

# Supporting of QoS and Micro-Mobility in MPLS-based IPv6 Wireless Networks

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**Abstract:** MPLS has allowed us to add connection-oriented capabilities over Internet. In addition to this, by reading only the label rather than the entire IP packet, routers are able to achieve higher forwarding speeds. Supporting mobile users in MPLS-based wireless networks and its various derivatives is quite a new subject, still in the research stage. Several schemes to support mobility in MPLS (e.g. H-MPLS) have been proposed to further support better performance of mobile users. However, the Quality of Service (QoS) issue within the concept of MPLS and wireless networks has not been discussed. In our paper, we propose a new network architecture (QoS-MPLS) that can support both QoS and mobility within the MPLS framework. A Gateway Router (GWR) is used as the edge node of local domain instead of the concept of Foreign Domain Agent (FDA). A Central Location Management Server (CLMS) is introduced to administer the location information of those roaming mobile users. This can free the responsibility of the Gateway Router to become a generic, connecting the outside networks to the local domain. Utilizing the Class of Service (CoS) field in the MPLS header, QoS can be supported with mobility. Multiple LSPs can be established for the same destination mobile host in order to accommodate applications with different QoS requirements. Our approach can deal with multiple flows destined to the same mobile host instead of one LSP for all.

## 1. Introduction

Wireless communications has become one of the fastest growing technology sectors. This growth is exemplified by the appearance of many devices requiring wireless connectivity, such as PDAs, sensors, actuators, video-audio systems etc. Wireless network gradually becomes the universal access network, pushing wired networks mostly to a backbone role.

MPLS [1][2] has been proposed to provide end-to-end connectivity through fast forwarding of IP packets by means of label switching. It integrates the key features of both Layer 2 and Layer 3 and becomes one of the preferable solutions over modern backbone networks. However, conventional MPLS does not support mobility. Therefore, Mobile MPLS [3] was proposed to combine the advantages of Mobile IP [4] and MPLS protocols in

the mobile environment. The scalability of Mobile IP data forwarding process [3] is also improved in this integration. However, as Mobile IP mainly handles macro-mobility scenarios, such as moving from one domain to another, the integration of MPLS with Mobile IP does not provide satisfactory results when frequent handoffs occur. Recent wireless networks show the tendency of reducing the cell size in order to allow higher system capacities [5]. This type of network architecture dramatically increases the handoff rate of a Mobile Host (MH). The H-MPLS fast handoff scheme [6], MM-MPLS [5] and other mobility-supporting approaches [7][8][9] have been proposed to handle this scenario. These approaches address the fast handoff issues, yet we find them lacking the capability of support QoS.

In this paper, we propose a new MPLS-based network architecture, capable of providing QoS and micro-mobility support to wireless mobile users. We introduce the concept of the Gateway Router (GWR), which is used as the edge node of the local domain instead of the concept of Foreign Domain Agent (FDA) [5][6][8] or Gateway Foreign Agent (GFA) [7]. A Central Location Management Server (CLMS) is introduced to administer the location information of those roaming mobile users. This frees the Gateway Router from the responsibility of maintaining all location information of the roaming user and becomes a generic bridge, connecting outside networks to the local domain. In our approach, we assume the Internet is using IPv6 [10], by which the infamous “triangle-routing” can be avoided by applying bigger address size (128 bits) and other features in IPv6. We also utilize CoS field (3 bits) in the MPLS header to provide various QoS levels (two levels: High Priority (HP) and Best Effort (BE) in our simulation). Priority queuing schemes is be applied to the buffered packets at GWR, intermediate Label Switch Routers (LSRs) and Foreign Agents (FA) according to the COS settings in order to enhance the QoS performance.

The rest of the paper is organized as follows. In Section II, we briefly review the principles of MPLS and several proposals that support mobility and/or QoS. The new network architecture for supporting QoS and mobility in MPLS-based wireless networks (QoS-MPLS) will be described in Section III. In Section IV, we provide simulation results, performance analysis and discussion. Conclusions of this paper are presented in Section V.

## 2. MPLS and Mobility Support

In MPLS, the incoming IP packets are assigned a “label” by a Label Edge Router (LER). Packets are forwarded along a Label Switch Path (LSP), where each Label Switch Router (LSR) makes forwarding decisions solely based on the contents of the label. At each hop, the LSR strips off the existing label and replaces it with a new label, which indicates to the next hop how to forward the packet. The MPLS header consists of the Label, Class of Service (CoS), S bit and Time to Live (TTL) four fields as shown in Figure 1. A Forwarding Equivalence Class (FEC) is used to make any set of packets able to be forwarded in the same manner through a network. It provides a “virtual path” for the data to flow to the destination.

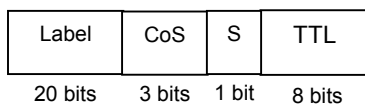


Figure 1.  
MPLS Header Structure

Several approaches [5][6][7][8][9] have been put forward to support mobility in MPLS-based wireless networks. In H-MPLS [6][8], the LSP between HA and FDA is unaffected from the user’s mobility. Another LSP from FDA to FA is set. Thus changes according to the current user location. When the MH handoffs from one FA to another, only this LSP will be replaced by another LSP from the FDA to the new FA. Hence, less LSP establishment processes occur. In MM-MPLS [5], a crossover LSR is defined as the LSR closest to the MH that is at the intersection of two paths, one between the FDA and the previous FA, the other between the FDA and the new FA. The Crossover LSR must be found and is responsible for switching the path from the old FA to the new one. In [7], Label Edge Mobility Agent (LEMA) has been chosen to handle localized mobility. In [9], the Gateway Foreign Agent (GFA) has similar functionality to that of FDA. When the MH moves to a neighboring cell, it performs regional registration and LSP re-routing, using partial LSP re-establishment. These approaches certainly provide possible mobility support to the wireless user in MPLS-based networks. However, most of them still consider networks that are based on Mobile IPv4, thus experiencing the “triangle routing”. All the packets from CN are directed first to HA then forwarded to MH via an LSP tunnel. The HA becomes an inevitable segment in the communication path between CN and MH. Moreover, not much attention has been paid to the support of QoS. Service differentiation has not been incorporated in the service of multiple flows destined to the same MH. In this paper, we define an MPLS network architecture that is based on IPv6 thus eliminating the “triangle routing”. Also, the CoS field in MPLS header is utilized to support service differentiation in MPLS-based wireless networks.

## 3. Supporting QoS and Mobility in MPLS

In this section, we propose a new MPLS-based network architecture to provide QoS and micro-mobility to wireless users. We named this approach as QoS-MPLS. In the approach described in [5][6][7][9], FDA or GFA is the only router the traffic to and from the MH goes through and is also the only point that represents the MHs to their home agents; if it fails, the mobility support is lost. It is only logic not to be placing all the tasks and information of the roaming user management to just one node. In our approach, we introduce a new management server, the Central Location Management Server (CLMS), which stores the information of all the roaming mobile hosts within the local domain. The edge node that links the outside networks to the domain is the Gateway Router (GWR). There may be more than one GWR in the domain. All GWRs are connecting to the central location management server to obtain current MH location information. The role of GWR is not that critical as compared to the FDA or GFA. If one GWR fails, the backup one can replace it and continue to function. More than one GWR means that one domain has more interfaces to the outside network. In addition to increasing reliability, it is also useful for the support of traffic balancing and traffic engineering task. Our proposed network architecture is shown in Figure 2.

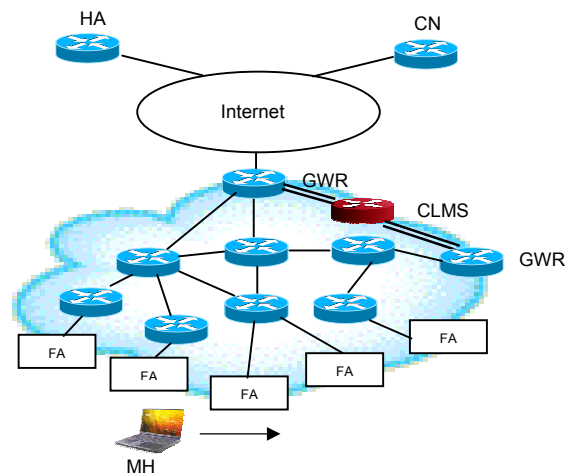


Figure 2.

QoS and Mobility Support MPLS-based Wireless Network Architecture

In H-MPLS [5][8], MM-MPLS [5] and LEMA [7], packets forwarded to the roaming MH are re-directed from the home agent (HA). This is inherited from the property of the Mobile IPv4 scheme and therefore introduces the infamous “triangle routing” – packets from a corresponding node (CN) are routed to MH’s HA first and then tunneled to the MH’s COA in the foreign domain. “Triangle routing” is undesirable because more network load is added on the HA, making it a potential bottleneck node. In the future, IPv6 is expected to become a dominant technology, pushing wireless Internet to a new era. In IPv6 header, the source address consists of 128 bits, which results in that addresses in IPv6 are

three times bigger than IPv4 addresses. In Mobile IPv6 [11], the only type of care-of address (COA) is the collocated care-of address. This benefits Mobile IPv6 and eliminates “triangle routing” by forwarding packets from CN directly to the COA of a MH connected to a foreign link. Based on these facts, we assume that in our network architecture when a MH acquires a temporary COA from any FA within the domain, that COA can be used uniquely throughout the entire domain to represent this roaming MH. Therefore, no more aggregated IP is needed to represent all MHs within in a particular FA.

### 3.1. MH Registration in Foreign Domain

The mobile host determines its current location (whether it is at the home domain or in a foreign domain) from the agent advertisement messages broadcasted by the FA. After determining it is in a foreign domain, the MH then acquires a temporary COA from the FA. A registration request message targeted to MH’s HA is sent to the FA first. Upon receiving the Registration Request from the MH, the FA will generate a unique COA for this MH by either “Stateful Address Auto-configuration” or “Stateless Address Auto-configuration” [11]. This COA will remain associated with the MH for the duration it stays inside this particular domain. The FA will forward this Registration Message to the GWR instead of the HA by using normal IP forwarding. The GWR understands that this is a Registration Request from a roaming user and sends its current location information to CLMS to create a new entry in the Location Management Table (LMT). Information such as the MH’s home IP address, current assigned COA in the domain, initial registration location, and current location are entered in the LMT. Then, the GWR forwards this Registration Request message to the HA of the MH. The HA gets the request and stores the current COA information of the MH in its management table for future use when a CN requests connection. When the MH goes into a new foreign domain, the same registration process will take place. The new COA will be sent to the HA in a Registration Request message, which has the same function with a Binding Update message [11] in Mobile IP. Therefore, the HA always knows the updated COA of the MH in a foreign domain and is able to provide this information to any CN that requests it. Since the COA is a universal routable IP address, the HA sends a Registration Reply message directly to this IP address. The message is then routed back to the GWR (not necessary to be the same one), which refers to the CLMS table for the MH’s current location information. Then, the GWR forwards the Registration Reply message to the FA where the MH is currently attached. When the FA receives the Registration Reply, it relays the message to the MH with the new COA and completes the registration procedure. As compared to H-MPLS and MM-MPLS, in our registration process, no LSP setup is involved, because we wish to leave the LSP setup be controlled by the QoS requirements.

### 3.2. MH Receiving Packets in Foreign Domain

When a CN needs to send packets to the MH, the CN first sends a Location Acquiring message to the home IP address of the MH, which is intercepted by the HA. If the MH currently is roaming in a foreign domain, the HA searches its management table and forwards the COA of MH to CN. Learning the current roaming IP address of the MH, the CN tries to establish a LSP between itself and the MH.

Based on the applications that CN is running and its QoS requirements, CN sends one or more Label Request towards MH’s COA. Note that we use not only MH’s home IP address but also the flow’s QoS service level as FEC in order to provide flexibility to set up different LSPs for different levels of QoS. In our approach, we categorize voice and video traffic as HP class and data traffic as BE class, associated with the CoS field in the MPLS label header. Since the COA is a routable IPv6 address, the message will be routed to the GWR first.

After referring to the CLMS, GWR is acquainted with the FA that MH is currently attaching to. Instead of forwarding all the Label Request messages through one route to the FA, GWR examines the nature of the application that need to establish the LSP first and carries on one of the following selection: 1) if the flow belongs to HP class, the GWR will select one of the routes towards the FA with less delay, according to the often updated LSP information stored in the GWR. 2) If it is a BE type of traffic, GWR will “randomly” select a route, but also trying to avoid jeopardizing the HP traffic on that route. In this way, Label Request message may be forwarded to the FA via different routes. On receiving these messages, the FA determines that this is a LSP setup process for an outside roaming user and decides to act on behalf of this MH. The FA then responds by sending a Label Mapping message along the same route towards the GWR. Then, the GWR relays this message back to the CN. When the message arrives at CN, an LSP between CN and FA is established with the MH’s home IP and QoS level as FEC, providing a seamless backbone transmission tunnel for the roaming MH. In the MPLS header of each packet, the CoS field is set to indicate the QoS level of this particular flow. If there are more than one flow with different QoS needs to be sent to MH, either from the same or different CNs, a different LSP may be established according to the QoS level of the application.

In H-MPLS, all traffic that goes to the MHs attached to the FA will travel in the same LSP without taking application’s QoS into consideration. Our approach supports more than one LSP to accommodate the flows towards a particular MH. Meanwhile, different MHs within the same FA may also have various routes to receive and/or send packets.

CN sends the flow of packets through LSP to the FA using normal MPLS label switching. After the FA receives the packet, it will look up its label table. Since it is the egress LSR of the LSP from the CN to the FA, the

label and outgoing port fields are empty. The FA then strips off the label from the packet and forwards the normal IP packet to the MH.

At each node (GWR, LSR and FA), two queues with limited buffer size are associated with incoming traffics for EF type and BE type of applications. Priority queuing scheme is applied. This is one step further to provide differentiated service among multiple flows.

The MH registration process and LSP establishing process are shown in Figure 3.

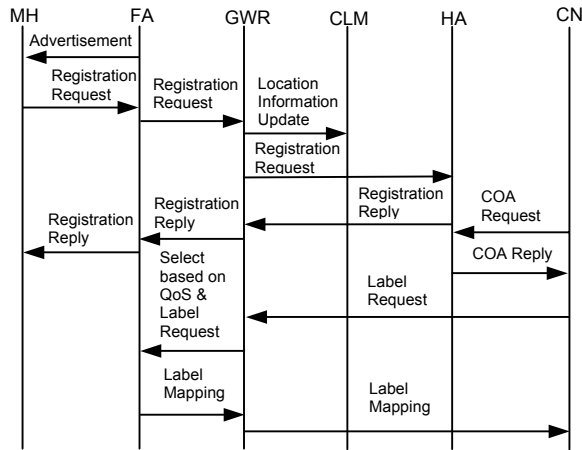


Figure 3. Registration and LSP Establishing Process in QoS-MPLS

### 3.3. Micro-mobility Handoff

As mentioned earlier, in order to expand the system's capacity, smaller size cells (micro-cells) are used in wireless networks. This generates more frequent handoffs to the mobile users. Many consequent QoS challenges also rise and need to be answered. We have an argument to make, as long as we keep it as a soft-handoff process, i.e. the data path (LSP) is established before the MH's handoff, a seamless handoff process still can be achieved.

In the previous work, how FA or MH determines to handoff has not been discussed clearly. Yet this is another important issue when wishing to provide QoS guarantees to mobile users. In our case we adopt the following approach on hearing a broadcasted advertisement from the neighboring FA, the MH compares the signal strength and quality and sends the measurement result to its current FA periodically. The FA analyses these results and determines whether the MH needs to handoff to the new FA. When the current FA decides that this MH should handoff, it first establishes a temporary path to the new FA with a timeout parameter (if no packet is transmitted on this route for a certain period of time, the route is torn-down automatically). This route does not have to be an LSP that relates to the route from CN to FA. It can be just a normal IP path since the packets in FA are already being stripped off the MPLS header and tend to be sent to MH via the IP layer. If it happens that this IP route cannot provide the same QoS as the flow requires, the application should drop the bandwidth consumption to a lower layer (e.g. eliminate one or more

of the enhancement layers). After this route is established, the current FA: 1) sends out notification to the MH informing it to handoff to the new FA, and 2) redirects the incoming packets destined for the MH to the new FA.

After switching to the new FA, the MH sends a new Registration Request message. As we mentioned above, the COA of the MH will remain the same as long as the MH remains within this domain. Therefore, there is no need to forward this message to the MH's HA. When the new FA sends the registration message to the GWR. When it notices that this is a micro-mobility registration update message, it updates the CLMS of any changes of the roaming MH status, including the current FA, where the HA is attached. Similar, the GWR needs to examine the QoS condition of available routes to select one that complies the original application's QoS requirements better and issues another Label Request message. As soon as this LSP is established, GWR sends back a Registration Reply message to the MH and switches from the old LSP path (going to the old FA) to the new LSP path (going to the new FA). Buffered packets in the old FA continue to flow to the MH while new packets arrive via the new FA. After the timeout of the route between old FA and new FA, the MH starts to receive packets only from the new FA. As we can see from the approach, though GWR is very important to the registration, MPLS packet forwarding and handoff manipulation, it does not store all the important information in itself. Hence, if this particular GWR fails, a backup one is very easy to replace it and maintain communication. The concept of CLMS helps a lot in this scenario. Both HA and CN do not need to be notified of the MH's mobility, therefore unnecessary signaling over the network is avoided. The process of the MH handoff from current FA to new FA is shown in Figure 4.

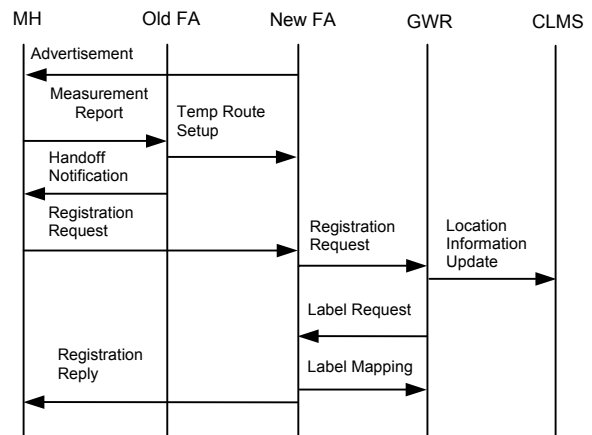


Figure 4. Handoff Process in QoS-MPLS

## 4. Simulations and Analysis

The simulation environment is implemented using OPNET [12]. Average mobile user application lifetime is 60s. Each user randomly moves within the 3 available

cells with an average residing time of 12s. To give sufficient time for mobile users traveling from cell to cell, each simulation was ran for the duration of 1200s. The number of mobile users varies from 40 to 70. The link bandwidth between GWR and LSR or between LSR and FA is 10Mbps. Buffer size for EF and BE class at GWR, LSR and FA are 20 and 500 packets.

We tested voice, video and data traffic in our proposed MPLS-based IPv6 wireless network. Each corresponding node is running one voice, one video and one data application with the mobile host. According to the nature of voice and video applications, they belong to the EF class traffic. Data is BE class traffic. The voice traffic is produced according to a three-state Markovian model [13], consisting of principle talkspurt, principle silence and mini silence periods. The talkspurt, principal gap, mini-talkspurts and mini-gaps have mean duration  $t_1$  (1s),  $t_2$  (1.35s),  $t_3$  (0.275s) and  $t_4$  (0.05s), respectively. Average talkspurt traffic is 32kbps. Voice packet size is set as 512bits. Video traffic comes from a H.263 trace file with variable frame size. The video frame is packetized as 12kb/packet before it is transmitted into the network. Average throughput of a single video source is 300kbps. A Poisson process with a mean arrival rate of 0.024s is used to produce data traffic with 12kbits of packet size.

We are comparing two scenarios: 1) H-MPLS with best effort service at each node. Single LSP is provides to accommodate all the traffic from one corresponding node. We denote this scenario as H-MPLS. 2) The network is capable of providing different LSPs from the GWR to a particular FA in order to accommodate QoS requirements of various application traffics from one CN. At each node in the MPLS network, differentiated QoS service are provided to treat EF and BE traffic. We can denote this scenario as QoS-MPLS. The simulation network architecture is shown in Figure 5.

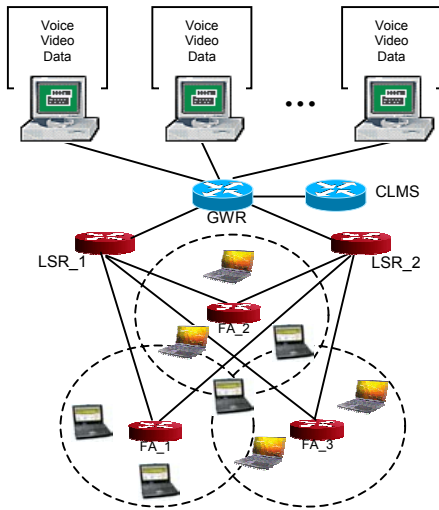


Figure 5. Simulation Network Architecture

As shown in Figure 6 and Figure 7, QoS-MPLS (flows to one MH may have more than one LSP to balance QoS requirements) can provide much better End-to-End (ETE)

delay performance to voice application as compared to H-MPLS with BE service. In H-MPLS, voice application is sharing the same LSP with video and data flows. In QoS-MPLS, different LSP may be offered to the EF class traffic (voice and/or video). These EF traffics do not have to go through the same LSP that data traffic travels to avoid potential delay caused by the BE traffic. Even when the number of mobile user reaches 70, ETE delay is less than 70ms in QoS-MPLS that satisfies the voice delay requirement.

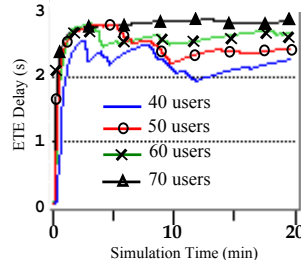


Figure 6. Voice ETE Delay in H-MPLS

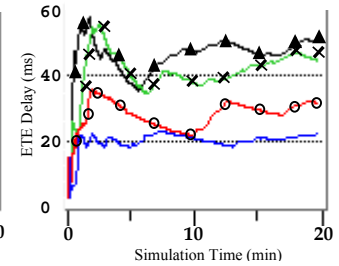


Figure 7. Voice ETE Delay in QoS-MPLS

Performances of voice total packet loss are shown in Figure 8 and Figure 9. Packet loss is due to buffer overflow, handoff, and time-out. Similar, QoS-MPLS can support more mobile hosts than H-MPLS because QoS-MPLS can provide more than one LSP to separate EF and BE traffic towards one mobile host. When there are 70 users moving within the network, more voice traffic experience longer delay and causes the EF buffer to overflow. Thus increases the packet loss rate.

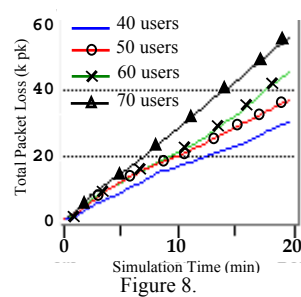


Figure 8. Voice Packet Loss in H-MPLS

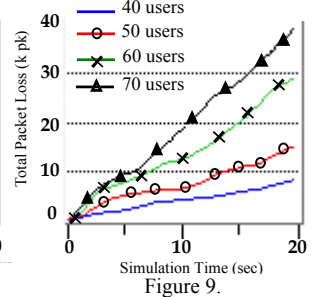


Figure 9. Voice Packet Loss in QoS-MPLS

Due to the nature of video application, it is treated as EF class traffic. Therefore, video packets are transmitted through the same LSP as voice packets for the same mobile host. According to Figure 10 and Figure 11, video packets experience similar ETE delay as the voice packets. In H-MPLS, average video ETE delay is 2.2s, 2.5s, 2.7s and 2.9s, respectively when the number of mobile host is 40, 50, 60 and 70. Obviously, the performance cannot support video application. QoS-MPLS, however, support ETE delay less than 65ms.

Video application is sensitive to both delay and loss. Therefore, in the simulation, video application belongs to EF class, which is further mapped to CoS in MPLS header. Similar to the performance of voice packet loss, video traffic experiences three types of packet loss, as shown in Figure 12 and Figure 13. QoS-MPLS offers

better packet loss performance than that of H-MPLS to loss-sensitive applications by allowing these traffics to go through another route than the BE class traffic.

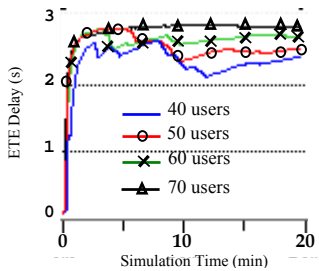


Figure 10.  
Voice ETE Delay in H-MPLS

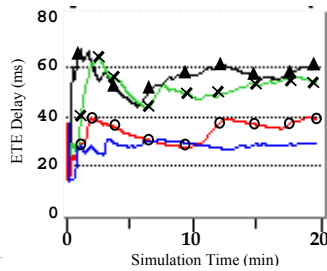


Figure 11.  
Voice ETE Delay in QoS-MPLS

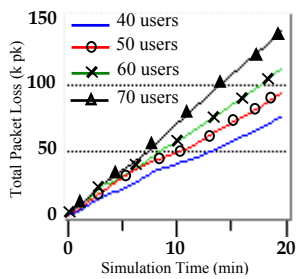


Figure 12.  
Video Packet Loss in H-MPLS

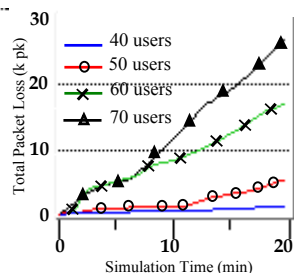


Figure 13.  
Video Packet Loss in QoS-MPLS

As compared to voice and video applications, data application can sustain longer delay. If use one LSP per mobile host, when serving data packets, other queued application packets will experience longer delays. By separating data traffic and categorizing it as BE class gives EF traffic more opportunities to be serviced before time out. Assigning lower priority to data traffic results in longer ETE delay (varies from 2.5ms to 150ms) as shown in Figure 14 and Figure 15. However, this will not greatly affect the performance of data traffic. As long as there is enough buffer size in the data queue at each node, less packet loss can be expected.

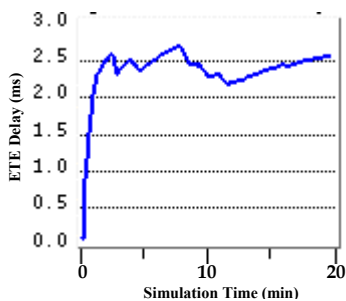


Figure 14.  
Data ETE Delay in H-MPLS

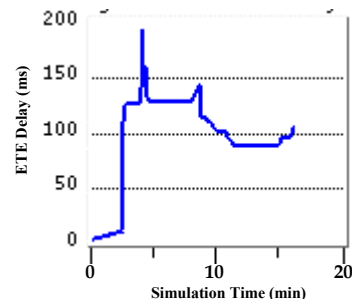


Figure 15.  
Data ETE Delay in QoS-MPLS

The throughput of data traffic decreases in QoS-MPLS. Given lower priority and buffered at each node for longer time, data packets are more likely to experience buffer overflow packet loss and result in the shrinkage of the average throughput.

From the simulation, we also evaluate hard handoff scheme (break-before-establish) and our soft handoff scheme in both H-MPLS and QoS-MPLS. It appears that as compared to the hard handoff, the soft handoff has appealing performance in that uplink handoff registration packets are sent as high priority packets. This is due to the concept of QoS-MPLS handoff that our scheme provides the seamless handoff that a data path is being established while MH still receives packets through the old FA. Voice and video applications do not lose much throughput when the MH handoffs in QoS-MPLS.

## 5. Conclusions

In this paper, we proposed a new network architecture (QoS-MPLS) that can support both QoS and micro-mobility to mobile users in MPLS-based wireless networks. Concepts such as Gateway Router, Central Location Management Server and integration with IPv6 have been introduced. The “triangle routing” problem is eliminated due to the adoption of IPv6 in our network architecture. This paper focuses on the issues associated with service differentiation by utilizing CoS field in MPLS header to map the QoS criteria. Multiple flows to the mobile host can be directed via different LSPs to accommodate their various QoS requirements. Priority queuing packet scheduling algorithm is integrated into the GWR, LSRs and FA to provide further support of QoS. A seamless soft handoff scheme is introduced to support micro-mobility in the MPLS networks and provides solution to QoS-related smooth handoff. Our proposed network architecture and procedure is a positive step to the direction of supporting QoS and micro-mobility in MPLS-based IPv6 wireless networks. Incorporation between our approach and macro mobility support (inter-domain) will be one of the future research topics. More advanced packet scheduling schemes [14] can be incorporated to support further QoS performance.

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