

Maintaining Quality of Service on Integrating Mobile Ad hoc Networks with 4G Cellular Networks

Yixin Dong, Dimitrios Makrakis

Broadband Wireless and Internetworking Research Laboratory, SITE, University of Ottawa

email: {ydong, dimitris}@site.uottawa.ca

Abstract: The 4th Generation wireless networks are expected to become the access network technology of preference and be fully connected to the Global IP core network. Meanwhile, Mobile Ad hoc Networks (MANET) are typically formed on a temporary basis, to serve some urgent communication needs or extend communications in hot spots that are beyond the transmission range of cellular infrastructures. MANETs can offer Internet connectivity by integrating with cellular networks. 4G cellular networks will be capable of supporting multimedia applications with certain end-to-end Quality of Service (QoS) requirements. Thus, maintaining QoS for end users in MANETs affiliated to cellular networks is unavoidable, should an integrated QoS supporting solution be desired. In this paper, we investigate current technologies, specifically, the use of the MPLS protocol, which are potentially able to fulfill this task. MPLS technology has been extended to wireless domains to handle user mobility and support of QoS. The Micro Mobility MPLS (MM-MPLS) protocol, which performs the best out of all MPLS extensions for wireless networks [1, 2], is described in detail. In order to ensure seamless integration of MANETs and cellular networks, new design challenges have to be successfully overcome. We investigate the extendibility of the MM-MPLS protocol to MANETs, which will allow seamless QoS support. We also propose a new extension of MM-MPLS on MANETs and its applicability is conveyed through analysis and simulations.

1. Introduction

4G wireless networks [3] are expected to provide IP-based universal coverage and extensive mobility support. Meanwhile, as complements, Mobile Ad hoc Networks (MANET) can be deployed in hot spots that are beyond the transmission range of the cellular infrastructure. MANETs [4, 5] are typically formed on a temporary basis and are easily deployed, without requiring preexisting infrastructure. Connections to mobile hosts in MANETs usually traverse multiple hops. Besides internal traffic, MANETs also support Internet traffic communications. This could be implemented by having gateway nodes between cellular networks and MANETs. Figure 1 illustrates such a paradigm. Note that the gateway node is also a member of the ad hoc network.

4G cellular networks are expected to be able to provide QoS to mobile users inside the service cells. On the ad hoc domain, almost all current research on QoS is concentrated on stand-alone networks. The integration of MANETs and cellular networks has not

been addressed adequately. Thus, this issue deserves further exploitation. Maintaining QoS in the integrated architecture needs to address several issues. End-to-end QoS support and IP mobility are among the most important ones. Therefore, in this paper, we focus our discussion on extending Multi Protocol Label Switching (MPLS) [6] to integrate cellular and ad hoc networks. MPLS is now emerging as a crucial standard technology that offers multiservice functionality for large-scale IP networks. MM-MPLS is an extension of MPLS to support micro-mobility and QoS on cellular networks. It establishes Label Switch Paths (LSP) from the Corresponding Nodes (CN) to Mobile Hosts (MH) located in foreign domains. MM-MPLS can handle fast handoff while capable of maintaining QoS [2]. Thus, it holds the potential of being applied to MANETs in order to implement seamless integration, allowing a LSP to traverse both cellular and ad hoc networks.

The rest of the paper is organized as follows. In Section 2, we discuss some related work of supporting IP mobility and QoS on MANETs and we review the MM-MPLS protocol. In section 4, we introduce the extension of MM-MPLS on MANETs. Finally, Sections 5 concludes the paper.

2. IP Mobility in MANETs

In this section we introduce MM-MPLS as a candidate to support IP mobility and QoS in the integrated architecture. We first review some related work. Then the significance of applying MM-MPLS is explained. We also review the MM-MPLS protocol.

2.1 Related Work

The MIPMANET protocol has been proposed in [7] for the purpose of combining Mobile IP (MIP) with MANETs. It solved the problem of connecting an ad hoc network, in which on-demand routing is used, to the Internet. MIPMANET provides Internet access by using MIP with Foreign Agent (FA) Care-of-Addresses (CoA) and reverse tunneling. It allows mobile nodes to receive the mobility services from MIP while it keeps the requirements for routing protocols to a minimum. MIPMANET has two major drawbacks. First, it did not address the micro mobility issue. Mobile nodes switching service cells have to re-register to their Home Agents (HA). This may trigger extensive signaling into the networks. Second, MIPMANET only provides mobile nodes Internet services. QoS support has not been considered. A modification of MIPMANET was reported in [8], in which table-driven protocols were applied instead of on-demand routing protocols. However, the two drawbacks mentioned above remained in the new version.

Mobile MPLS [9] extended MPLS to wireless networks. In Mobile MPLS, a Label Switch Path (LSP)

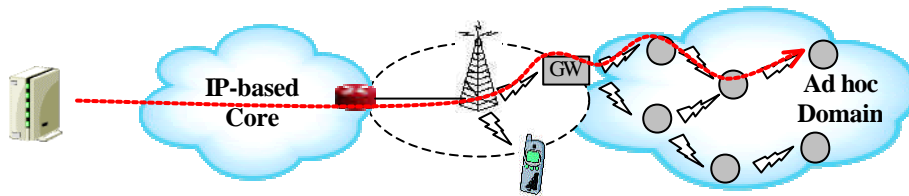


Figure 1: Integration of multihop ad hoc networks with cellular networks

from a HA to a FA is established during the registration request and reply process. The COA of the MH is the Forwarding Equivalence Class (FEC) of this LSP. Packets from the Corresponding Node (CN) to that MH are delivered along the LSP by label swapping. The FA is the egress of the LSP and it strips off the label and sends the packet to the MH through the IP layer. One of the disadvantages of Mobile MPLS is the scalability issue. A MH will register to its HA through a FA whenever it moves into a new cell. Also, there will be a disruption in the traffic flow during handoff if the registration process is very long.

The Hierarchical Mobile MPLS (H-MPLS) [1] approach was proposed to improve the Mobile MPLS protocol. The idea behind HMPLS is to handle the movement of MHs locally. When a MH moves within the same MPLS domain, no location update messages are sent to the remote HA. This is achieved by introducing Foreign Domain Agent (FDA) into each MPLS domain. Thus, each foreign MPLS domain consists of two levels: FDA and FAs. When a MH first enters a foreign MPLS domain, the location update message is sent to the Home Agent (HA), as defined in Mobile MPLS. Every subsequent location update message is forwarded to the FDA, instead of the HA. The FDA is responsible for steering the traffic to the current FA. H-MPLS improves the scalability issue of Mobile MPLS while reduces delay and delay jitter during the handoff periods.

2.2 MPLS on MANETs

As MANETs can obtain Internet connectivity via 4G cellular networks, the IP mobility support of users connected through MANETs has to be dealt with. MIP could potentially provide mobility solution in MANETs if its scalability problem is not a major concern. Since MPLS is a packet-forwarding scheme with high scalability, there is a trend in integrating MIP with MPLS. The integration improves the scalability of the Mobile IP data forwarding process. Another reason of applying MPLS in the wireless networks is its rising

importance and popularity in Internet, where it is becoming a key technology for traffic engineering and fast packet forwarding. Data packets are assigned labels at the ingress Label Switched Routers (LSR) of an MPLS domain. Subsequent classification, forwarding, and services for the packets are only based on labels. The IP header examination is avoided on core LSRs. MPLS supports QoS differentiation by combining FEC with LSP. Packets with the same FEC go through the same LSP and have the same scheduling and drop treatment. Thus, it is significant to extend MPLS into MANETs in terms of both scalable mobility support and QoS support. Among all proposed MPLS extensions for wireless networks, Micro Mobility MPLS performs the best. It holds the following features: first, the signaling to handle micro mobility is limited up to the crossover router, rather than reaching the FDA or HA; second, MM-MPLS adopts mechanisms such as MPLS forwarding and Resource Reservation Protocol (RSVP) soft state to better support QoS. We shall visit the MM-MPLS protocol and discuss it in more detail in what follows.

2.3 MM-MPLS Protocol

MM-MPLS [2] combines Mobile IP with MPLS to support MPLS forwarding, localized signaling, and soft-state location management. Figure 2 illustrates the architecture of MM-MPLS. It assumes the existence of an access network between FDA and FAs. When a MH moves for the first time into a foreign domain, it will send a Registration Request message to the nearest FA (e.g. node D in Figure 2). The FA relays this Registration Request message to the FDA of this MM-MPLS domain. After the FDA gets this message, it negotiates with the HA of the MH and establishes a LSP between the HA and the FDA, following the same procedure as defined in H-MPLS. Then the FDA establishes a LSP between the FDA and the current FA by using RSVP-TE that is a soft-state signaling protocol. The soft-state property of RSVP-TE allows us to apply soft-state location management on the MHs

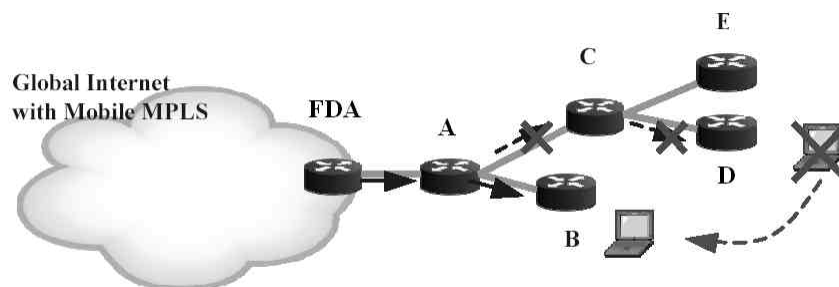


Figure 2: MM-MPLS architecture

within the MM-MPLS domain. The FDA sends a RSVP PATH message, with a LABEL_REQUEST object, to the current FA. Note that the MH's home address, instead of the current FA's address, is used as FEC in MM-MPLS. When the current FA receives the PATH message containing a LABEL_REQUEST object, it responds with a RESV message that contains a LABEL object on behalf of the MH. The LABEL object contains the label binding that the downstream LSR communicates to its upstream neighbor. The RESV message is forwarded upstream, towards the FDA, in a direction opposite to that followed by the PATH message. When the RESV message arrives at the FDA, the LSP between the FDA and current FA is established. Finally, the FDA relays the Registration Replay message, sent from the HA, to the MH along the LSP between the FDA and current FA.

When there is a CN sending some packets to the MH, the HA will use the incoming label value as an index to look up its label table and find the outgoing label and outgoing port for this packet. Then the packets are delivered from HA to the FDA along the LSP by label swapping. The FDA receives the packets and continuously forwards them through the LSP from FDA to the current FA. After the FA gets the packets, it will look up its label table. Since it is the egress of the LSP from the FDA to FA and the out label and outgoing port fields are empty, the FA strips off the label and sends the packets to the MH through the IP layer.

When the MH moves from one cell to another cell within the same foreign domain, it will send a Registration Request to the new FA. Then, the new FA (i.e. node B in Figure 2) will relay the Registration Message to the FDA. Every intermediate LSR from the new FA to the FDA will check whether there is an entry for the MH, i.e. an entry with the MH's home address as FEC, in its label table. The Registration Request message eventually reaches a crossover LSR (node A in Figure 2), which has a forwarding entry for the MH. We define the crossover LSR 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. In the worst case, the crossover router is the FDA. Upon reception of the Registration Request message, the crossover LSR will setup a new LSP to the new FA using the MH's home address as FEC. After the new LSP from the crossover LSR to the new FA is established, the crossover LSR will change its label table and redirect the LSP, with the MH's home address as FEC, to the new FA. The crossover LSR will then intercept the next PATH message from the FDA to the old FA, generate a RESV message containing new EXPLICIT_ROUTE OBJECT (ERO), which defines the new path from the FDA to the new FA, on behalf of the MH, and returns the newly-generated RESV message back to the FDA. Afterwards, all the following PATH messages in RSVP-TE, sent by the FDA, will include the new ERO and therefore be forwarded through the new LSP by the crossover LSR to the new FA. Finally, the entries of the old path (node C and node D in Figure 2) will timeout, and they will be deleted from their label tables. All the

subsequent packets from the CN to the MH will follow the new LSP. Figure 2 illustrates how the packets from the CN are redirected to the MH, which handoffs to a new cell, by the crossover LSR (node A). Note that in this case, the FDA will not notice the movement of the MH. During handoff, the MH may also notify the previous FA of its new COA, by sending a binding update message. This allows the previous FA to cache the new binding of the MH. If the FDA forwards later a packet to the MH using out-of-date cache entry, the previous FA will receive the packet, establish an LSP to the new FA, and send the packet to the new FA through the LSP. Figure 3 illustrates the singling procedure of handoff.

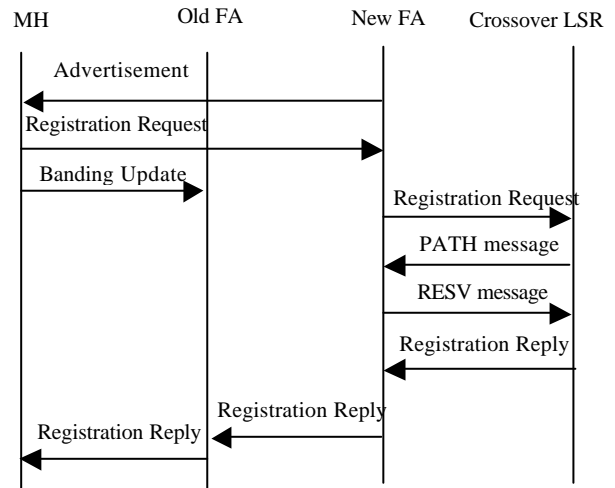


Figure 3: Handoff procedure in MM-MPLS

Since a crossover LSR is an intermediate LSR between the FDA and current FA, it will take a shorter time for the Registration Request message to get to the crossover LSR than to the FDA. Hence, one of the advantages of MM-MPLS over HMPLS is that the MH may experience lower delay and delay jitter during the handoff periods. In fact, the handoff latency in HMPLS is the worst case of MM-MPLS, which occurs when the FDA becomes the crossover LSR. This improvement is achieved by using the MH's home address, instead of the current FA's address in HMPLS, as FEC to establish the LSP from the FDA to the current FA in MM-MPLS. Thus, in MM-MPLS the crossover LSRs are able to search the label table, find the row with the MH's home address as the FEC, and change the "outgoing port" and "out label" to the same values as the ones for the LSP to the new FA. Another benefit of using MM-MPLS is that soft-state location management is applied in this scheme, which allows us to switch the LSP to another FA dynamically. This also increases the robustness of the protocol to router and link failures. In HMPLS, the FDA has to manage all the MHs in the domain, which puts a lot of burden on it. It is obvious that the FDA becomes the bottleneck of the system if a large number of the MHs move into the domain. MM-MPLS distributes this job to all the routers inside the domain, which improves the scalability of the system.

3. Extending MM-MPLS on MANETs

3.1 Some Design Issues

There are some challenges to apply MM-MPLS in MANETs because of the unique characteristics of mobile ad hoc networks.

- *Multihop connection to FAs.* In MM-MPLS, the wireless connection between FAs and MHs is only one-hop. However, the routes between FAs and MHs in MANETs may pass through multiple mobile wireless nodes. Besides the data packet forwarding, the registration messages and RSVP signaling need the support from routing protocols. On-demand routing protocols are not suitable for control messages since it causes network wide broadcasting in order to set up routes for a small amount of packet forwarding. Table-driven routing protocols do not perform well for data packet delivery in MANETs with high mobility.

- *FA advertisement.* By default, a FA sends advertisement message every second in MIP. In order to inform all mobile nodes in the attached MANETs, the agent advertisement messages need to be forwarded by flooding the entire network. In [7], the beacon period is increased to reduce the flooding rate. However, longer advertisement period has negative effect on agent discovery, movement detection and reachability, since the information about available agents is spread less frequently within the MANETs.

- *Multiple FAs.* A group of mobile nodes may connect to the Internet through more than one FA. Generally, a MH should choose the FA with the shortest route to register to. However, other metrics may be applied to choose FA if QoS support or traffic engineering is taken into consideration. Moreover, evenly distributing mobile nodes to multiple FAs can potentially balance traffic load, resist the failure of a single FA, and improve the scalability.

- *LSP maintenance in MANETs.* In MM-MPLS, a mobile node is the end user and its movement only influences its own communication. In a multihop environment, mobile nodes are also routers for other stations. Thus, a MH in MANETs is the egress router for its own data session while at the same time could be act as a core LSR for other data traffic passing through. This increases the difficulties of LSP maintenance.

- *High signaling load.* MM-MPLS can better support QoS and Mobility on the expense of extra signaling load. Besides the agent advertisement and registration request/reply messages, MM-MPLS relies on the periodical refreshing of RSVP-TE messages to setup and maintain LSPs. If no attention to the resource consumption is paid, these control messages may consume a large part of the channel resource.

3.2 Hierarchical Network Structure

To address the above issues, we propose to extend MM-MPLS to MANETs using a hierarchical network structure. In such ad hoc networks, some nodes can serve as supernodes [10] to improve the resource and mobility management. A supernode is the head of its cluster. Every other MH in MANETs must be associated with one of the cluster and be located within the transmission range of the cluster head. We focus primarily attentions on MANETs with slow relative movement. To list a few scenarios of such MANETs, let us first mention MANETs with group mobility. For

example, a train, a bus, or a boat carrying mobile users accesses Internet via the cellular infrastructure. Another example is the case of an intelligent car, equipped with sensors, actuators, and on-board network, exchanging information with engine maintenance and collision preventive service through the cellular infrastructure. The relative positions among mobile users do not change frequently. Some powerful stations can serve as supernodes. Sensor networks can also be deployed with such network structure. Some static nodes are deployed to pre-process and deliver sensing data. The Roofnet network [11] also falls into this type of architecture. The hierarchical structure can be formed at the network “warm-up” time. After several rounds (for example, 3 times) of information exchange, each node produces a list of [neighbor node, degree] pairs. A node’s degree is the number of its neighbors. Then each node is assigned a randomly selected clustering time. The first node beginning to form the clusters will search one of its neighbors (including itself) with the maximum degree. If two nodes have the same degree, the one with smaller ID wins. Then the first node appoints the node as its supernode by sending a SUPERNODE APPOINTMENT message to it. The node receiving this message will broadcast a CLUSTERING message to its one-hop neighbors. After that, the first cluster is formed. The subsequent nodes will follow the same procedure at their clustering time given that they have not received any SUPERNODE APPOINTMENT or CLUSTERING messages. After the timeout of all clustering times, every node will be either a supernode or it will belong to a supernode. Note that gateway nodes always turn into supernodes.

3.3 Supernode Trees

In our network model, gateway nodes are bridges between MANETs and cellular networks. The gateway nodes are stations having direct connection with FAs. They are usually equipped with two wireless interfaces, one for the cellular network and another one for the MANET. Each FA has a corresponding gateway station. Mobile stations register to FAs via the FAs’ gateway nodes. Each gateway node maintains a multicast tree that consists of only supernodes. A supernode joins the supernode tree that is rooted on its nearest FA. The construction of supernode trees is as follows. A gateway initializes the generation of supernode tree by broadcasting a ROUTE REQUEST message. The messages include the gateway’s ID and the hop count. Every node only broadcasts the route request packet one time. A node increases the hop count by one before forwarding the request messages. Also, the ID of the upstream station is recorded. A supernode that receives the ROUTE REQUEST message will decide if it joins this tree based on the hop count. If it is already in a supernode tree that is rooted on another gateway, it will join this tree if the new FA is at least two hops closer than its current FA. However, if the supernode is not in any tree, it will join this tree. The supernode then marks itself a member of this tree (identified by the ID of initiating gateway) and acknowledges its upstream node with a ROUTE REPLY message. Upon the reception of ROUTE

REPLY messages, a node, regardless if it is a supernode or not, will become a member of this tree if it is not a member yet. The node also records the ID of the downstream node that sent the ROUTE REPLY message. New members inform their upstream nodes by sending ROUTE REPLY messages to their upstream nodes until a member or the gateway is reached. After the establishment of the supernode tree, every member has entries of its upstream node, its downstream nodes, and the hop count to the gateway.

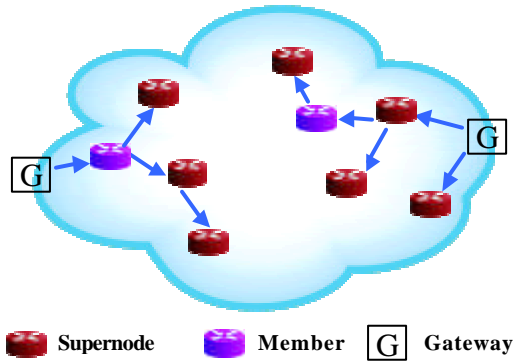


Figure 4: Illustration of Supernode trees

Figure 4 illustrates the structure of supernode trees. Note that other nodes that are not supernodes or members are not drawn for the purpose of simplifying the illustration. A supernode might leave a tree due to its mobility. To repair the tree, the supernode enquires its neighbors that are less than three hops from it. Since a node is either a supernode or a direct neighbor of a supernode, the nearest supernodes are at maximum three hops away. A supernode should always join a tree. Thus, local search within three hops guarantees to find the nearest tree. A supernode or a member on supernode trees could reply the local search. With the comparison of hop count, a supernode will choose the tree rooted on the closest gateway in multiple replies. Therefore, the supernode trees can be maintained without triggering network size flooding of control overhead.

The benefits of constructing gateway rooted supernode trees are three fold. First, since the connectivity between MANETs and FAs is determined by the existence of the gateway nodes between them, gateway nodes can filter the FA advertisement messages. In Mobile IP, a FA sends advertisement message every second, in order to let the MHs to discover the FA without long latency. In our system, the MHs in MANETs always register to the FAs via corresponding gateways. A MH can obtain the available FAs by checking if its supernode (or itself) is on a supernode tree. Even without direct reception of agent advertisements, a node still can find the nearest FA and register to it. Thus, it is logic that a gateway only forwards the advertisement messages into MANETs when the gateway leaves the current cell and approaches a new cell. However, we set an advertisement timer on each gateway and the messages are forwarded into MANETs for each time out. This way, every supernode on the MANETs can receive the advertisement and know the distance from every FA. A

leaf supernode may change to connect to another tree rooted on the gateway that is at least two hops closer than the current gateway.

Second, the supernode trees can be used to forward Registration Request/Reply messages between FAs and MHs. Even though a MH may traverse several hops to reach a FA, no routing procedure is needed. When a MH moves into a MANET, it first selects a supernode and attaches to the supernode's cluster. The Registration Request message then is forwarded along the unicast routes on the supernode tree towards the gateway. Since a supernode selects the tree that leads to the nearest FA, a MH also registers to its nearest FA. After the FA gets the Registration Request, it follows the same procedure as MM-MPLS does in order to negotiate with the MH's HA and establishes a LSP from the HA to the FA. When the FA obtains the Registration Reply from the HA, it establishes a LSP to the MH and then sends the Registration Reply message back to the MH along the supernode tree. Therefore, no routing support is needed for Registration.

In addition, the LSP setup and maintenance between FAs and MHs may benefit from the supernode trees. The PATH and RESV messages could be forwarded along the supernode tree and the LSPs are established along the supernode trees. Alternatively, a FA can find a route to the MH that is registering to it through a reactive routing protocol, for example, AODV or DSR. The subsequent soft state RSVP signaling follows the same routes as selected during the LSP setup stage.

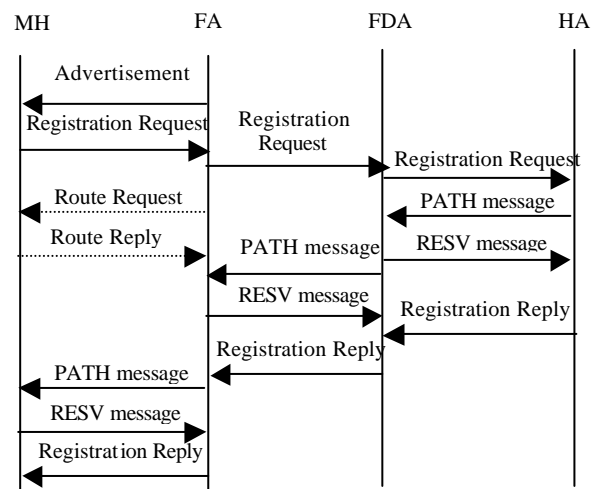


Figure 5 presents the procedure of Registration.

Figure 5: Registration of MH in MANETs

3.4 Handoff

Within the integration structure, a MH may experience two types of handoff. The first type occurs when a mobile gateway moves into a new service cell in the same foreign domain. In this case, all MHs that are registered with the old FA need to handoff. We propose an efficient method to deal with this kind of handoff. A gateway performs the handoff on behalf of the MHs that is on its supernode tree. The notion behind the mechanism is that the LSPs between the gateway and the MHs are unaffected by the handoff. This type of handoff follows the same procedure as described in MM-MPLS. Thus, the Registration

signaling initiates from the gateway and is limited up to crossover routers. On the other hand, if supernode trees are not applied, the registration signaling initiates from the MHs and passes through the gateway. Obviously, the proposed integration system experiences a shorter delay and produces less control signaling.

For effective usage of the wireless channel capacity, the MHs need to handoff when they switch to a new FA, if it is at least two hops closer than the old FA. This kind of handoff might be caused by relative mobility inside the MANETs, whereas the last type of handoff is the outcome of group mobility. Another reason for this handoff process is its ability to support traffic engineering. If the LSP via the old FA is not capable of supporting the required QoS because of network congestion, a MH can setup an alternative LSP to a new FA and switch into the new cell. If the new FA is in the same foreign domain as the old FA, the handoff signaling initiates from the MHs and is limited up to crossover routers. In this case, our system outperforms the MIP in terms of handoff delay. Otherwise, the handoff needs the registration reply from the HAs as the procedure in MIP.

With the help of supernode trees, MM-MPLS preserves its scalability in the integrated system. Meanwhile, the mobility and QoS support capability of MM-MPLS remains unaffected in ad hoc networks. Thus, we can safely conclude that our proposed extension of MM-MPLS to an integrated cellular and ad hoc environment is a practically viable solution that will allow effective end-to-end support of QoS, use of advanced traffic engineering techniques and fast packet forwarding.

3.5 Overhead Analysis

The extension of MM-MPLS in MANETs can be justified if it only involves reasonable amount of control overhead. The total overhead on the ad hoc domain consists of the MIP related overhead, ad hoc routing overheads, and MPLS related overhead. MIP and MPLS signaling need the support of ad hoc routing. Signaling packets, which are usually of small size, are always initiated or terminated at gateways in MANETs and they are not transmitted on continuous fashion. Therefore, it would be more efficient to have proactive routes from each mobile to its gateway and from each gateway to its mobiles. In our proposed system, only the supernode tree needs to be maintained instead of every route, with the MIP and MPLS related signaling being forwarded along the supernode trees. Moreover, the connection between two neighbor supernodes involves only local route search without the need of network wide flooding. Thus, the approach of supernode trees provides more efficient routing overhead usage. In MIP, the FA advertisement messages need to be sent to every mobile via broadcasting. In our scheme, however, the gateways control the advertisement to a reasonable amount by applying a filtering mechanism. Therefore, the MANETs transmit less advertisement messages without delaying the discovery of FAs. In addition, the Registration Request/Reply messages are transmitted on unicast routes on the supernode trees. If MM-MPLS

is applied on the ad hoc domain, RSVP signaling messages are sent out from FA along established LSPs for every soft state time out. Thus, the MPLS related overhead is influenced by the refreshment time and the number of data sessions of outside traffic.

To survey the total MIP and MPLS related overhead with the variety of registered mobile and refreshment time, we conducted the following simulations. 50 mobiles are randomly deployed in a 1000*500 meter area. A static node is on the edge to serve as the gateway. Other nodes move in the closed area with maximum speed of 2 m/s. The random way point model is simulated. The transmission range of each MH is 250 meters. The number of registered mobile nodes is changed from 2 to 50. At the beginning of the simulations, supernodes are selected and a supernode tree is constructed following the same procedures as those described in 4.2 and 4.3. With the results of multiple runs, there are in average 7.2 supernodes out of the total 50 stations. In the simulations that are referred as "Multicast 1" and "Multicast 2" in Figure 6, the filter timer of agent advertisement is set to 5 sec. In the simulations that are referred as "Broadcast" in Figure 6, an agent advertisement message is transmitted every second via flooding as the procedure in MIP. In "Multicast 1" and "Multicast 2", the RSVP refreshment time is 30 seconds and 15 seconds respectively. In "Broadcast", no MPLS related signaling is applied. Figure 6 presents the simulation results. As expected, the broadcasting scheme maintains a constant overhead rate since the MIP related overhead is irrelevant to the number of registered mobiles. Even though MPLS related overhead is included, the multicast scheme with 30 sec refreshment time outperforms the broadcasting scheme if the number of registered mobiles is less than 50. However, if the time is decreased to 15 seconds, the broadcasting method cause less MIP and MPLS related overhead when there are more than 25 registered mobiles. This implies that through careful selection of the refreshing time MM-MPLS can be extended to MANETs without triggering additional overhead. Note that we only analyzed the overhead on the ad hoc domain while MM-MPLS holds the scalability micro-mobility support on the cellular and IP core networks.

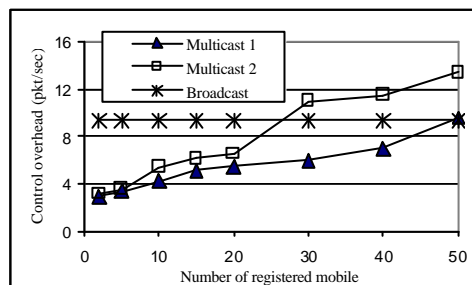


Figure 6: Mobile IP and MPLS related overhead

4 Conclusion

We have introduced the DAS scheduling algorithm and MM-MPLS protocols as potential candidates to support QoS in MANETs when they are integrated with cellular networks. Following the design issues rising by the integrated architecture, we discussed the support of

IP mobility in the integrated architecture. After reviewing the detail of the MM-MPLS protocol, we present the extension of MM-MPLS on MANETs with hierarchical network structure. Its applicability is justified via overhead analysis. The research reported in this article is only the first step towards the development of a complete architecture that integrates MANETs with 4G cellular networks.

Reference

- [1] T. Yang, and D. Makrakis, "Hierarchical Mobile MPLS: Supporting Delay Sensitive Applications over Wireless Internet," International Conference on Info-Tech & Info-Net (ICII 2001), Beijing, China, October 2001.
- [2] T. Yang, Y. Dong, Y. Zhang, and D. Makrakis, "Practical Approaches for Supporting Micro Mobility with MPLS," *International Conference on Telecommunications 2002 (ICT 2002)*, Beijing, China, June 23, 2002.
- [3] W. Webb, "The Future of Wireless Communications," Boston: Artech House Inc., 2001.
- [4] J. Jubin and J. Tornow, The DARPA Packet Radio Network Protocols, *Proceedings of the IEEE*, 75(1): 21-32, 1987.
- [5] IETF Mobile Ad-hoc Networks (manet) Charter, <http://www.ietf.org/html.charters/manet-charter.html>.
- [6] IETF Multiprotocol Label Switching (MPLS) Charter, <http://www.ietf.org/html.charters/mpls-charter.html>.
- [7] U. Jonsson, F. Alriksson, T. Larsson, et al, "MIPMANET-mobile IP for mobile ad hoc networks," *MobiHOC*,
- [8] Mustafa Ergen, Anuj Puri, "MEWLANA-Mobile IP Enriched Wireless Local Area Network Architecture," *IEEE VTC2002*, Vancouver Sep., 2002.
- [9] Zhong Ren, Chen-Khong Tham, Chun-Choong Foo, and Chi-Chung Ko, "Integration of Mobile IP and Multi-Protocol Label Switching", *ICC2001*, June 2001.
- [10] Y. Dong, T. Yang, D. Makrakis and I. Lambadaris, "Supernode-based Reverse Labeling Algorithm: QoS Support in Mobile Ad hoc Wireless Networks," *CCECE'02*, Winnipeg, Canada, May 2002, vol. 3, pp. 1368-1373.
- [11] Roofnet, <http://www.pdos.lcs.mit.edu/roofnet/>.