisions for MHs in the same cell, no extra overhead is actually put to wireless receivers, making the protocol efficient.

(2) Uplink (Sender in Wireless Network)

When WRESV_REQUEST message from the sender MH arrives at AP, AP maps the necessary information in WRESV_REQUEST and sends RSVP_Path to wired receivers, along the path selected by a specific routing protocol. Due to some possible errors, RSVP_PathErr may be sent from receiver or an intermediate router to AP. In this case, no reservation request is received at the AP. After some time, AP times out and may send RSVP_PathTear message to the receiver to remove all the path states. Note that the reservation messages outside of the wireless LAN is processed by

RSVP/SBM agents located at intermediate routers. Thus, as far as AP's concern, it receives two messages, RSVP_Resv or RSVP_ResvTear, indicating the success or failure of the corresponding flow reservation in the wired network, respectively. AP then acts accordingly as follows. If a RSVP_Resv is received, WBM enforces the admission control in the wireless LAN. If it is successful, AP maps the necessary information in the reservation message and sends WRESV_RESPONSE to the sender. At the same time, AP sends RSVP_ResvConf back to the receiver for the confirmation of the reservation. On the other hand, if WBM rejects the reservation in WLAN, AP sends WRESV_ERROR to the sender and also RSVP_ResvTear to the receiver to remove all the soft states stored in the intermediate routers as well as receivers in the wired network. The sender may try later after an unsuccessful flow reservation.

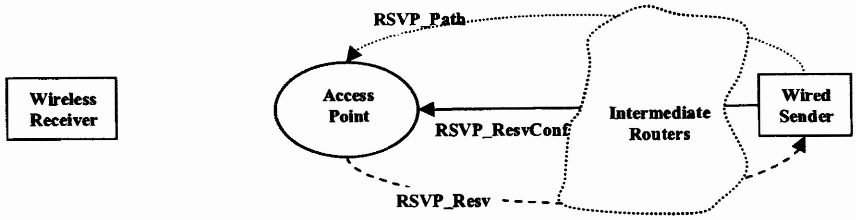


Figure 4. End-to-end reservation setup procedure of downlink flows

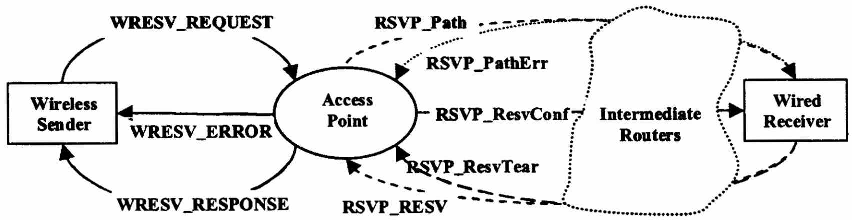


Figure 5. End-to-end reservation setup procedure of uplink flows

(3) Optimization for Uplink Reservation

An optimization, named *dual admission* technique, can be made for reservation of uplink flows. Upon receipt of the WRESV_REQUEST from a MH, WBM checks if the flow can be admitted immediately. If the reservation request cannot be supported in the WLAN, then it is not necessary to send RSVP_Path to the destination. On the other hand, if enough bandwidth is available in WLAN, there is still no guarantee that QoS requirements of the flow can be supported in the wired network. Therefore, reserving bandwidth for the flow at this time may take the risk of incorrectly denying future flows. However, it is still not safe to reserve bandwidth for a flow even after AP receives RSVP_Resv, i.e., the success of the reservation in wired network. WBM has to enforce admission control again to make sure that bandwidth availability does not change during the time interval between sending RSVP_Path and receiving RSVP_Resv at AP. Although certain overhead is involved in checking bandwidth availability, this technique can effectively avoid unnecessary signaling and thus saves wireless bandwidth.

## 4.2 Support of Multicast Session

A very desirable feature of RSVP is support of multicast session over Internet. Therefore, it is very important that this feature is kept in the integrated protocol. Now, we discuss the following situations according to the locations of receivers of a multicast session.

(1) All receivers are in the wired network

If the sender is also in the wired network, then this multicast session can be taken care by RSVP/SBM alone. Otherwise, as discussed above, AP acts as the proxy for the wireless sender. Thus, all reservation requests from receivers are merged at AP and the WBM then enforces admission control according to the final merged reservation message. Since this merging is handled at the network layer by RSVP/SBM, the multicasting is actually managed by RSVP/SBM no matter where the sender is located.

(2) All receivers are in the wireless network

If the sender is also in the wireless network, then this multicast session can be supported efficiently with only one broadcast of each packet from the sender. Of course, the list of the receivers should be piggybacked with the broadcast message so that wireless stations that are not in the list will discard the packet.

If the sender is in the wired network, we propose the following optimization. AP records the list of receivers subscribing the same multicast sessions. For each such session, AP only reserves bandwidth (if admitted) for one subscriber. When AP receives data packets from the sender (the multicast session has been reserved successfully), instead of sending multiple flows to each of the receivers, AP simply piggybacks the receiver list in the data packet and broadcasts it.

(3) Some receivers are in the wired network, others are in the wireless network.

This situation is actually the combination of the previous two. Thus, we can classify the receivers and handle it accordingly with the methods discussed above separately.

In above discussion, if AP is the sender/receiver, then end-to-end reservation is established in either wireless side or wired side, depending on where the receivers are located. However, no cross-boundary integration is necessary.

4.3 Support of Node Mobility

In WLAN, MHs may leave one cell (home cell) and enter another cell (target cell), which is called "Hand-off". When a MH moves from less crowded cell to a more crowded cell, its QoS requirement may not longer be satisfied. Therefore, support of mobility in the context of QoS in WLAN imposes another important concern of when and whether to insert/remove a MH in the reservation list while it is moving. In this paper, we assume that MHs move infrequently and they do not move back-and-forth between two or multiple cells within a very short period of time. Also, we assume that a MH does not move to a target cell that can not satisfy its QoS requirements. The operation of hand-off in our reservation scheme works in following steps:

- Handoff Request
  Before moving to the target cell, a MH sends a handoff request to the AP of its home cell (home AP). Home AP then forwards the request and piggybacks the MH's QoS requirements to the AP of the target cell (target AP) through the wired infrastructure.
- Handoff Grant/Denial
  Upon receipt of the handoff request, target AP enforces admission control. If the MH's QoS demand can be met, then target AP sends back a success notification to home AP. Otherwise, a failure message is returned.
- Handoff Commit/Abort
  When home AP gets the notification from target AP on the acceptance of the handoff from target AP, home AP sends a message to the MH. The MH will take action according to the decision of the target AP. If the handoff request is granted, MH sends a *disassociate* message to home AP and sends an *associate* message to target AP. Then, home AP and target AP will remove and insert the MH in the reservation list, respectively. If the handoff request is denied, a MH has to stay in the home cell and may retry after later.

4.4 Admission Control Strategies

To extend flow reservation (such as RSVP) used in the Internet to wireless LAN, the success of the flow reservation largely relies on the accuracy and efficiency of the admission control decision at the wireless side. We proposed a general threshold-based admission control algorithm that is capable of working with any underlying MAC scheduling algorithm such as DCF, EDCF, and DFS. However, there are several problems with threshold-based admission control schemes. First, the fixed threshold can not exactly reflect the differences between different traffic characteristics. Second, when the network is reaching saturation status, adding/removing a flow may have dramatic influence on the performance of the system. Thus, if the threshold is not appropriately set, threshold-based admission control strategy may make incorrect decision on admitting a new flow.

4.5 Functionalities of Access Point

With integration, the wireless LAN can be viewed as a specially managed segment of the whole network. Within this segment, AP acts as the WBM that records all the bandwidth allocation information, delegates the requests/responses of MHs, manages node mobility, and enforces admission control as necessary. In WRESV, the admission control decision is made at the MAC layer, not the network layer. Therefore, message mapping is necessary for correct operations of the protocol. The functionalities that must be performed by AP are illustrated in Figure 6. Since the wireless part and wired part are connected at the IP layer, layer interaction only exists between wireless IP layer and IEEE 802.11 MAC layer in order for both parts to be aware of QoS characteristics of flows to be reserved. Therefore, standing in the center of the functionalities of AP is the cross-layer interaction, i.e., message mapping between IP layer and MAC layer in wireless network.

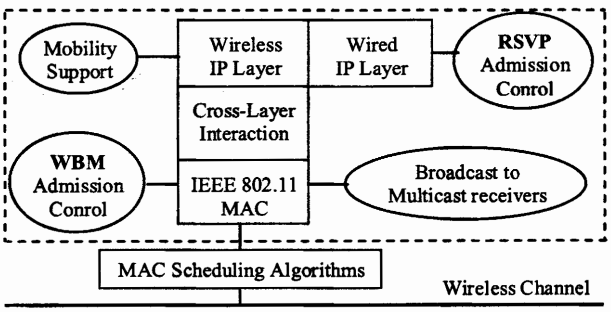


Figure 6. Functionalities of Access Point.

4.6 Message Mapping at Access Point

As discussed in section 4.1, in the case of uplink flow reservation, two message mappings are needed, i.e., WRESV_REQUEST to RSVP_Path, and RSVP_Resv to WRESV_RESPONSE. Since WRESV is essentially a MAC layer protocol and RSVP is a network layer protocol, it is necessary to pass information between these two layers. This message mapping, termed *cross-layer interaction*, makes integration of protocols residing on different layers much easier and more efficient. For our integration, the parameters that need to be shared by cross-layer interaction are source address, destination address, flow id or session id, flow rate, and flow priority. In addition, parameters in RSVP messages and WRESV messages should be mapped in order to initiate new reservation messages at AP in uplink directions. Basically, the mapping from WRESV_REQUEST to RSVP_Path goes one layer up from MAC layer to network layer, while mapping from RSVP_Resv to WRESV_RESPONSE goes one layer down from network layer to MAC layer. The two different parameter mappings between messages are shown in Table 1 and Table 2, respectively.

Table 1. Downlink parameter mapping

| Fields in WRESV_REQUEST | Fields in RSVP_Path |
|---|---|
| Flow Rate | Token Bucket Rate |
| Flow ID | Session ID |
| Flow Priority | User_Priority (TCLASS) |

Table 2. Uplink parameter mapping

| Fields in RSVP_Resv | Fields in WRESV_RESPONSE |
|---|---|
| Rate (FLOWSPEC) | Flow Rate |
| Session ID | Flow ID |
| User_Priority (TCLASS) | Flow Priority |

In Table 1 and Table 2, the user priority value is useful when the underlying 802.11 MAC scheduler is priority based, such as EDCF. For EDCF to work properly in end-to-end context, we must map the user priority value of a flow to EDCF MAC priority such that EDCF can correctly differentiate flows by their priority. This priority mapping can be handled by IEEE 802.1p [17] according to Table 3.

Table 3. 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 |

## 5 INTEROPERABILITY WITH DIFFSERV

Integration of WRESV and DiffServ is straightforward, and this integration is not necessarily to be limited to EDCF as underlying MAC scheduler. However, WRESV is essentially a reservation-based scheme and is closely matched with IntServ. In order to work with DiffServ smoothly for end-to-end service differentiation, similar flow discrimination schemes should be deployed in WLAN. Therefore, for DiffServ, WRESV might not be an ideal candidate for integration.

However, simple priority mapping may lead to failure of QoS support for EDCF. Li and Prabhakaran [14] study the performance of EDCF under high traffic load and propose a priority re-allocation scheme for better quality of service guarantee. Here, the idea is to reallocate users' priority appropriately so that better control on the guarantee of QoS support can be provided in coordination with priority based MAC schedulers.

## 6 CONCLUSION

Wireless users accessing Internet often require QoS guarantees from both the wireless and wired network. To address this issue, we propose to integrate the widely accepted RSVP and the proposed scheme WRESV, a general flow reservation and admission control scheme in IEEE 802.11 wireless LANs. The proposed integration scheme considers both the features of RSVP as well as the characteristic of wireless medium and it can efficiently support multicast session as well as node mobility. With cross-layer interaction, overhead of message mapping at the boundary of the wired and wireless network is significantly reduced. Implementation and performance evaluation will be our future research work.

The success of end-to-end flow reservation scheme largely depends on the accuracy and efficiency of admission control strategies in wireless networks. In WRESV, we proposed a general threshold-based admission control algorithm in MAC layer. However, static threshold-based algorithm cannot correctly reflect the traffic load of the system when the network is in quasi-saturation status. Note that admission control in wireless network is itself an important issue to be further studied.

Although we focus on extending IntService to wireless LAN, WRESV can be easily integrated with Differentiated Service also. Currently, we are working on better priority re-allocation strategies in IEEE 802.11e wireless LANs.

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