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Design of the multicast service for mobile users in the 802.16 network environment

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A B S T R A C T

Middle-domain mobility management provides an efficient routing, low registration cost and handoff latency for layer 3 (IP layer) 802.16-based mobile network environment. In the middle-domain, the 802.16 base station (BS) acts as an agent or proxy to manage mobile networks to achieve this goal. The BS could only address external traffic but without internal case management. In order to complement this defect, an enhanced version for the middle-domain mobility management is designed in this paper. Moreover, we research and design the multicast extension for the middle-domain by applying the idea of the enhancement, which is called HMP (Hierarchical Multicast Protocol). Associated handoff scheme is also proposed in this paper. Since it is a complicated case for designing the multicast service in 802.16 network environment, we need a characteristic method to address this case. In order to fulfill this achievement of designing HMP scheme, we introduce a reduction process (RP) in this paper. By using the RP, a complicated 802.16-based network environment can be actually reduced to a simpler network environment. The mathematical analysis and simulation study are presented for performance evaluation. Simulation results have demonstrated that the enhanced middle-domain mobility management has the better network performance in terms of registration cost, handoff latency and routing cost in comparing with conventional mobility management schemes. Moreover, the proposed multicast extension for HMP scheme is simple and has scalability and network performance advantages over other approaches in mobile multicasting.

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1. Introduction

Mobility management [1–10] is an essential component in enabling mobility of hosts while maintaining the packet routing efficiency between the hosts. *Mobile IP (MIP)* [11–14] has been designed to serve the needs of the burgeoning population of mobile computer users who wish to connect to the Internet and maintain communications as they move from place to place. The proposed standard for Mobile IP (mobility management referred to as *macro-mobility*), however, has several drawbacks ranging from triangle routing and its effect on network overhead and end-to-end delays, to poor performance during handover due to communication overhead with the home agent (HA), and instead, *Cellular IP (CIP)* [15–18] (mobility management referred to as *micro-mobility*) was proposed. CIP provides local mobility and handoff support for frequently moving hosts, which means that mobile hosts can migrate inside a CIP network with little disturbance to active data flow.

Recently, a new wireless technology called 802.16 (or WiMAX) [19–28] is emerging. In our previous work [29], we have discussed that it is not suitable to fit macro- or micro-mobility technologies into 802.16-based network environment, because of frequent registration and increased handoff latency in Mobile IP, and lengthy internal data path with gateway in Cellular IP. Thus, *middle-domain mobility management* is proposed in [29] to insert in between macro-domain and micro-domain. The middle-domain mobility management for layer 3 (L3) 802.16 mobile network environment is designed to be able to accommodate different micro-mobility protocols and is transparent to macro-mobility and micro-mobility protocols. Moreover, it has significantly reduced the registration cost and handoff latency since localized registration is designed in the middle-domain. For the middle-domain, the 802.16 devices en route create the location cache for the corresponding mobile host. The registering procedure for Mobile IP in the middle-domain can be terminated at the crossover node (i.e. a shared node on the rooted path) because each 802.16 device en route intercepts the Mobile IP registration message for the location cache at crossover. Therefore, efficient mobility management can be addressed within the middle-domain.

Different from HMIPv6 [30] technology, middle-domain adopts an efficient direct routing through referring to these location ca-

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ches for packet delivery but not tunneling. The idea of improving handoff and communication performance for mobile nodes through using location cache is useful, particularly for the considered wireless mobile network environment. On the contrary, the tunneling is an inefficient routing for 802.16 network performance because of the IP-in-IP encapsulated packets and *Tunnel Convergence Problem*[31]. Though middle-domain provides low cost for home registration and less time for handoff, it does not still solve the problem of tunnel-based protocols. While acting in case of internal traffic, middle-domain mobility management does not be mentioned. To complement this defect, we consider supporting an enhancement for the middle-domain.

Moreover, demand for applications has recently risen such as (1) teleconferencing in which part of or all of the participants are mobile users in distributed networks, (2) live video, and (3) multiplayer online games, where mobile users located in different parts of the world participate via Internet. Multicasting could prove to be a more efficient way of providing necessary services for these applications. However, no efficient research into multicasting for WiMAX applications has been performed yet. Therefore, in this paper, we mainly aim to design the multicast extension by inheriting the idea of enhanced middle-domain mobility management, which is denoted by *HMP (Hierarchical Multicast Protocol)*. On the design of the HMP scheme, we find that the traditional tunnel-based multicast routing protocols such as BT[31,32], MoM [33] fitted into the 802.16 network environment are not appropriate and difficult since inefficient multicast routing problems such as *triangular routing*, *duplicate of tunnels*, *tunnel convergence problem* and *frequent DMSP* [33,34] *handoff problem* would occur. These problems would be mentioned and discussed in Section 4.1.

For simplifying the complicated case, a *Reduction Process (RP)* needs to be addressed in this paper. With the concept for RP, the HMP scheme can be easily designed based on the associated idea of the enhanced version for the middle-domain mobility management with the MoM-applied scheme to do the multicast service. Lastly, simulation study and theoretical analysis have demonstrated that proposed enhanced version for middle-domain mobility management and HMP scheme for multicasting can achieve better network performance in 802.16-based network environment.

The rest of the paper is organized as follows. First of all, we make a brief of survey of (1) conventional mobility management (2) middle-domain mobility management (3) multicast extension for Mobile IP, and (4) hierarchical mobile multicast in Section 2. An enhanced version for middle-domain mobility management is presented in Section 3. In Section 4, multicast extension associated with idea of middle-domain enhancement in the 802.16 network environment called *Hierarchical Multicast Protocol (HMP)* is proposed. Simulation environment and results for performance evaluation for mobility management (unicast version) and multicast case are mentioned in Sections 3.5 and 4.5, respectively. Theoretical analysis and characteristic for the middle-domain are researched in Section 5. Finally, Section 6 concludes this paper.

2. Related work

2.1. Conventional mobility management: MIP, FMIPv6, HMIPv6

For conventional mobility management, *Mobile IP* (MIP[11–14]), *Fast Handover for Mobile IPv6 (FMIPv6*[46]*)*, and *Hierarchical Mobile IPv6* (HMIPv6 [30]) are all famous schemes which will be detailed as follows.

In Mobile IP, a *mobile host (MH)* uses two IP addresses: a fixed home address and a *care-of-address (CoA)* that changes at each new point of attachment (subnet). A router called *Home Agent (HA)* on an MH's home network is responsible for maintaining the mapping (binding) of the home address to the CoA. When a mobile host moves to a foreign network, it obtains a new CoA from the *Foreign Agent (FA)* and registers the CoA with its HA. In this way, whenever a mobile host is not attached to its home network, home agent gets all packets destined for mobile host and arranges to deliver to the MH's current point of attachment by tunneling the packets to the MH's CoA.

FMIPv6 provides seamless handover by minimizing handover latency, associated with anticipative movement detection to reduce handover latency and packet loss. After discovering one or more nearby access points, mobile host performs the layer 3 handover when it is connected to a *PAR (previous access router)*, and in this case, the PAR must have known information about an *NAR*

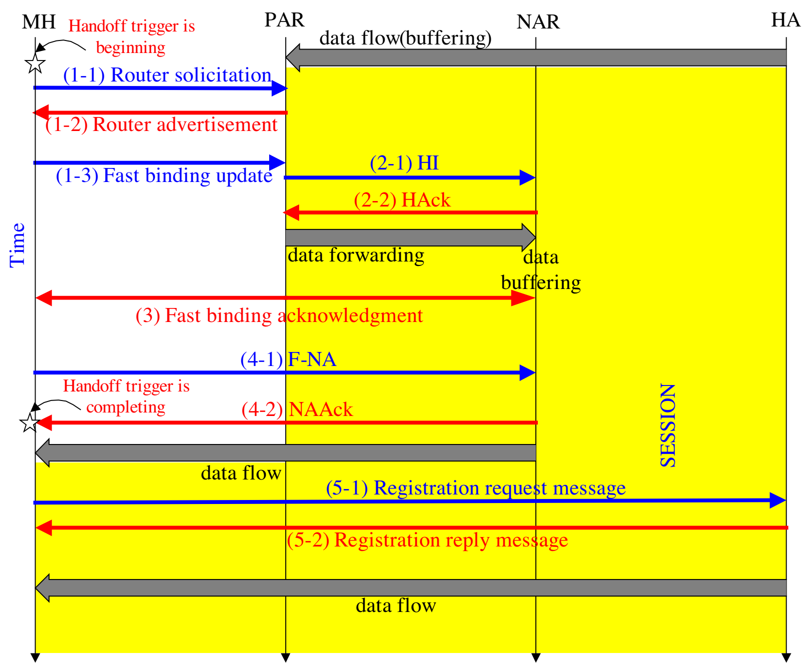

Fig. 1. Flow sequence chart for FMIPv6.

(next/neighbor access router). Through a *router solicitation for proxy (RtSolPr)* and a *proxy router advertisement (PrRtAdv)* messages, the mobile host obtain information of NAR. The mobile host requests tunneling sending a *fast binding update (FBU)* message with PAR. The PAR establishes a tunnel between itself and the NAR, and then verifies the MH's new CoA by exchanging a *handover initiate (HI)* message and a *handover acknowledge (HAck)* message. Packets that arrive at *previous care-of address (PCoA)* are forwarded to the NAR through an established tunnel during the handover, and the NAR buffers the packets. When the mobile host arrives at new location, the *Fast Neighbor Advertisement (F-NA)* message is used to inform the NAR. In latter, the NAR replies a *Neighbor Advertisement Acknowledgment (NAACK)* to mobile host, and the buffered packets are forwarded to it. Fig. 1 shows the flow of FMIPv6.

HMIPv6 has been proposed to provide a method for efficient mobility management in a network where MHs frequently change their points of attachment. The manageability of traditional Mobile IP can be enhanced by using a *Mobility Anchor Point (MAP)*. A MAP acts as a local *Home Agent (HA)* for MHs in the foreign domain, and a multilevel hierarchy of MAPs in HMIPv6 is recommended. The operations of the MAP in HMIPv6 scheme are presented in the following. When an MH attaches to a new link, it receives a router advertisement, including a MAP option. The MAP option informs the mobile node of the MAP's IP address. The MH generates a *regional care-of address (RCoA)* based on the MAP's prefix and another address for the *on-link care-of address* (*LCoA*; address derived from the foreign link's prefix). The MH then sends a binding update to the MAP, using its RCoA as a home address and its LCoA as the care-of address. Moreover, the MH also sends a binding update to the home agent, it binds its RCoA to its home address. Hence, whenever the home agent receives packets destined to the MH's home address, it will intercept them and forward them to the RCoA. Since the MAP is also acting as a local home agent for the MH's RCoA, it will intercept those packets and forward them to the MH's current location (the LCoA stored in the MAP's binding cache). Through using this concept of localized registration in the MAP, there is no required to do binding update if MH is always moving under the MAP domain.

2.2. Middle-domain mobility management: SFA

In our previous work [29] for the middle-domain, we investigate the characteristics of IEEE 802.16 and conclude that it is better to equip base station (BS) and subscriber station (SS) with Layer 3 (L3) functionality. Therefore, an 802.16 network can act as the backbone network of different subnets for better deployment. As illustrated in Fig. 2, a basic L3 802.16 network consists of a BS and a couple of SS that connects to BS via a high-speed wireless link. The BS acts as a gateway to the Internet. The complex subnet systems in micro-domain can connect to the 802.16 network via SS. Note that for each frame in Fig. 2, it presents "Device" and "Functionality", respectively. For instance, the BS device could equip with SFA functionality, SS device is equipped with regular router (R) functionality, and GR device could equip with MIP FA functionality. For Fig. 2, the micro-domain gateway router (GR) under each SS is required to equip with FA functions of Mobile IP and is responsible for MIP home registration.

The operation for middle-domain is summarized as follows. If a mobile host enters the middle-domain the first time, the GR acts as FA for performing the registered procedure of Mobile IP. But the registration requests issued by the GR are intercepted by SS or BS in order to maintain proper location (downlink) cache information of the mobile hosts. When this request message is relayed and arrived at the BS, the BS would act as a *super foreign agent (SFA)* to perform home registration of Mobile IP on behalf of FA. The SFA, which is a new defined term in this paper, allocates a *middle-domain care-of-address* (denoted by *M-CoA*) for the mobile host. The M-CoA is usually the address of the BS and is used in Mobile IP registration. Moreover, the BS issues a Mobile IP registration request including the M-CoA to the HA of mobile host on behalf of the foreign agent GR. Meanwhile, the BS also sends a Mobile IP reply message back to the GR instead of the HA. In this way, there is no need to perform Mobile IP home registration with HA as mobile host handoffs within the middle-domain. This is also the basic idea of SFA for the middle-domain.

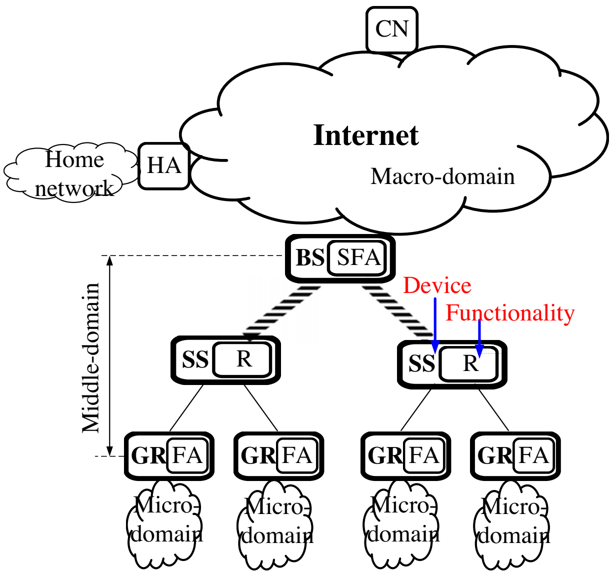

Fig. 2. Deployment of layer 3 802.16 network environment for the middle-domain.

M-CoA: Middle-domain CoA, MH:Mobile host

BS:	*MH's ID*	*Next Hop*	*M-CoA*	*Micro-domain CoA*

SS:	*MH's ID*	*Next Hop*	*Micro-domain CoA*

Fig. 3. Cache structure in the middle-domain.

In order to support middle-domain operations, the cache structures in BS and SS for a mobile host are displayed respectively in Fig. 3, in which *MH's ID* is the home address of the mobile host, the *Next Hop* for a mobile host in BS is the address of the next SS, the next hop for a mobile host in SS is the address of the next GR, the *M-CoA* is used in Mobile IP home registration, and the *Micro-domain CoA* is used in Mobile IP reply to the GR.

2.3. Multicast extension for Mobile IP: RS, BT, MoM

Mobile IP proposes two approaches to support mobile multicast, which is called *Foreign Agent-based multicast* (referred to as *Remote Subscription, RS [35]*) and *Home Agent-based multicast* (referred to as *Bi-Directional tunneling, BT [31,32]*). Afterwards, Harrison et al. proposed a home agent-based protocol called *MoM (Mobile Multicast) [33]* to enhance performance of BT scheme. For the Mobile IP multicast protocols, we make a brief survey in the following.

In RS scheme, a mobile host must have the responsibility to resubscribe to its desired multicast groups each time it enters a foreign network. RS has better performance if mobile host stays for a long time within a network, otherwise multicast delivery tree will be updated frequently. More specifically, RS offers a shortest

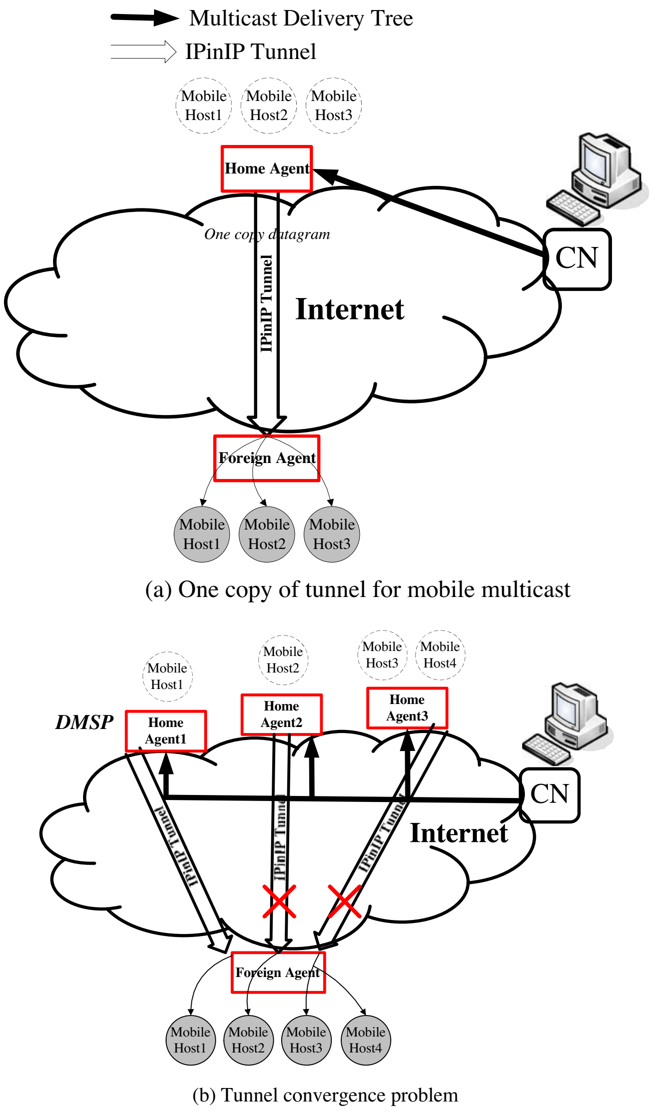

Fig. 4. Home agent-based multicast extension for MoM.

routing path for delivery of multicast datagrams to the mobile host, and the overhead is the cost of reconstructing the delivery tree while a handoff occurs.

In BT scheme, the mobile host receives all multicast datagrams by its home agent using unicast Mobile IP tunnels. This approach handles source mobility as well as recipient mobility, and in fact hides host mobility from all other members of the group. However, there are three main drawbacks for this approach. First, tunnel for delivery path may be in triangle routing, which can be far from optimal. Second, the home agent has to replicate and delivery tunnel multicast datagrams to each mobile host, regardless of at which foreign networks they reside. Third, if multiple mobile hosts that belong to the different home networks visit the same foreign network, duplicated copies (tunnels) of multicast packets will arrive at the common foreign network, which is denoted by *Tunnel Convergence Problem* [31–33]. Thus, the network resources will be wasted.

A home agent-based multicast extension namely *mobile multicast (MoM)* scheme is to use the home agent functionality of Mobile IP to effect delivery of multicast datagrams to mobile host. There is only one copy of the multicast datagrams tunneled from home agent to a foreign agent in the event that the home agent has multiple mobile hosts ever presented there. Upon receiving the multicast packet, a foreign agent deliveries it to mobile hosts using link-level multicast (see Fig. 4(a)). Moreover, MoM uses the *DMSP (Designated Multicast Service Provider)* to solve tunnel convergence problem. As illustrated in Fig. 4(b), the foreign agent performs a selection to appoint one of multiple home agents (i.e. *home agent1*) as the DMSP. The DMSP forwards only one datagram into the tunnel, while other home agents that are not the DMSP do not forward the datagram. Though MoM scheme provides a better network performance in a distributed system, it is not suitable to be fitted in a hierarchical-based network environment. Once a high-level hierarchical network is deployed, the tunnel convergence problem including with duplicated tunnels becomes more and more aggravation so that network performance is to go down.

2.4. Hierarchical mobile multicast: HMoM

In Mobile IPv6 networks, HMIPv6 [30] introduces hierarchical mobility management to allow for local mobility handling. Acting as a local home agent at a visited network, a *Mobility Anchor Point (MAP)* will receive all packets on behalf of the mobile host it is serving and will encapsulate and forward them directly to the current address of mobile host by tunnel. When a mobile host moves within the same MAP domain, it only needs to register its new CoA with the MAP. Using this feature, Wang et al. [36] proposed a speed-based idea for a hierarchical multicast protocol in Mobile IPv6 networks *(HMoM)*, which utilizes the advantages of hierarchical mobility management in handling unicast routing. For HMoM scheme, if a mobile host is expected to stay at a new visited network for a relatively long period of time, it will register to the MAP with the smallest distance and the selected MAP joins the multicast group on behalf of the mobile host. Otherwise, the MAP with the furthest distance is selected as a multicast agent in order to avoid frequent tree reconstruction. The multicast agent is selected dynamically and can be located at any level in a hierarchical network of routers according to the handoff frequency of mobile hosts. However, it remains tunnel-based defects in hierarchical networks. For example, as these mobile hosts with various speeds handoff to a same access network, the multiple MAPs with different distances would be selected. The data delivery firstly aggregate at their MAPs. These MAPs would tunnel them to mobile hosts by multiple unicast. The technology for HMoM degenerates to be as a unicast scheme and it wastes the network bandwidth. Besides, the dwelling time based on history data is adopted in HMoM. It is not transparent for the mobile host because the mobile host always needs to evaluate their speed based on the history dwelling time. Also, this rule is not precise and objective for a complicated hierarchical network environment, especially for mobile multicasting. Therefore, in this paper, a better network performance for multicasting is researched in Section 4 and tunnel-based problems would be resolved within the middle-domain. Moreover, our scheme is transparent to micro-mobility and macro-mobility protocols.

3. Enhanced middle-domain mobility management

For the conventional Mobile IP-based mobility management schemes such as HMIPv6 and FMIPv6 fitted into 802.16 network environment, the tunnel-based problems would happen. These problems would be *tunnel convergence*,[1] *triangle routing* and *IP-in IP Encapsulation problems*. As shown in Fig. 5(a), the HMIPv6 scheme presents that data delivery designated for the mobile host is intercepted by HA and then MAP, the repetitions for tunnels are between

[1] In most of papers, the term for "*tunnel convergence*" is for multicast issue, not for mobility management case (Unicast). But, we think that the similar concept for the repeated tunnels can also be applied in mobility management case for this paper.

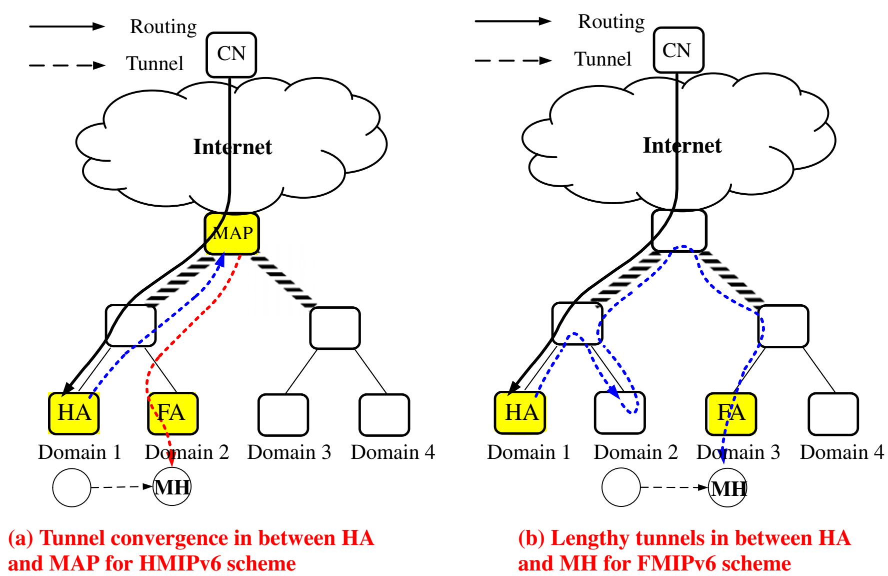

Fig. 5. Tunnel-based problems for conventional Mobile IP-based schemes fitted into 802.16 network environment.

them. Another case for FMIPv6 scheme, as displayed in Fig. 5(b), whenever a high speed MH passes along the different access routers, this technology would be failing. These repetitions for 802.16 network resources would be wasting by applied these conventional Mobile IP-based mobility management schemes. Therefore, we would need to try designing more suitable mobility management technology for 802.16-based network environment. In the previous work [29] for the middle-domain concept fitted in 802.16-based network environment, it has already improved the 802.16 network performance. But, some issues still remain in previous work. In this paper, we would complement these drawbacks and detail them in latter.

3.1. Basic idea

From the concept of the middle-domain as mentioned in related work, the BS can be regarded as a super node to be an agent or proxy of *MIP FAs (Foreign Agents of Mobile IP)*. As illustrated in Fig. 6(a), an efficient routing is presented as *home agent (HA)* located outside the 802.16 network. Corresponding node (CN) is indicated as a source node. External traffic for data packet is sent from CN to HA, the HA intercepts them and tunnels packet to FA of *mobile host (MH)*. Meanwhile, the BS en route intercepts the tunnel packet on behalf of MH's FA since the BS acts as a *Super Foreign Agent (SFA)* to perform MIP FA operations for managing MIP FA in the middle-domain.

On the other hand, the middle-domain can not address the case of HA located within the 802.16 access network since the BS was merely designed for managing a set of foreign agents but not home agents, an inefficient routing emerges. For example in Fig. 6(b), the *Triangular Routing Problem* [31,33] happens since the BS lacks the ability of managing home agents. Therefore, our basic idea for the enhanced middle-domain mobility management in this paper is: besides the idea of SFA-applied, we think that the BS should be also equipped with *MIP HA (Home Agent of Mobile IP)* function-

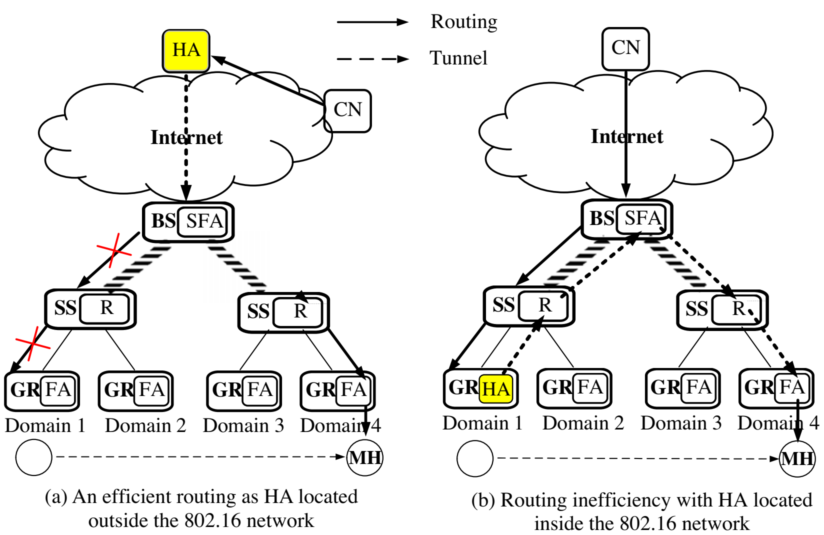

Fig. 6. Mobility management in middle-domain.

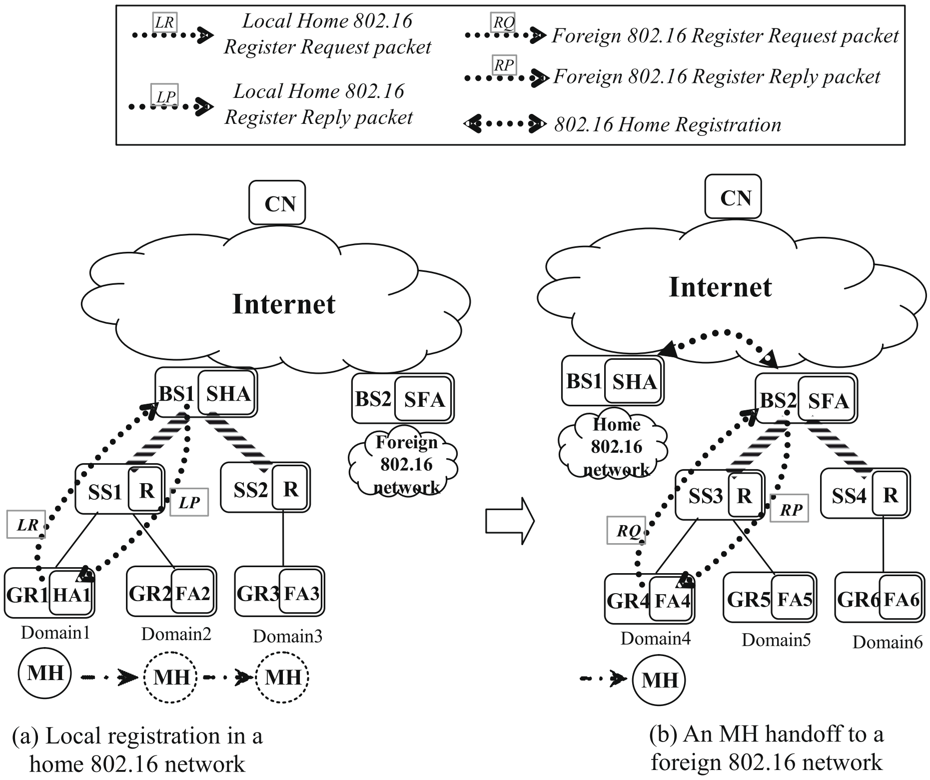

Fig. 7. Location management for SHA/SFA.

ality to be an agent or proxy for managing HAs of mobile hosts. The newly defined term for the BS is called *Super Home Agent (SHA)* in this paper.

In order to solve inefficient routing problem for the middle domain, it is not suitable for only applied either SFA or SHA. We recommend it is better included with both idea of SFA and SHA. Therefore, an enhancement of the middle-domain mobility management associated with SFA and SHA is proposed in this paper. Moreover, we also propose a multicast extension based on SFA- and SHA-applied concepts which will be mentioned in Section 4. Before the present of the multicast service, location management and handoff scheme for mobile host needs to be addressed firstly in next subsection.

3.2. Location management

For the enhanced middle-domain mobility management, SHA manages multiple home agents in home 802.16 network and SFA manages multiple foreign agents in foreign 802.16 network, respectively. As each mobile host stays at home 802.16 network, as illustrated in Fig. 7(a), the micro domain gateway router (i.e. GR1) equipped with home agent (i.e. HA1) functionality is required to perform an *local home 802.16 registration* (new defined packet) with its super node BS (i.e. BS1). Meanwhile, SS and BS en route intercept this registration request in order to perform downlink actions of middle-domain. The BS is regarded as super home agent on behalf of the HA (i.e. HA1) to perform Mobile IP operation. Thus, all data packets sent from CN are first intercepted by the super home agent and it has responsibility to forward these packets along with the downlink cache of the middle domain to MH.

The handoff of an active mobile host results in the change of location for any possible data transmission. Therefore, in order not to let obsolete cache data (i.e. wrong downlink) lead to wrong redirection, the handoff scheme must be mentioned. There are two types of handoff an MH can make as follows: (a) Intra-BS handoff (b) Inter-BS handoff. For case (a), Mobile IP registration can be addressed at a crossover node since en route the downlink cache can be recorded at a shared node on the rooted path. It could reduce the cost for the registration and handoff latency. As shown in Fig. 7(a), MH handoffs from GR1 to GR2 within home 802.16 network, the Mobile IP registration request is only arrived at crossover nodes SS1. Through the operation of Mobile IP, en route the crossover SS1 updates downlink cache to GR2. Similarly, when the mobile host continuously handoffs from GR2 to GR3, BS1 creates downlink cache to SS2 and the SS2 creates its downlink cache to GR3 since the crossover node is at the BS1. Note that for an 802.16 home network in middle-domain, data packets perform a tree-based routing along recorded downlink cache to micro-domain gateway router GR. Once the GR received data packets, it could adopt one of these existed micro-mobility protocols for data delivery to mobile host and it is transparent to micro-domain for each mobile host. On the other hand, for case (b), if a mobile host enters a foreign 802.16 network the first time as shown in Fig. 7(b), the following actions are taken on the intercepted Mobile IP registration request:

(1) *Downlink cache creation*: The mobile host issues a Mobile IP registration request message to its home agent. The BS and SS en route create the downlink location cache for the mobile host.
(2) *SFA actions*: The BS in the foreign 802.16 network allocates a *middle-domain CoA* (denoted by *M-CoA*) for the mobile host. The M-CoA is usually the address of the BS and is used in Mobile IP registration. When the BS received the Mobile IP registration request in the foreign 802.16 network, the BS (with functionality of SFA) issues a Mobile IP registration request which including with the M-CoA to the home agent of the mobile host on behalf of the micro-domain gateway

router GR (with functionality of FA). Meanwhile, the BS sends a Mobile IP reply message back to the GR on behalf of the home agent.

(3) *SHA actions*: The BS (with functionality of SHA) in home 802.16 network en route intercepts Mobile IP registration request issued from SFA, and updates location information of the mobile host into SHA-cache so that a redirection can be established on between SHA and SFA. The super home agent for SHA has responsibility to reply Mobile IP message back to the SFA on behalf of home agent of the mobile host, and simultaneously it should also forward the Mobile IP registration request message with its home agent for completing a Mobile IP procedure.

Signaling flow for a mobile host entering a foreign 802.16 network the first time for Inter-BS handoff is illustrated in Fig. 7(b). Location cache and message sequence chart of Fig. 7 are displayed in Figs. 8 and 9, respectively. Moreover, as a case for the CN located inside a home 802.16 network, the routing scheme requires to be mentioned in next subsection.

3.3. Dealing with CN inside the home 802.16 network

As CN is located inside the home 802.16 network, the routing scheme requires all data packets to be routed to the BS first. Meanwhile, if downlink cache in crossover node provides with destination information, the data packet will be intercepted and redirect the route to the destination. Thus, all data packets should not go beyond the crossover node so that registration cost and handoff latency can be further reduced. For example, as a source node CN initially located at an MH's HA inside the home 802.16 network can act as a mobile host and both must have the local home 802.16 registrations with a super node BS. Meanwhile, SS and BS intercept the registration request issued from the both CN and MH in order to cache the downlink information and perform the proper actions of the middle-domain. As the MH stay away from its HA, Mobile IP registration procedure can be terminated at a crossover node since previously intercepted downlink cache information. Thus, the routing can be redirected at crossover node either SS or BS. The handoff scheme for Intra-SS and Inter-SS as CN located inside a home 802.16 network is illustrated in Fig. 10(a) and (b), respectively.

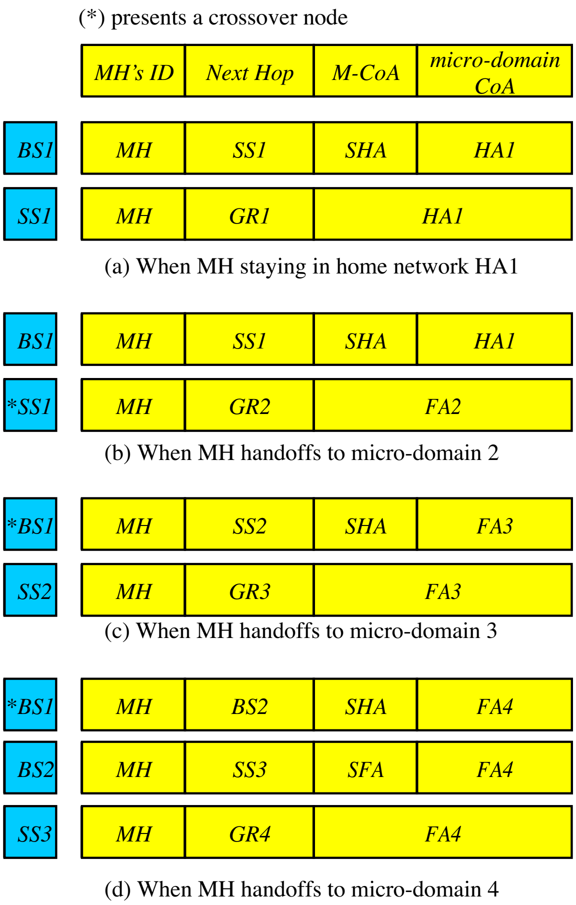

Fig. 8. Location Cache of Fig. 7.

3.4. Data delivery

Data delivery from the CN to an MH is explained as follows. As illustrated in Fig. 11, data packets destined to an MH's home address are first intercepted by the SHA. Since the care-of-address of middle domain registered for mobile host is the M-CoA, the SHA tunnels packets to the SFA by using an allocated M-CoA address. The SFA decapsulates the received packets and forwards them to the correct GR according to the location cache maintained by the BS and SS. Lastly, forwarding of the packets within a micro-domain is based on one of these micro-mobility protocols, which can be either tunneling-based (e.g. MIP-RR[37]) or routing-based (e.g. CIP [15–18]).

Similar to CIP, data packets transmitted by mobile host in 802.16-middle domain are first forwarded toward the gateway BS. However, the handling of the internal data flow is more efficient in the middle-domain as explained in the following. Since BS and SS maintain the location cache for each mobile host and if the data packets are destined to the other mobile hosts in the same 802.16-middle domain, the crossover node between micro domains will identify the corresponding location cache for the destination MH and relay data packets to correct downlink location.

3.5. Simulation study

One 802.16 network is created in the simulation as illustrated in Fig. 12. One base station (BS) connects to Internet, four subscriber stations (SS) and four micro-domains (i.e HA or FA) are connected to the BS and SS, respectively. There are mobile hosts from range 5 to 100 assigned in the network. In the beginning of the simulation, these initial mobile hosts are uniform distributed in the micro-domains which include one HA and fifteen FAs. Time is slotted in the simulation and each mobile host leaves its current micro-domain and moves to one of the neighboring micro-domains with probability 50% for every time slot. The total number of samples for the simulation is about 50,000 simulated topologies, and each sample performs 100 time slots. The total run time is 5,000,000 time slots. Details of the simulation parameters are displayed in Table 1.

Three performance criteria are defined for comparing our proposed scheme and the conventional MIP-applied contrasts: (1) the *average binding cost*, (2) the *average handoff latency* and (3) the *average routing cost*. The average binding cost is total accumulated registration cost for MHs' handoffs per time slot, and the average handoff latency is defined as the total accumulated time to complete binding update after handoffs for each time slot. The average routing cost indicates that the routing path is from the source CN to delivery data to the MH.

Fig. 13 shows the average number of control packets for accumulated binding update of MHs per time slot in comparing with enhanced middle-domain mobility management (i.e. SHA + SFA scheme) and conventional MIP-applied contrast schemes for IEEE 802.16. Fig. 13 has demonstrated that the proposed enhancement

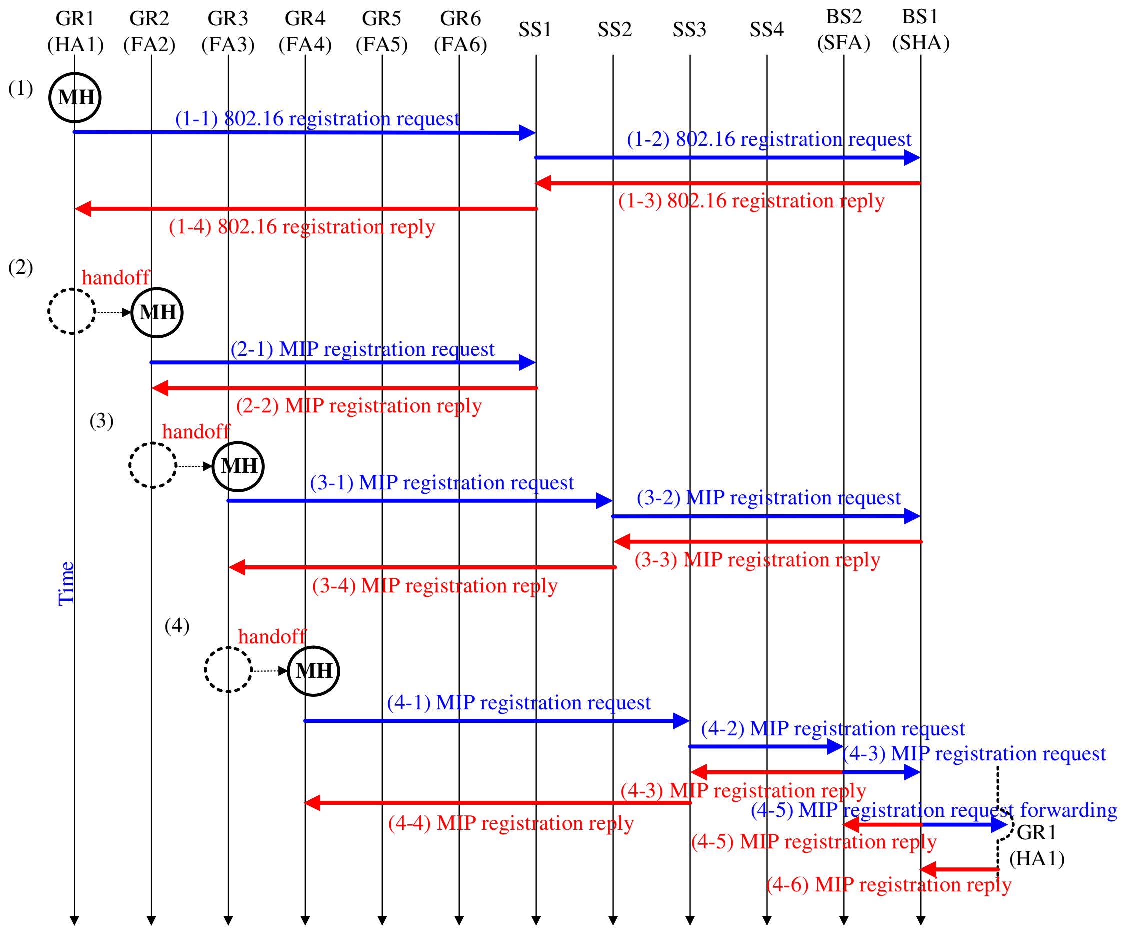

Fig. 9. Message sequence chart for Fig. 7.

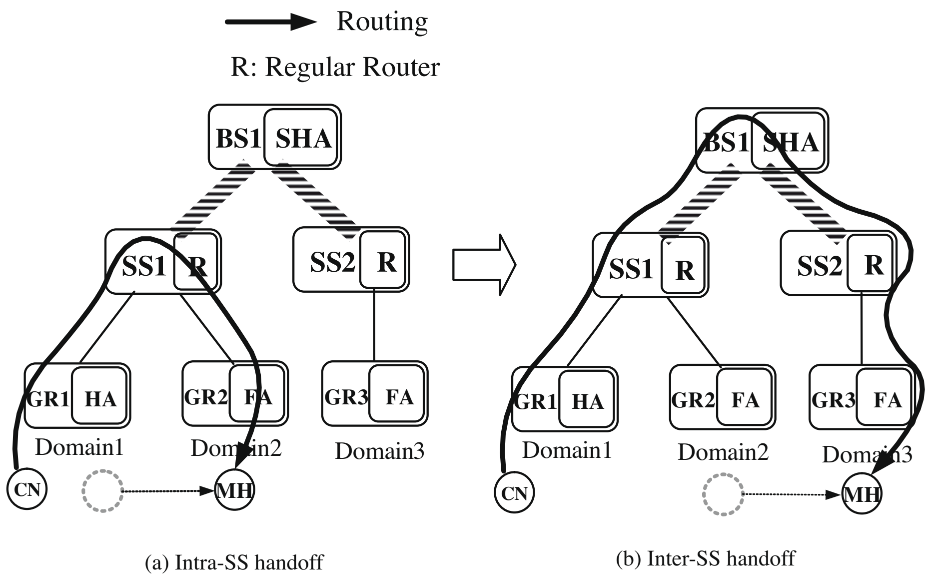

Fig. 10. Location management as CN located inside a home 802.16 network.

with idea of SHA and SFA-applied has significantly reduced binding cost in comparing with the contrast schemes, because of localized registration. Performance of the average handoff latency is displayed in Fig. 14. Because FMIPv6 scheme can perform pre-handover actions so that handoff latency is very small, we merely consider in three cases for SHA/SFA, HMIPv6 and Mobile IP in Fig. 14. The relation of Figs. 13 and 14 is presented in the following as they have the same trend in the results. For each MH's handoff

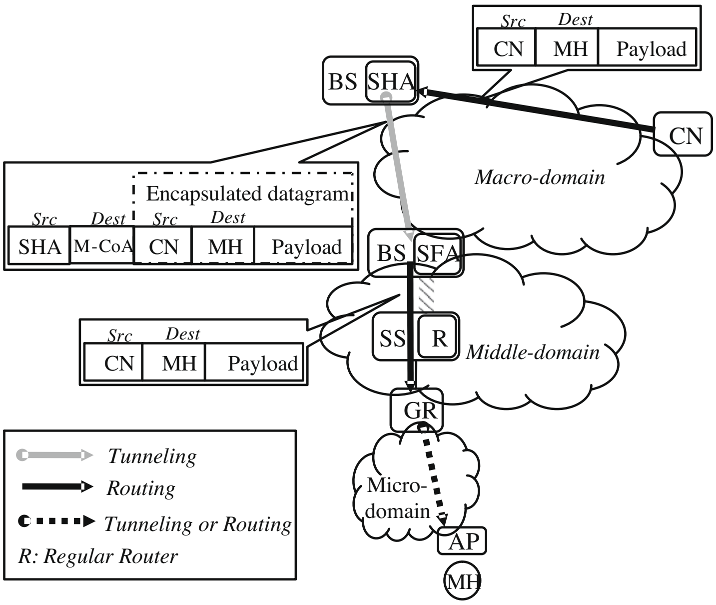

Fig. 11. Data delivery by using the idea of SHA and SFA.

in MIP scheme, the signaling control packets including with home registration request and reply message need to be addressed in between MH and HA. For FMIPv6 scheme, besides of the MIP-applied home binding cost, the pre-handover cost for significant number of binding updates also needs to be mentioned. For HMIPv6 scheme, the binding update messages are always delivered to its highest MAP location (i.e. BS) per handoff for each MH, regardless of the neighboring location for MHs. However, with SHA and SFA-applied idea, MIP registered procedure should not go beyond the crossover node. The registration cost and handoff latency are

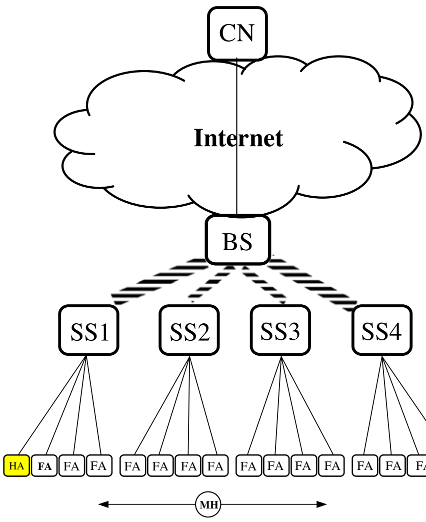

Fig. 12. Simulation environment.

Table 1
Simulation parameters.

MH# = 5, 10, 20, 40, 60, 80, 100	
Samples = 50,000	
Per sample performs 100 time slots	
Handoff probability = 0.5	
Horizontal move	
Signal cost unit	$S_{MH\text{-}FA}$, $S_{MH\text{-}HA}$, $S_{FA\text{-}SS}$, $S_{HA\text{-}SS}$, $S_{SS\text{-}BS}$(1 cost unit each)
Delay time	$L_{MH\text{-}FA}$ = 1 Time Unit $L_{MH\text{-}HA}$ = 1 Time Unit $L_{FA\text{-}SS}$ = 2 Time Unit $L_{HA\text{-}SS}$ = 2 Time Unit $L_{SS\text{-}BS}$ = 3 Time Unit
Routing path	$P_{CN\text{-}BS}$ = 100 hops

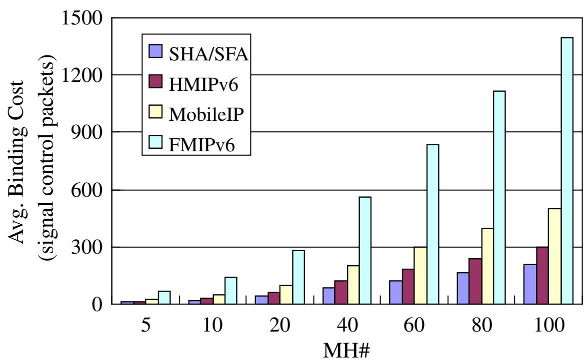

Fig. 13. Average binding cost for each time slot.

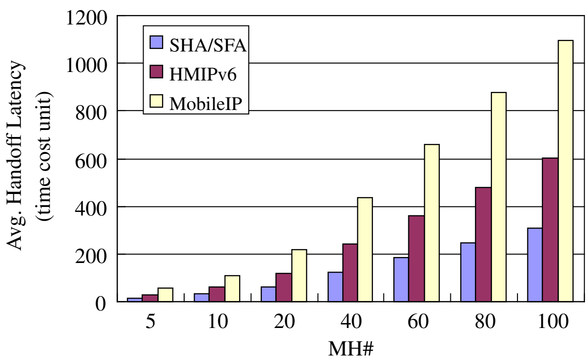

Fig. 14. Average handoff latency for each time slot.

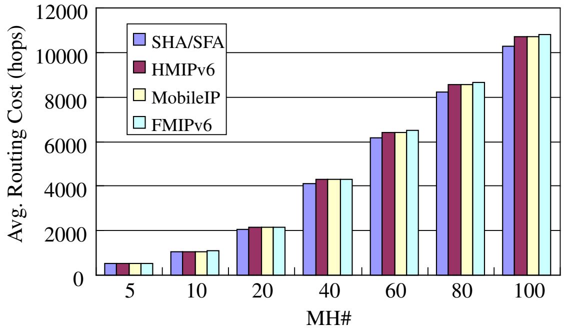

Fig. 15. Average routing cost for each time slot.

only terminated at a crossover to show the same trend in less cost evaluation.

The average routing cost in different number of MHs for comparing with our scheme and conventional MIP-applied schemes is displayed in Fig. 15. Fig. 15 shows that the proposed SHA/SFA mobility management scheme outperforms conventional MIP-applied mobility management schemes (without idea SHA/SFA) in terms of average transmission cost. In order to achieve seamless handoff, FMIPv6 uses pre-handover technology to build a forwarding tunnel path so that the routing cost becomes increasing. If a high-speed MH moves along different wireless areas, the routing make the 802.16 network performance degenerate. To avoid the routing cost increases too fast so that the simulation graph can be well displayed, we limit the lengthy routing from FMIPv6 in the simulation. That is whenever an MH passes twice in between wireless areas, the binding update should be addressed by its HA to shorten the routing path. The routing cost is thus reduced, but it still keeps a worst case in comparing with the other schemes. Please note that this simulation for mobility management is mainly focused within a home 802.16 network, but not in case for HA outside of the 802.16 network. Moreover, for the simplicity, in case of route optimization (RO) for the simulation would be ignored since the proposed SHA/SFA mobility management scheme can also apply the RO easily. The considering is simple, fair and acceptable.

4. Hierarchical multicast protocol (HMP)

4.1. Inefficient routing problems

As mentioned in the related work, HA-based multicast extension, i.e. MoM over BT[2], has enhanced the performance of BT. The MoM scheme maintains scalability through the use of a *designated multicast service provider (DMSP)* optimization per multicast group for each foreign network, and the use of dynamic multicast tunnels to foreign networks for solving inefficient tunnel of BT scheme. However, for MoM applied in 802.16 network environment, if the BS is merely regarded as a regular router without adopting the idea of SHA and SFA, some inefficient multicast routing problems emerge as explained in the following:

(1) *Triangular routing*: As illustrated in Fig. 16(a), two-fold routing happens within the 802.16 network. Multicast datagrams destinated to MH are firstly intercepted by HA, and HA tunnels the data to FA in which MH's current point of attachment. Meanwhile, the path between HA and BS is passed twice for data delivery. Thus, the transmission time is delayed.

(2) *Duplicate tunnels*: As an HA tunnels the multicast packets to a group of FAs, the number of tunnels is related to the number of FAs in which MH's current point of attachment. For example in Fig. 16(b), there are two duplicate packets sent separately from HA to two FAs by tunneling. This wastes the network bandwidth.

(3) *Tunnel convergence problem*: The multiple tunnels result from different HAs to go through a common BS, and terminate at MHs' FAs. In Fig. 16(c), it shows a tunnel convergence problem for 802.16-based network environment as the BS has not the ability to appoint a DMSP from one of multiple HAs. The BS is passed three times and it results in higher traffic load in the BS.

(4) *Frequent DMSP handoff*: For MoM, if there are multiple visitors from their different HAs to arrive at the common foreign network, any mobile host handoff may make DMSP handoff occurs. For example in Fig. 16(d), the mobile hosts M1 and M2 are far from their home agents HA1 and HA2, respectively, and the tunnels are quite long. Assume that the common foreign agent FA designates HA1 to be a DMSP (not HA2) for serving the mobile hosts M1 and M2. Once the DMSP member M1 handoff, the DMSP handoff should also occur. Moreover, as a mobile host handoff occurs, its home agent can learn the mobile host's new FA immediately by using Mobile IP registration procedure. But the previous FA can not know the handoff until timeout. Thus, before the new DMSP is selected, none will serve the mobile hosts within the previous network. Multicast packets for mobile hosts will be lost during this period.

In summary, once one of these problems happen as mentioned above, we call the multicast meeting a *Hierarchical-based Tunnel Convergence Problem (H-TCP)* in this paper. If the BS could also act as Mobile IP HA or FA to manage multicast, the H-TCP problem can be solved well. Therefore, we consider adopting the idea of SFA and SHA of middle-domain mobility management to enhance the 802.16-based multicast service. This is also the basic idea of designing the HMP scheme. Moreover, in order to simplify the design of the HMP scheme, the multicast solution can be researched in two parts: (1) *multicast within the middle-domain* and, (2) *multicast outside the middle-domain*. Two cases are detailed in Subsections 4.2 and 4.3, respectively.

4.2. Multicast within the middle-domain

In HMP, the BS is responsible for group membership management. As illustrated in Fig. 17, data traffic is first intercepted by the BS and multicasting among group members requires related nodes in the multicast tree to maintain proper membership information for the group. Therefore, we design a simple cache structure for the middle-domain to achieve this goal. Group downlink cache records members' ID of a group that a downlink can lead to and helps in transmitting multicast packets to proper downlinks. The group downlink includes the following fields: (1) *Group ID*, (2) *Downlink ID*, (3) *ID of the group members this downlink can lead to*. Manipulation of the group downlink is presented in the following.

When a mobile host wants to join a group, it sends out an *IGMP-Join (Internet Group Management Protocol)* message to its micro domain gateway router GR. The IGMP-Join message is then forwarded along the uplink path to the BS. Each en route node that relays the IGMP-Join message establishes group downlink cache for the newly member. For example, in Fig. 18(a), mobile host M1 is the first member to join/create group G1. When the BS has received the

[2] In *BT (Bi-directional Tunneling)* technology, an inefficient multiple unicast is adopted for data delivery. The new term "*MoM over BT*" presents a multicast extension of BT, which means that the design of the MoM scheme is also based upon the BT technology or environment.

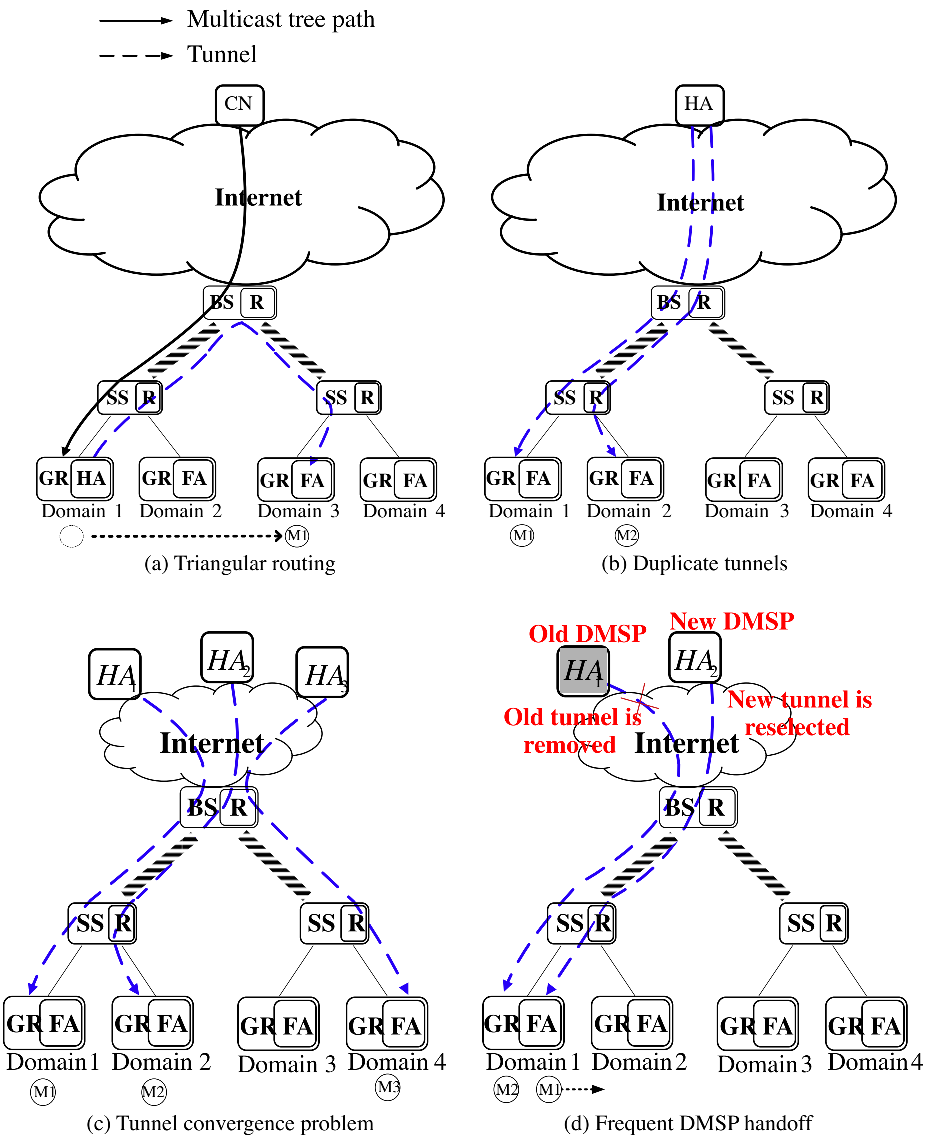

Fig. 16. Problems for the BS without SHA and SFA functionalities in mobile multicast routing.

IGMP-Join message issued by M1, a group downlink path for M1 has been established. Similarly, mobile hosts M2 and M3 want to join group G1, M2 and M3 send out IGMP-Join messages which

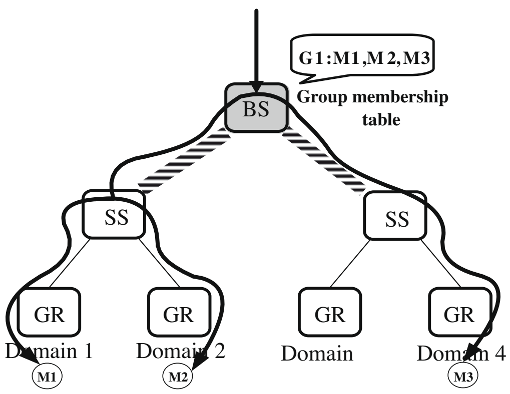

Fig. 17. Multicast traffic propagated into the middle-domain.

help establishing the group downlink cache in Fig. 18(b) and (c), respectively. Location cache for the HMP-tree of Fig. 18 is displayed in Fig. 19.

HMP-tree of a group needs to be updated when a group member moves to a new GR. Thus, the handoff scheme in HMP has to deal with the update of the group downlink when the handoff of a group member occurs. Two new signal messages for manipulating the group downlink cache during the handoff of group members are defined in HMP: *HMP handoff-join* and *HMP handoff-leave*. After group member handoffs to new GR but Intra-BS, it sends out an HMP handoff-join message to the new GR. The message is forwarded by GR along the uplink path until it arrives at the crossover node (SS or BS) of the handoff. The crossover node then sends out an HMP handoff-leave message along the downlink path to clear the obsolete group downlink caches in case of Inter-SS but Intra-BS as shown in Fig. 20(a). Moreover, there is not requirement for HMP handoff-leave message in Inter-GR but Intra-SS handoff. For example in Fig. 20(b), HMP handoff-join message issued by a mobile host M2 is only terminated at crossover node SS2. The HMP handoff-leave message is ignored since the downlink

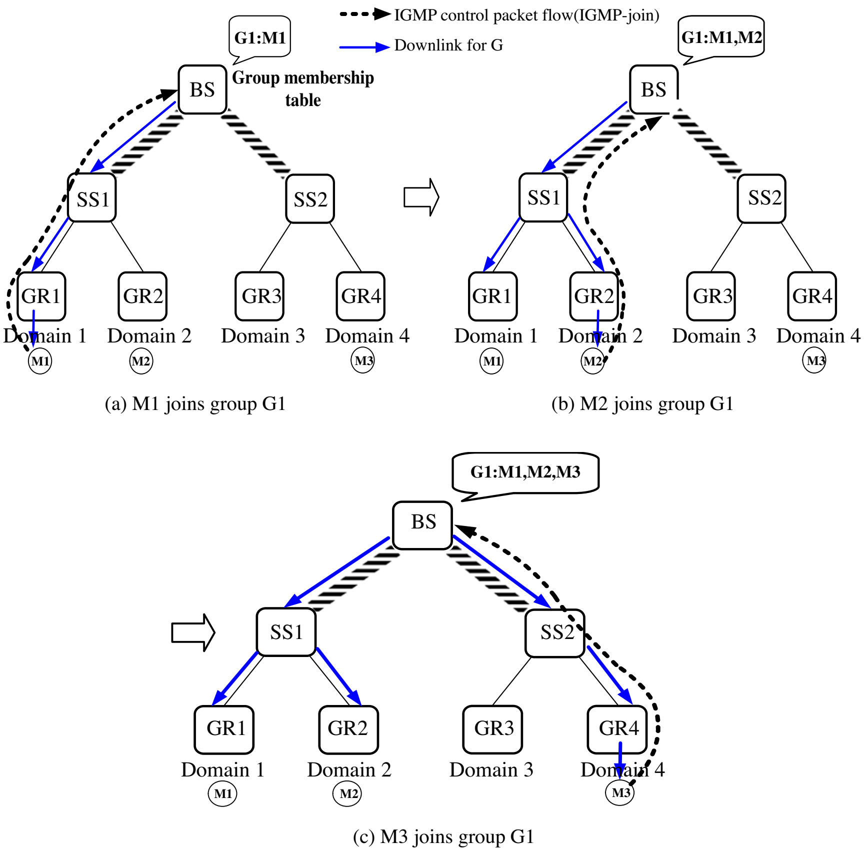

Fig. 18. Constructing HMP-tree.

cache information for SS2 has been updated from micro-domain GR3 to micro-domain GR4.

4.3. Multicast outside the middle-domain

When a mobile host enters to a new foreign 802.16 network the first time, it is regarded as a complicated network environment which consists of micro-, middle- and macro-domains as shown in Fig. 21(a). However, by introducing the idea of SHA and SFA, a *Reduction Process (RP)* for 802.16 networks is proposed in the following viewpoints. First, the 802.16 BS is required to be equipped with MIP HA and FA functionalities for managing proper actions of middle-domain. Second, the BS1 can be regarded as a super home agent on behalf of a group of HAs within the home 802.16 network and the BS2 can be regarded as a super foreign agent on behalf of a group of FAs within the foreign 802.16 network, respectively. Actually, the SHA and SFA can be similarly as functions HA and FA of MoM-applied scheme. Therefore, a complicated 802.16-based network environment can be easily reduced to a simpler 802.16 network environment namely *MoM over BT network environment* in Fig. 21(b). Moreover, the idea of SHA and SFA applied hides host mobility in the middle-domain as mobile host handoffs between 802.16 networks.

	Group ID	Next Hop	Member
BS	*G1*	*SS1*	*M1,M2*
		SS2	*M3*
SS1	*G1*	*GR1*	*M1*
		GR2	*M2*
SS2	*G1*	*GR4*	*M3*

Fig. 19. Location Cache of HMP-tree in Fig. 18.

In the reduced 802.16 network environment, SHA acts as an HA of MoM over BT network environment to join multicast group with CN. The multicast traffic presented in between the macro-domains (Internet) can be addressed by MoM over BT which associates with idea of SFA and SHA, and once the traffic continuously propagated into the middle-domain, it can be addressed by HMP-tree of the middle-domain as mentioned above in Subsection 4.2. The multicast data delivery for the reduced 802.16 network is shown in Fig. 22(a). In order to provide clearer present for readers, a flowchart for HMP-tree based routing of the middle-domain associated with MoM over BT of macro-domain is displayed in Fig. 22(b). Please note that our proposed HMP scheme for the multicast service is based upon the Mobile IP registration procedure (unicast method) to achieve the multicast service, which is also similar that the MoM (philosophy) is based on Mobile IP to do multicast. But, we specially improve the network performance of MoM in hierarchical-based network environment via our proposed idea in SFA and SHA.

4.4. Designated multicast service provider (DMSP)

In this paper, we consider that the BS is better with DMSP function because of the tunnel convergence problem. A tunnel convergence problem for 802.16 network results from multiple tunnels to

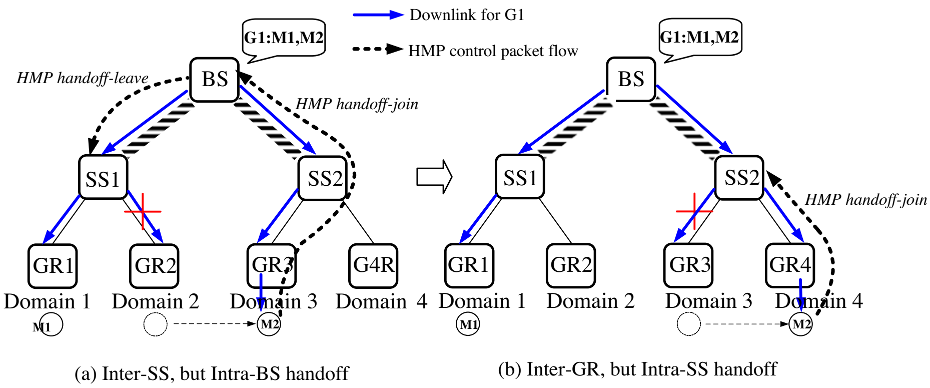

Fig. 20. Mobile host handoff within an 802.16 network.

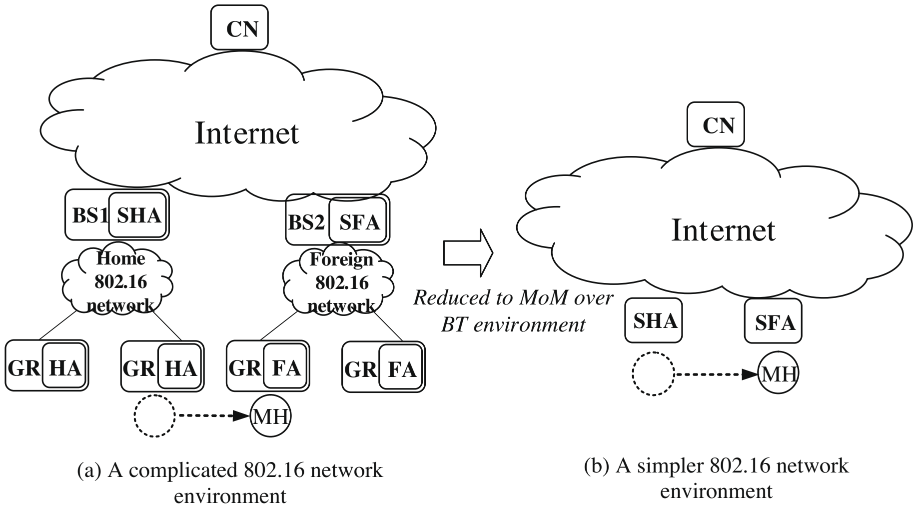

Fig. 21. The reduction process from complicated to simple 802.16-based network environments.

go through a common BS. If the idea of SHA and SFA can be applied, SFA would with a DMSP ability for performing a selection to appoint one of multiple SHAs. The designated multicast service provider for SFA can only receive one copy of each multicast datagram. For example, in Fig. 23, one of super home agents SHA1, SHA2, and SHA3 is selected to be a DMSP by SFA. Only one copy (rather than three) of the datagrams will be received by SFA. Therefore, our proposed HMP scheme has a better scalability particularly as the number of mobile group members increases.

4.5. Simulation study

4.5.1. Simulation environment and performance criteria

Network topology for 802.16 in simulation is 8×8 mesh as shown in Fig. 24. For the simulation, we refer from the theoretical environment of our previous work[29]. Each node in the mesh represents a base station (BS). Four subscriber stations (SS) are connected to one BS, and four micro-domains (GR) are connected to one SS. Initialized location for super home agents is uniform distributed in 8×8 mesh networks. Mobility model for mobile hosts is adopted by *Random Way Point* [38]. In order to model the mobility of the hosts, time is slotted and each mobile host leaves its current micro-domain to one of the neighboring micro-domains with probability 50% for every time slot. Details for simulation parameters are displayed in Table 2.

To evaluate the performance of the HMP, we create 1000 groups and build corresponding HMP-Tree with a given SHA size. Corresponding node (CN) is randomly located at a micro-domain in the beginning of the simulation. Total run time in the simulation is 500,000 time slots, mobile hosts of each group can move for 10 time slots in order to research the effect for HMP-tree and handoff scheme. After for each 10 moving time slots, network topology and simulation parameters should be re-initialized. There are 50 repetitions for 1000 groups in the simulation, which present that there are totally 50,000 samples (network topologies) simulated in this work. Some performance criteria are defined as follows:

(1) *Transmission cost.*
(2) *Multicast delivery ratio.*
(3) *Number of DMSP handoffs.*
(4) *Tree maintenance cost.*
(5) *Signaling overhead.*

The average transmission cost is defined as the total number of data packets to transmit a packet to all group members. Multicast delivery ratio is calculated as the ratio of the transmitted packets for tunneling and multicasting (tree-based routing). The average

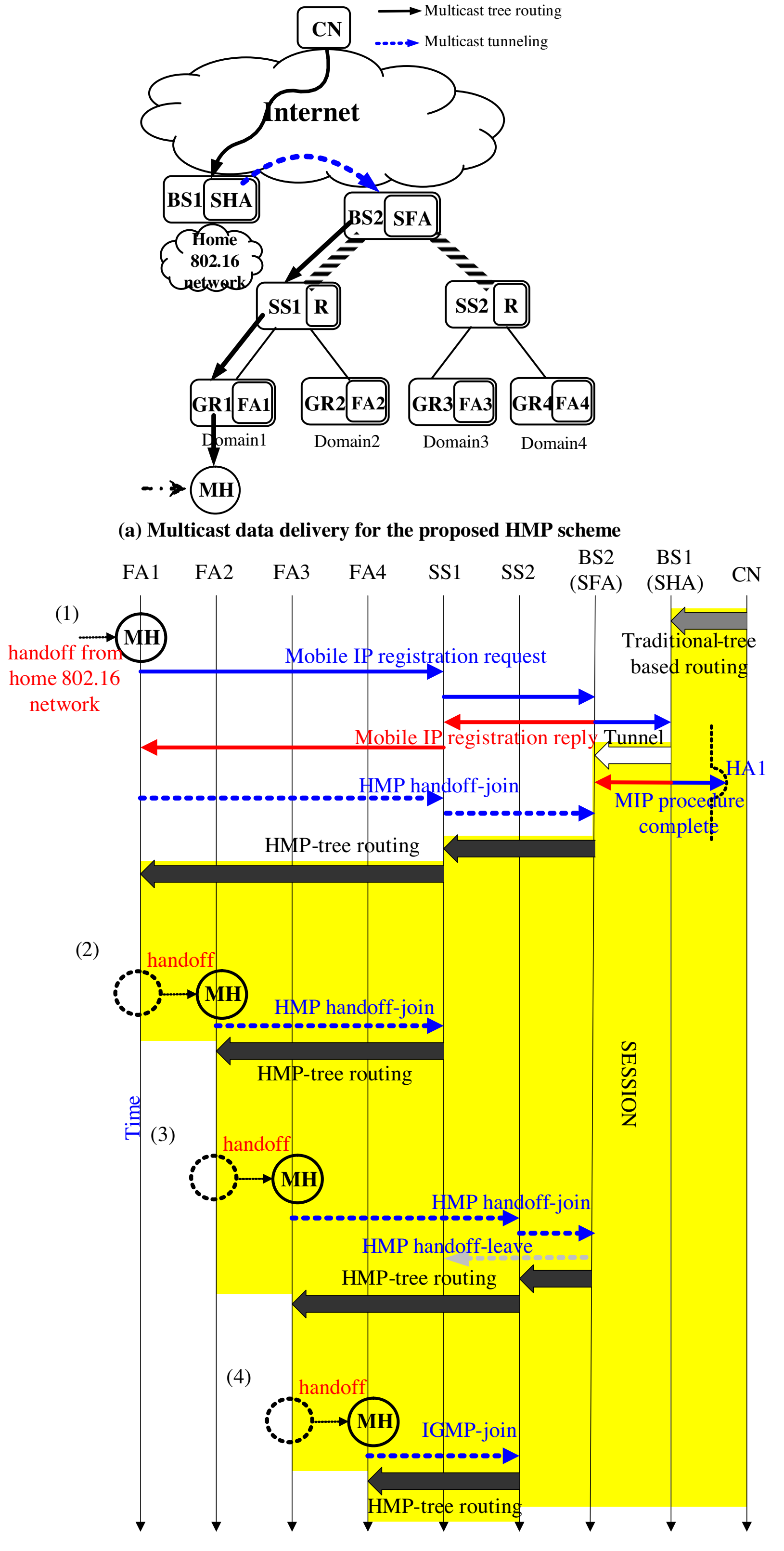

Fig. 22. The operation for HMP scheme in 802.16-based multicast service.

number of DMSP handoffs calculates total number of DMSP handoffs for each group. Tree maintenance cost is the average number of modified links which are grafted and lifted in the multicast tree when a mobile host handoffs. Signaling overhead is calculated as follows. With HMP, the signaling overhead includes the control packets in home registration, DMSP handoff and group manage-

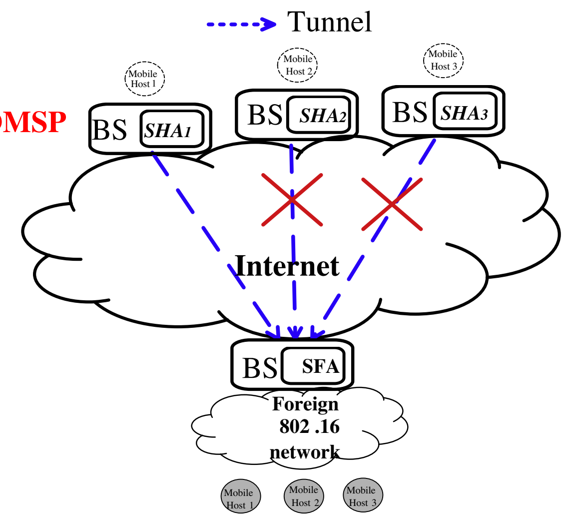

Fig. 23. A function of designated multicast service provider (DMSP) in SFA.

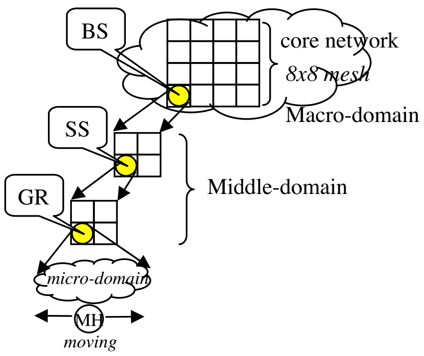

Fig. 24. Network topology for the simulation.

Table 2
Simulation parameters.

Mesh network: 64BSs (8 × 8 mesh), 1BS = 4SSs, 1SS = 4GRs
Number of CN = 1, Handoff Probability = 0.5
Total run time = 500,000 time slots
Number of SHA(SHA size) = 1–10, 1SHA = 16HAs = 16 MHs,
Number of MH in each HA = 1
Link latency: $L_{GR\text{-}SS}$ = 2 ms, $LS_{S\text{-}BS}$ = 3 ms, $L_{BS\text{-}BS}$ = 5 ms
Mobility model: *Random Way Point*

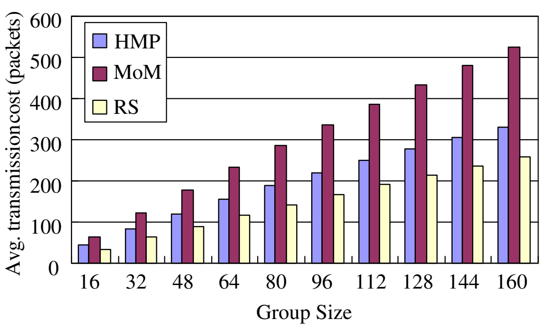

Fig. 25. Average transmission cost (handoff probability = 0.5).

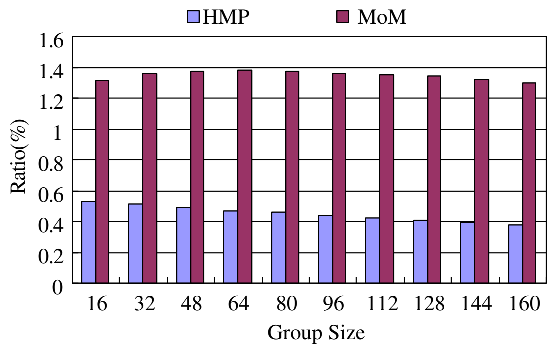

Fig. 26. The ratio for tunneling path and multicast tree path (handoff probability = 0.5).

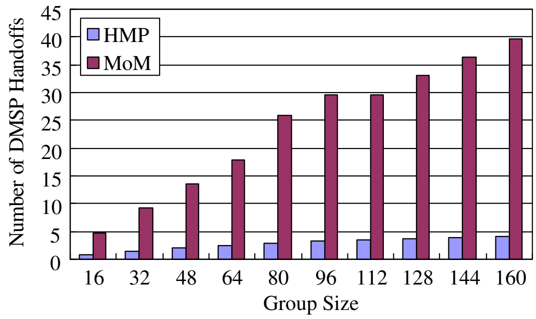

Fig. 27. Average number of DMSP handoffs per group (handoff probability = 0.5).

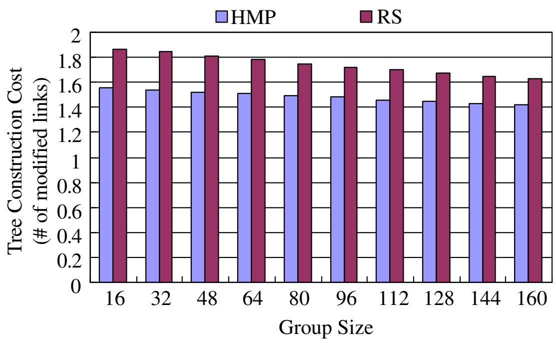

Fig. 28. Average number of modified links per handoff in tree reconstruction (handoff probability = 0.5).

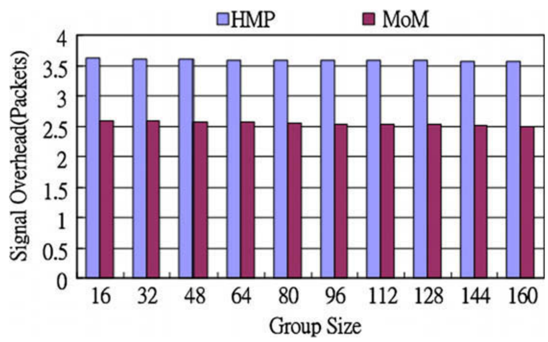

Fig. 29. Average number of control packets per handoff (handoff probability = 0.5).

ment. With MoM, control packets for home registration and DMSP handoff are involved in the overhead.

4.5.2. Simulation results

The average transmission cost and multicast ratio in different group sizes for HMP and MoM are displayed in Figs. 25 and 26 respectively, and the ideal case (i.e. RS) for optimal routing path is also displayed in Fig. 25 for comparison. Fig. 25 shows that proposed HMP outperforms MoM (without idea SHA/SFA) protocol in terms of average transmission cost. Moreover, Fig. 25 also shows that HMP can save up to 31% of the transmission cost over MoM for group size 16, and for a large group size (e.g. 160), 37% of the transmission cost can be saved by HMP. The main reason is that more triangle routing for tunnels is adopted in MoM. Though the property of the tunnel has scalability for MoM as shown in Fig. 26, triangle routing problem brings out of network performance degradation for comparing with our proposed HMP scheme. A curve (or ratio) to rise and then fall for MoM in Fig. 26 is explained as follows. As group size gets larger, more tunnels need to be sent from MH's home agents, and the saturation for tunnels is achieved in group size 64. Therefore, the cost for tunnels is to rise. Once the group size increases to 160, MoM shows a better performance since multiple MHs arrive at a common FA to share a tunnel (i.e. from a common DMSP), which means that more group members can share a common DMSP tunnel. Thus, the cost for tunnels is to go down as group sizes is greater than 64.

Fig. 27 shows the average number of DMSP handoffs for each group with different group size for comparing with HMP and MoM. For comparing with MoM, HMP can save about 83% DMSP handoffs as the group size is small (i.e. 16). On the other hand, there is about 89% DMSP handoffs can be reduced by HMP as the group size is large (i.e. 160). Thus, Fig. 27 implies that our proposed HMP scheme has a good property and scalability in dealing with DMSP handoff.

To investigate the overhead of HMP in dealing with the handoff of a group member, we calculate tree maintenance cost and signal control packets in Figs. 28 and 29, respectively. Fig. 28 shows the average number of modified links in the tree reconstruction per handoff to compare with HMP and RS. HMP shows the better result than RS since tree reconstruction does not go beyond a crossover node. Though proposed HMP scheme sacrifices a little signal overhead than MoM in Fig. 29, it implies good routes for delivery of multicast datagrams to mobile hosts in Fig. 25, much less of tunnels in Fig. 26, smaller DMSP handoff times in Fig. 27 and smaller tree maintenance cost in Fig. 28.

5. Theoretical analysis

5.1. Theoretical environment and parameters setup

The theoretical environment for the analysis of the hierarchical architecture is displayed in Fig. 30. We assume there are x BSs located in the core network (Internet), each BS comprises ℓ SSs, and each SS comprises ℓ GRs (HA or FA). Each of the other base stations has the same structure with the BS_0. The leaves of BS_0 are HAs, while those of other BSs are FAs. The distance from CN to each BS is equal (h hops). Suppose there are m MHs in BS_0, which are all members of multicast group G, and distribute uniformly in the n HAs. Once mobile hosts handoff, all m MHs are considered to be distributed uniformly to the other base stations among $x-1$ BSs. In this paper, it is not easy to make a precise performance comparison for all proposed schemes, we mainly refer to the calculation of multicast cost of literature [45] in formulas (1)–(3) as follows:

The probability of k ($k \leqslant \min(n,m)$) HAs having at least one MH connecting with them is:

$$P_k = C_n^k \frac{\sum_{i=0}^{k-1}(-1)^i C_k^i (k-i)^m}{n^m} \tag{1}$$

Then the mathematical expectation of k is derived in:

$$\overline{K}_{HA} = \sum_{k=1}^{\min(n,m)} kP_k \tag{2}$$

In literature [45], a r-*layer* tree (with ℓ-*branches* for each parent node), has ℓ^{r-1} leaves. The hops of the multicast distribution tree between the root and the a leaves of those ℓ^{r-1} leaves are (summing up the distribution tree branches of the $r-1$ layers):

$$C_{multicast}(a,r) = \sum_{i=1}^{r-1} \sum_{k=1}^{\min(a,\ell^i)} kC_{\ell^i}^k \frac{\sum_{t=0}^{k-1}(-1)^t C_k^t (k-t)^a}{\ell^{ai}} \tag{3}$$

5.2. Calculation of the multicast cost

The multicast cost presents the calculation of the average number of hops for a multicast packet to arrive at MH. The link from

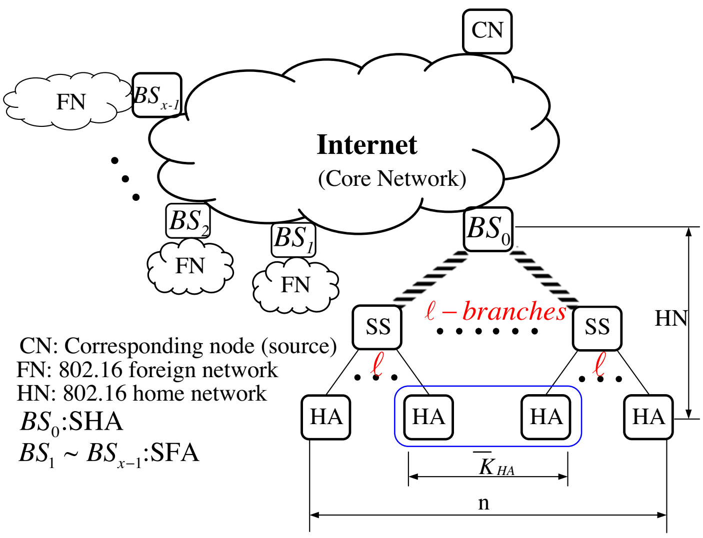

Fig. 30. Theoretical environment.

leaf to mobile host is regarded as one hop. In the following, we calculate the multicast performance for each scheme.

(1) Bi-directional tunnel (BT) scheme

In BT scheme, the mobile host receives all multicast datagrams by its HA using unicast tunnels. Thus, the cost for a multicast packet arriving at m MHs is:

$$Total_{BT} = h + C_{multicast}(\overline{K}_{HA}, 3) + m(2 + Tunnel_{Avg.} + 3) \quad (4)$$

The first term on the right side in (4)) is the cost for one multicast packet to arrive at BS_0 from CN. The second is the cost for this packet to arrive at $\overline{K}_{HA}$ HAs through a *r-layer* (i.e. 3-*layer*) multicast tree. The third is the cost for HAs to forward this packet to m MHs by tunnel. The term $Tunnel_{Avg.}$ indicates the average number of hops for tunneling in between base stations.

For the calculation in (4), we get the average cost of BT scheme as follows:

$$C_{BT} = \frac{1}{m} Total_{BT} = (5 + Tunnel_{Avg.}) + \frac{h + C_{multicast}(\overline{K}_{HA}, 3)}{m} \quad (5)$$

(2) MoM scheme

MoM uses the DMSP to solve tunnel convergence problem. Thus, there is only one copy of the multicast datagrams tunneled from HA to an FA in the event that HA has multiple MHs present there. The average cost for MoM is calculated in:

$$C_{MoM} = \frac{1}{m}[h + C_{multicast}(\overline{K}_{HA}, 3) + \overline{N}_{FA}(2 + Tunnel_{Avg.} + 3)] \quad (6)$$

In (6), the first term and second term in the bracket are the same as formula (4). The third is the cost for DMSP to forward multicast packets to $\overline{N}_{FA}$ FAs by tunnel. The $\overline{N}_{FA}$ is different from literature [45] and we present as follows:

$$\overline{N}_{FA} = \overline{S}_{BS} \times \overline{F}_{FA} \quad (7)$$

Adapting to philosophy concept of formulas (1) and (2), the probability of S BSs of those $x-1$ BSs having at least one MH connecting with them is:

$$P_S = C^S_{x-1} \frac{\sum_{i=0}^{S-1}(-1)^i C^i_S (S-i)^m}{(x-1)^m}$$

The mathematical expectation of S is:

$$\overline{S}_{BS} = \sum_{S=1}^{\min(x-1,m)} SP_S \quad (8)$$

The average number of mobile hosts for each one BS can be easily calculated in:

$$\overline{BS}_m = \frac{m}{\overline{S}_{BS}} \quad (9)$$

Thus, the average number of F FAs having at least one MH connecting with them under each one BS is calculated as $\overline{F}_{FA}$ (the mathematical expectation of F):

$$\begin{cases} \overline{F}_{FA} = \sum_{F=1}^{\min(n,\overline{BS}_m)} FP_F \\ \text{where } P_F = C^F_n \frac{\sum_{i=0}^{F-1}(-1)^i C^i_F (F-i)^{\overline{BS}_m}}{n^{\overline{BS}_m}} \end{cases} \quad (10)$$

(3) Remote subscription (RS) scheme

In this case, an MH must resubscribe to its desired multicast group each time it enters a foreign network. Thus, the average cost of RS scheme is:

$$C_{RS} = \frac{1}{m}[\overline{S}_{BS} \times (h + C_{multicast}(\overline{F}_{FA}, 3) + \overline{F}_{FA})] \quad (11)$$

In (11), the first term in the bracket is the cost for the average number of BSs having at least one MH connecting with them, and the remained terms are the cost to forward multicast packets to MHs.

(4) Our scheme

For our proposed HMP scheme, all multicast data arrives at BS_0 (i.e. SHA) from CN and SHA has responsibility to forward them to those SFAs which the mobile hosts attached. The average cost of HMP scheme is:

$$C_{HMP} = \frac{1}{m}[h + \overline{S}_{BS} \times Tunnel_{Avg.} + \overline{S}_{BS} \times (C_{multicast}(\overline{F}_{FA}, 3) + \overline{F}_{FA})] \quad (12)$$

In (12), the first term in the bracket is the cost for one multicast packet to arrive at BS_0. The second is the cost for the SHA tunnels to those SFAs between base stations in the core network. The third is the cost for those SFAs to forward multicast packets via middle-domain multicast tree to MHs.

5.3. Numerical results

For calculating numerical results, we need to set several parameters as follows. The h and $Tunnel_{Avg}$ is set to 100 hops. The x is set to 11 base stations. The BS_0 presents a SHA node and the BS_1 to BS_{10} indicate the SFA nodes. For evaluating our 3-tier architecture of multicast tree in the middle-domain, we set ℓ-branches to 2 (binary tree) and set r-layer to 3. The number of mobile hosts for the parameter m is set in range 20–160. The average multicast costs in different m under the parameter setting are displayed in Fig. 31. The figure brings out some performance characteristics of four schemes as explained in the following:

1. In Fig. 31, as the number of mobile hosts increases, the proposed HMP scheme outperforms BT and MoM schemes in terms of the average multicast cost because of the redirection in between SHA and SFA (not in between HA and FA). Moreover, compare with RS scheme (i.e. the ideal case for the shortest path), the proposed HMP scheme is near to the optimal routing of RS.
2. For MoM scheme in Fig. 31, the curve to rise and fall as the number of mobile hosts increasing is explained as follows. Since the cost for tunnel is highly relationship with the number of FAs (i.e. $\overline{F}_{FA}$), the probability for FAs having at least one MH connecting with them under a BS is small as m is less than 40. Therefore, the cost increases. On the other hand, the probability for FAs is large as the number of mobile hosts increasing in greater than 40, the cost decreases. The main reason is based on the idea of the DMSP of MoM scheme which has demonstrated the same scalability as mentioned above in the simulation study of Section 4.5. Particularly, MoM scheme shows a good scalability as the number of mobile hosts increase in large value. Thus, MoM is more suitable to be applied in our proposed HMP scheme for the macro-domain. Through the handling of the MoM tunnel in core network (macro-domain), the multicast cost is greatly reduced.

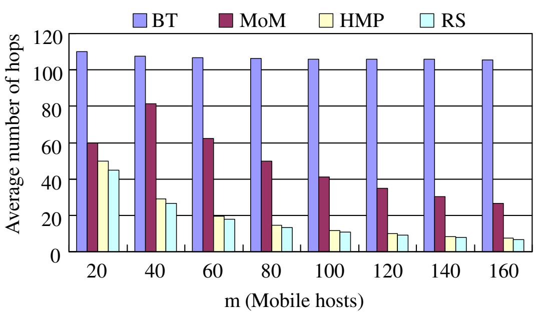

Fig. 31. The average multicast cost under different m.

5.4. Characteristic in middle-domain

The Internet research [39] community has proposed many routing protocols such as *Multicast Extensions to Open Shortest Path First (MOSPF)* [40], *Distance Vector Multicast Routing Protocol (DVMRP)* [41], *Protocol-Independent Multicast Sparse Mode (PIM-SM)* [42], and *Core-based Tree Protocol (CBT)* [43] to support efficient multicast by using a multicast tree [44]. The main drawback of these protocols is that they are developed for multicast parties whose members are topologically stationary and they do not consider the extra requirements to support either topologically mobile receivers or mobile sources. Unfortunately, when a multicast receiver is mobile it will experience additional delay in receiving multicast packets due to handover delay, join latency, and increased propagation delay to the new location. Therefore, the technology of Mobile IP is required for the mobile topology. Current version of Mobile IP is focused on two approaches to support mobile multicast, i.e. tree-based routing protocol (*RS, remote subscription*) and non-tree based routing protocol (*BT, bi-directional tunneling*). The RS option is simple and gives an optimal routing path, but it causes packet loss and frequent tree reconstructed overhead. While for BT option, it guarantees multicast datagram delivery during roaming and handles the mobility of both the source and recipients. The drawbacks for BT are that the routing path for datagram delivery may be far from optimal and that tunnel convergence problem. Moreover, another disadvantage for BT is for the packet delivery of the *IP-in-IP Encapsulation* which wastes the network bandwidth. Details for RS and BT technologies have been mentioned in related work of Section 2.

Different from the other multicast routing protocols on distributed systems, our scheme is simple, transparent and comparable to Mobile IP. For HMP scheme, the distance between SHA and SFA in macro-domain adopts a tunnel-based (non-tree) routing such as MoM over BT scheme, and a tree-based (HMP-tree) routing is computed in the middle-domain. Thus, through the association of the tree-based routing and tunnel-based routing, our proposed HMP scheme can provide a hybrid approach that intends to achieve a balance between optimal delivery path and tree maintenance cost.

6. Conclusion

In this paper, an enhancement for the middle-domain mobility management namely *Super Home Agent (SHA)* is proposed. In the previous work for the middle-domain, BS is regarded as a *Super Foreign Agent (SFA)* to be an agent of a set of FAs for providing good registration cost and handoff latency. However, it has not the ability to manage multiple home agents in case of HAs located within the 802.16 network. Thus, our proposed idea SHA provides a better performance to complement the defect for the middle-domain mobility management. For conventional MIP-based mobility management schemes which include with *Fast Mobile IPv6 (FMIPv6)* and *Hierarchical Mobile IPv6 (HMIPv6)* fitted into 802.16 network environment, these tunnel-based issues such as tunnel convergence, triangle routing and IP-in-IP Encapsulation problems still need to be addressed. Through using our proposed idea for SHA and SFA, these drawbacks would be avoided. Furthermore, with idea of SHA- and SFA-applied, we mainly aim to design the multicast extension for the middle-domain, which is called *Hierarchical Multicast Protocol (HMP)* in this paper. On the design of the HMP, we found it is a complicated 802.16 network environment in between macro- and middle-domains. By introducing a *Reduction Process (RP)*, HMP can effectively associate with MoM over BT so that the design of the multicast protocol is becoming simple. The proposed HMP scheme is a special multicast routing protocol since it is based upon Mobile IP (unicast technology) to do multicast service. It is actually a balanced association of the tree-based routing and tunnel-based routing. Moreover, our proposed HMP scheme also solves these problems of traditional MoM-applied scheme (without idea SHA and SFA) in 802.16-based network environment. These tunnel-based problems are summarized in this paper and namely a *Hierarchical-based Tunnel Convergence Problem (H-TCP)*. The mathematical analysis is researched in comparing with a simple routing performance for different schemes and simulation results demonstrate that middle-domain enhancement has significant reduced registration cost, handoff latency and routing cost in comparing with conventional Mobile IP, FMIPv6 and HMIPv6 schemes. Moreover, on top of the proposed idea of middle-domain enhancement, multicast extension for HMP in simulation has better scalability and network performance over than other approaches in mobile multicasting.

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