

Research Perspective on Mobile MPLS: A Brief Survey

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ABSTRACT

Mobile MPLS is the extension of MPLS (Multiprotocol Label Switching) for mobile environment. It can simultaneously benefit from both Mobile IP's mobility support and MPLS's quality of service support. These benefits are important to present and future mobile networks supporting mobile users' increasing demand for various Internet services on the go. This article surveys the current status on Mobile MPLS research. Several proposals of Mobile MPLS are reviewed and discussed. This survey gives a perspective view of current Mobile MPLS research.

Keywords : Mobile MPLS; Micro Mobile MPLS; Mobile IP over MPLS; Mobile IP; Multiprotocol Label Switching (MPLS);

1. INTRODUCTION

The tremendous growth in the number of mobile users in recent years has indicated the trend towards more demand for wireless and mobile technology in everyday life. The demand for services through mobile networks has evolved from common voice communication using plain mobile phones to various services on the Internet using smart mobile devices. As the Internet has become more and more ubiquitous, the trend towards all-IP in both wired and wireless networks has become obvious. A mobility protocol is an important component to support roaming mobile users in wireless networks, and Mobile IP [1] [2] is the most recognized mobility protocol used in IP networks.

As the Internet becomes more ubiquitous and the

Internet users become more mobile, the demand for various Internet services and applications on-the-go has also immensely increased. These Internet services and applications include email, web browsing, audio and video streaming, Internet phone, gaming, and real-time multimedia, which require different levels of quality of service (QoS). As mobile users demand for more of these services, it is important that the mobile networks must be able to provide an appropriate level of QoS for each of these services. Multiprotocol Label Switching (MPLS) [3], viewed as a QoS solution in IP networks, can be used in the mobile networks to deliver appropriate levels of QoS to mobile Internet users.

Due to the mobility support benefit of Mobile IP and the QoS support benefit of MPLS as described above, the integration of Mobile IP and MPLS [4] was proposed to take advantage of these benefits. Subsequently, there have been many proposals on Mobile MPLS variations. These variations of Mobile MPLS research works focus on various aspects of performance improvement, such as micro-mobility support, handoff latency reduction, and QoS improvement.

This article surveys the current status on Mobile MPLS research. Several variations of Mobile MPLS that have been proposed are studied and compared. The proposed simulator module for Mobile MPLS is also reviewed. And finally, the future direction on Mobile MPLS research is discussed.

The rest of this article is organized as follows. Section II provides a brief overview of Mobile IP and MPLS. Section III presents various proposals and research on Mobile MPLS. And Section IV concludes the article with some final remarks and future direction on Mobile MPLS research.

2. BACKGROUND

2.1 Mobile IP

Mobile IP [1] [2] is a standard protocol that supports mobility in IP networks. It enables mobile devices to maintain their continuous communications while they are moving from one network to another. Computers or devices communicating with a mobile device can send messages to the mobile device's home IP address without the need to know its new IP address in the new network that it is currently located. Supporting mobility in IP networks, Mobile IP is an important part of the mobile networks providing Internet access for mobile users. There are two versions of Mobile IP currently in use, which are Mobile IPv4 [1] and Mobile IPv6 [2].

The components of Mobile IPv4 include home agent (HA), foreign agent (FA), mobile node (MN), and correspondent node (CN). MN has a permanent address called home address in the home network. When it moves to a new network, MN will get a temporary address called care-of address (CoA) in that foreign network. When a CN wants to communicate with the MN, it will send packets to the MN's home address. If the MN is not in the home network, HA will intercept the packets and send them to MN in the foreign network through IP tunnel between HA and FA. Mobile IP helps make the movement of MN transparent to CN. While MN can send the packet directly to CN, the packets from CN must always pass through HA before reaching MN, which causes inefficiency problem called triangle routing. To overcome this problem, route optimization in Mobile IP was proposed in [5], which still has some drawbacks for allowing CN to track the MN movement violating the original goal of Mobile IP as well as causing security problem in authenticating information of the MN's current location.

The components of Mobile IPv6 are similar to those of Mobile IPv4 except that FA is not a necessary component. Furthermore, Mobile IPv6 is a part of IPv6 protocol, and it uses next header options to send all Mobile IPv6 control messages with existing IPv6 packets, while Mobile IPv4 uses separate UDP packets for each control message. Additionally, route optimization support is built-in as an integral part of Mobile IPv6 instead of an added extension as in Mobile IPv4.

2.2 Multiprotocol Label Switching

Multiprotocol Label Switching (MPLS) [3] is a networking technology that forwards packets based on labels instead of destination IP addresses as in normal IP routing. MPLS works in between layer 2 and layer 3 of the OSI model. Labels in MPLS headers located between layer 2 and 3 headers will be used in the packet switching process. MPLS network comprises MPLS-capable

routers called label switching routers (LSRs). The LSRs at the edge of MPLS network are called label edge routers (LERs). The protocol used to distribute labels from an LSR to its neighbors is called Label Distribution Protocol (LDP). The mechanism of MPLS will create label switched path (LSP) for each forwarding equivalence class (FEC). Generally, FEC classification will be based on the destination address. However, FEC can also be classified according to other additional conditions, such as policies and traffic classes. Hence, MPLS can be used for traffic engineering as well as to support QoS in IP networks. MPLS is initially used in core networks. However, with the increasing need for delivering QoS to mobile users, using MPLS in access mobile networks is also beneficial in providing QoS to mobile users.

3. VARIATIONS OF MOBILE MPLS RESEARCH

3.1 The Integration of Mobile IP and MPLS

The interest in using MPLS as a forwarding scheme for Mobile IP has arisen from MPLS's scalability and QoS support. The work in [4] proposed the integration of Mobile IP and MPLS by using MPLS label switching along LSP, instead of IP-in-IP tunneling, in the packet forwarding process from HA to FA. The packet forwarding is done by looking at MPLS labels without the need to go up to the IP header. Because label headers are much smaller than IP headers, the traffic overhead from HA to FA is also reduced.

The Mobile MPLS in this research operates by having FA and HA working as LSR at the edge of the MPLS network. When MN has found that it is currently in a foreign network, it will register with the local FA located in that area. The FA will then forward the registration to the HA by normal IP routing, and wait for LDP Request back from the HA. After the HA has already updated the MN Binding information, it will send LDP Request to the FA, and the LSP between the HA and the FA will be established. Subsequently, packets from CN destined to MN will be received by the HA and will be forwarded to the FA by label switching along the LSP. When the FA has received the packets, it will then forward them to MN using normal IP routing.

The scheme proposed in [4] as described above has improved the scalability of Mobile IP and supports macro-mobility in MPLS network. However, it is not efficient to support micro-mobility concerning frequent movements which require short handoff delay.

3.2 Mobile MPLS : Micro-mobility Improvement

This subsection explains some of Mobile MPLS research works focusing on handoff performance and micro-mobility improvement.

3.2.1 Hierarchical Mobile MPLS

Hierarchical Mobile MPLS [6] is proposed to improve [4] to be hierarchical in order to improve handoff performance. The hierarchical structure is added to the work in [4] by including Foreign Domain Agent (FDA) into each MPLS domain to work as an agent of all FAs in that domain in communicating with HA. The FDA operates as a gateway of each domain. When an FA within a domain needs to communicate with HA, it will have to do this through the FDA of that domain. However, when MN has moved to a new FA within the same domain, the update signaling will only be sent to the FDA without the need to contact with HA. In this manner, the added hierarchy helps reduce the distance and the amount of update signaling in the network, and consequently reduce handoff latency.

3.2.2 FH / FC / MFC Micro Mobile MPLS

To overcome the limitation of [4] that only supports macro-mobility, Micro Mobile MPLS [7] is proposed to improve the original Mobile MPLS to efficiently support micro-mobility by using the idea of Mobile IP Regional Registration (MIP-RR). In Micro Mobile MPLS, the hierarchical structure is added by including one LER/Gateway (LER/GW) into each MPLS domain. When a mobile node has moved into an MPLS domain for the first time, it will register with the HA by using LER/GW address as its CoA. Subsequently, when the mobile node has moved to the new FA within the same domain under the same LER/GW, it will only need to regionally register with the LER/GW using the new FA as its new local CoA, and then the LSP from LER/GW to the new FA will be established as a path for sending packets between LER/GW and FA. New registration with the HA is not necessary for the intra-domain movement. The mobile node will need to register with its HA only when it has moved to a new MPLS domain.

Later the authors have improved their Micro Mobile MPLS and subsequently published many articles on the topic [8]-[10]. The latest work [10] explained in details the operations of three mechanisms, namely, Fast Handoff (FH), Forwarding Chain (FC), and Master Forwarding Chain (MFC) Micro Mobile MPLS. Analytical models and simulation results indicated that the proposed mechanisms can substantially reduce registration update cost, handoff latency, and packet loss rate. These three mechanisms are described in details as follows.

3.2.2.1 Fast Handoff (FH) Micro Mobile MPLS

FH-Micro Mobile MPLS [10] operates by predicting layer-3 handoff in advance using layer-2 movement detection, and establishing LSP before the MN has moved into the new network. For its operation, two types of LSP, active LSP and passive LSP, are defined. Active LSP is a working LSP that is currently used for data

forwarding from LERG to LER/FA at that moment, while passive LSP is a pre-established LSP from LERG to the possible subnetwork that MN is predicted to move into. When MN is moving into the overlapping area of the two cells, the passive LSP to the new cell will be pre-established, but still be inactive. The passive LSP will then be activated and used for data forwarding after the MN has moved into the new subnetwork and already registered with LERG.

3.2.2.2 Forwarding Chain (FC) Micro Mobile MPLS

FC-Micro Mobile MPLS [10] uses the forwarding chain principle, which operates as follows. When MN has moved to a new subnetwork, it will register with Master LER/FA instead of with LERG as usual. Master LER/FA is the first LER/FA that MN has communicated with when it first moved into that MPLS domain. When the MN has subsequently changed its location to a new subnetwork in the later times, it will register with the Master LER/FA every time. As from this, the LSP from LERG to LER/FA will be extended for each registration until the current forwarding chain gets longer than the threshold. Then the MN will start to register with LERG again, and the new LER/FA will become the new Master LER/FA making a new forwarding chain.

3.2.2.3 Master Forwarding Chain (MFC) Micro Mobile MPLS

The operation of MFC-Micro Mobile MPLS [10] is almost similar to that of FC-Micro Mobile MPLS with a difference in residing area concept. MFC-Micro Mobile MPLS defines a residing area around Master LER/FA. And the occurring chain will be newly calculated every time in order to get the shortest distance between the previous and the new LER/FA.

3.2.3 MiM-MPLS

MiM-MPLS [11] is another proposal on Micro Mobile MPLS. MiM-MPLS's architecture is also hierarchical as shown in Figure 1. Its features include multicasting, buffering, and pre-registration. Additionally, it has ability to predict the mobile node's possible next location by detecting the mobile node's link layer movement. These capabilities help improve the handoff performance of the Micro Mobile MPLS.

At the network initialization, the LSP between LFA and LG will be pre-established. When CN sends packets to MN, the packets will be sent along the pre-established LSP. When MN has moved to the boundary of the current AP, it will receive a beacon from the adjacent AP. With the link-layer mechanism, the MN's movement will be detected and the possible next location of MN can be predicted, and MN can begin pre-registration process with the new LFA. At the same time, the current LFA

will start buffering in-flight packets. When MN has reached the boundary of overlapping area, it will receive a layer-2 trigger and send a moving message to inform the old LFA which will reply with a moving reply message back to the MN. And layer-2 handoff then occurs. The MN then send registration message to the new LFA which will forward the message to the LG. At that time the old LFA will stop buffering and send the buffered packets to the MN in the new subnetwork through the pre-established LSP. Thus, MN will receive packets from the previous LFA through the new LFA before the layer-3 handoff is completed.

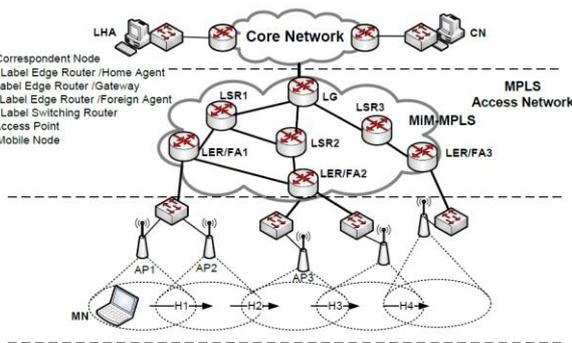


Fig.1 MiM-MPLS hierarchical structure.

3.3 Mobile MPLS : QoS Support Improvement

This subsection explains some of Mobile MPLS research works focusing on QoS support improvement.

3.3.1 Mobility-Aware MPLS

Mobility-Aware MPLS [12] proposed using MPLS in wireless access network to take advantage of MPLS's QoS support in combination with micro-mobility. Each Access MPLS Domain in Mobility-Aware MPLS will have a gateway (GW) to connect to core network. LSP will be established within the Access MPLS Domain, which can be done in two ways: static LSP and dynamic LSP.

Static LSP establishment will be done in advance according to the network administrator's policy. Many paths of static LSPs will be established between each base station and the gateway. These paths include ones for sending control signaling and ones for data forwarding per different class of services according the DiffServ model. This method improves handoff latency, because traffic can be immediately mapped to the pre-established LSP that has the same QoS level of another base station as soon as the handoff occurs.

Dynamic LSP will be established between MN and GW by using Resource Reservation Protocol (RSVP)

signaling to establish path according to the requirement of each application flow. This method supports QoS guarantee according to the IntServ model. When MN has moved within a domain, it will send signaling to reserve the new path only for the changed part. It is not necessary to create the whole path.

However, this work only proposed the concept. No implementation and experiment were done to test the concept.

3.3.2 Mobile DiffServ

MobileDiffServ [13] proposed to add mobile differentiated services architecture into Hierarchical Mobile MPLS [6] to support QoS for mobile users to get the same QoS level when roaming from home to a foreign domain.

As for the mechanism of Mobile DiffServ, at the beginning MN will have to inform HA its required level of QoS, which is called Traffic Profile. When MN has moved to a foreign domain, it will send registration request message to HA through FA and FDA respectively. And when HA has received registration request, it will start LSP establishment process from HA to FDA, and from FDA to FA. And HA will then send registration reply back to MN through FDA and FA along the created LSP. The Traffic Profile from HA will also be sent in the registration reply message. Upon receiving registration reply, FDA will get the Traffic Profile information from the reply and put it in Traffic Profile Table (TPT). Subsequently, FDA will send registration reply with Traffic Profile to FA. FA will then check if its network resource is enough for the QoS requirement from the Traffic Profile. If it has enough resource, it will send registration reply accepting to provide the service back to MN. After that, when MN has moved within the same domain, it will only need to inform the new FA and then to FDA. It is not necessary to further inform HA of the MN movement.

Additionally, in order to support the operation of the proposed Mobile DiffServ, this work also proposed to extend registration request and reply messages. Q-bit is added into the Flag field of registration request message, which will be set to one (1) when MN wants to request DiffServ service. And Traffic Profile extension is added to the end of registration reply message for sending Traffic Profile.

The simulation result for this work indicated that it improved delay and throughput during handoff.

3.4 Network Simulator for Mobile MPLS

The work in [11] designed and implemented a generic Micro Mobile MPLS module for Network Simulator 2 (NS-2) [14]. The proposed module is based on IEEE 802.11 as the link layer protocol for Micro Mobile MPLS simulation. It can simulate various mechanisms of Micro Mobile MPLS including multi-

channels, multiple interfaces, directional antennas, layer-2 handoff, layer-2 trigger, bicasting, buffering, and pre-established LSP.

The proposed NS-2 module was also tested and verified that it can correctly simulate the operation of Micro Mobile MPLS.

3.5 Route Optimization in Mobile MPLS

This subsection describes some research works focusing on route optimization in Mobile MPLS as well as route optimization in Mobile IP that may be applicable to Mobile MPLS.

3.5.1 Using Mobile IP Route Optimization for Mobile MPLS

Route Optimization in Mobile IP [5] was an IETF Internet draft proposed to solve the triangle routing problem in Mobile IP. According to the draft, CN may receive update for MN binding information from HA, and maintain this information in its binding cache. The draft defines Route Optimization messages which may be used to optimize the packet routing to the MN. These messages include Binding Warning, Binding Request, Binding Update, and Binding Acknowledge messages. However, there are some drawbacks for allowing CN to cache the binding information. First, CN will have to keep up with the MN current location. In other words, the MN movement is not transparent to CN, which violates the main goal of Mobile IP. Additionally, CN could be any computer that has no security association with HA, and this can cause security problem in authenticating the binding update from the HA.

Route Optimization in Mobile IP according to this draft can be applied to Mobile MPLS. Nevertheless, its drawbacks as discussed above make it not a good enough solution to triangle routing problem in Mobile MPLS.

3.5.2 Profile-Based Mobile MPLS

Profile-Based Mobile MPLS [15] proposed to maintain mobile user's behavior or profile including user's mobility pattern and travel schedule in order to predict user location in advance. The CN will obtain the profile, and know the current location of the mobile user, so it can forward the traffic to the place the user is expected to be located, thus avoiding the triangle routing. Having CN to keep up with the mobile user's profile, this approach has the same drawbacks as [5].

3.5.3 Agent-Based Route Optimization for Mobile IP

Agent-Based Route Optimization [16] solved the weakness of [5] related to having CN to be alert to MN location change by proposing an agent called Correspondent Agent into each network to maintain binding information for all the CNs in that network. This approach helps keep MN movement to be transparent to CN. However, the limitation of this work is that there

must be one Correspondent Agent for each of the network which CN is located. This is not practical and not scalable, because the network that CN is located can be any network and is not in our control.

3.5.4 Mobile MPLS with Route Optimization

Mobile MPLS with Route Optimization (MobileMPLS-RO) [17] proposed a route optimization mechanism to overcome triangle routing problem in Mobile MPLS. By adding a correspondent agent function to Mobile MPLS's edge routers, the mobility binding of a mobile node can be cached by the edge routers and the packet routing to the mobile node can be route-optimized.

The main components of the proposed route optimization are (1) correspondent agent and its binding cache at each of Mobile MPLS's edge router called LCA (label edge router / correspondent agent), and (2) route optimization messages which are binding request (BR), binding warning (BW), and binding update (BU). These components work together to provide the route optimization for Mobile MPLS, and consequently the triangle routing is eliminated.

The simulation study was also done to evaluate the proposed mechanism. The simulation results indicate that the proposed route optimization increases the Mobile MPLS performance by reducing its end-to-end delay.

3.6 Mobile IPv6-Based Mobile MPLS

The variations of Mobile MPLS as described above are based on Mobile IPv4. This subsection explains Micro-mobility-enabled MPLS (M-MPLS) [18] which is based on Mobile IPv6.

M-MPLS is the integration of MPLS and Hierarchical Mobile IPv6 (HMIPv6). HMIPv6 is an IPv6-based micro-mobility management protocol proposed to reduce update signaling to HA. HMIPv6 introduces a hierarchical structure containing the mobility anchor point (MAP) to be used as the MN's CoA when registering with the HA. And when the MN has moved within the same MAP, it only needs to register its new location with the MAP; registration with the HA is not necessary for this case. Thus the signaling to HA is reduced, and the handoff performance is improved.

M-MPLS introduces the multiple-domain network architecture, which each domain is a radio access network (RAN) containing mobility-enabled MPLS nodes. The edge gateway of each RAN works as the MAP of that domain, enabling the micro-mobility-based MPLS. M-MPLS is defined in two modes of operation: overlay and integrated. In an overlay framework, MPLS and HMIPv6 operate independently of each other without any common processes, tables, or signaling. In an integrated framework, related functions are merged and common processes, tables, and signaling are used. The

overlay framework is simpler because its existing protocols remain unchanged, so the overall deployment is faster. The integrated framework is more complicated, but more optimized and more efficient. The authors also published their more-detailed overlay M-MPLS in [19].

4. CONCLUSIONS

This article surveys various proposals on Mobile MPLS research. Several variations of Mobile MPLS that have been proposed are presented. In summary, according to our study of the previous research on Mobile MPLS, the early work suggested the integration of Mobile IP and MPLS to improve scalability with the focus on macro-mobility. Later works proposed ideas to reduce latency and increase performance during handoff in order to improve micro-mobility. There are many variations of research focusing on Mobile MPLS handoff performance and micro-mobility. Most works employ hierarchical architecture to decrease the amount of signaling updates, and use layer-2 movement detection to predict the next location of the mobile node in advance resulting in faster handoff. There are also some works focusing on improving QoS of Mobile MPLS, and route optimization in Mobile MPLS.

The future direction for Mobile MPLS research should be based on Mobile IPv6 instead of Mobile IPv4 in order to prepare for the transition from IPv4 to IPv6 in the future.

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