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AHS: Advanced Handoff Scheme for Nested Mobile Networks*

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Network Mobility Basic Support protocol (NEMO Basic) that is designed to offer network mobility is not efficient to offer low latency handoff in the case of nested mobile networks since fairly sub-optimal routing is utilized. A mobile network is composed of Mobile Network Nodes (MNNs) and a Mobile Router (MR). Route optimization for MNNs in IPv6 mobile networks is performed with Hierarchical Prefix Delegation protocol (HPD) and Reverse Routing Header (RRH). However, when a mobile network that contains a lot of MNNs moves locally in a nested mobile network, problems such as handoff latency, signaling overhead and packet losses will occur. This paper proposes an Advanced Handoff Scheme (AHS) which overcomes the limitations in conventional solutions. Combining the HPD and the Hierarchical Mobile IPv6 (HMIPv6) functionality can enable the improvement to the micro-mobility problem, and the location address of MNNs is created in Hierarchical Mobile Network Prefix (HMNP) assignment. Furthermore, a Mobility Management Router (MMR) is allowed to update the binding information of all MNNs in a mobile network without getting Binding Update messages (BUs) from the MNNs as the MMR receives a BU from the MR in the mobile network. The simulation is done by NS-2. The results show that a significant improvement is achieved compared to conventional solutions in terms of handoff latency, signaling overhead, and transmission delay.

Keywords: handoff, micro-mobility, nested mobile network, route optimization, hierarchical mobile IPv6, hierarchical prefix delegation protocol, AHS

1. INTRODUCTION

Mobile Networks are an emerging concept where mobility is considered for entire mobile networks. These mobile networks can provide, to mobile nodes (MNs), connectivity toward Internet via one or more MRs. The aggregated hierarchy of mobile networks is called a nested mobile network, where a mobile network may attach inside another mobile network. NEMO Basic [1] is an extension of Mobile IPv6 (MIPv6) [2]. In NEMO Basic, each MR uses bi-directional tunneling between the MR and home agent (HA) to preserve session continuity while the MR moves around. When a MR moves away from the home link and attaches to a new access router (AR), it acquires a Care-of Address (CoA) and sends a BU to its HA. The MR may also include information about the Mobile Network Prefix (MNP) in the BU, so that the HA can forward packets des-

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tined for MNNs in the mobile network to the MR. When a packet is sent by a Correspondent Node (CN) to a MNN in the mobile network, it gets routed to the HA of the MR (MR-HA). Then, MR-HA looks up for an entry in its binding cache corresponding to the packet destination address or its prefix and encapsulates the packet sent to the CoA of the MR (MR-CoA). The MR decapsulates the packet and forward it to the MNN. For outbound packets sent by the MNN, they are encapsulated by the MR to its HA and then redirected to the CN. Fig. 1 is a simple illustration of nested mobile network after two MRs move from home link to foreign link. In NEMO Basic, when a CN sends a packet to MN2 under the situation depicted in Fig. 1, the packet will pass through the tunnel between each MNN and its HA with the tunnel within a tunnel approach described by [1]. The packet from the CN traverses through following sequence for routers as shown in Fig. 2.

CN → MN2-HA → MR2 → HA → MR1-HA → MR1 → MR2 → MN2

As a result, NEMO Basic has some fundamental problems such as header overhead due to tunneling and high delay due to packet forwarding by HA. Moreover, with nested mobile networks, the problem increases with each nested level. In fact, exchanged packets must go through the HAs of all MRs of higher levels before reaching their destination. This is known as the "pinball routing problem". Furthermore, IP-in-IP encapsulations lead also to high handoff latency that may imply packet losses and disconnections.

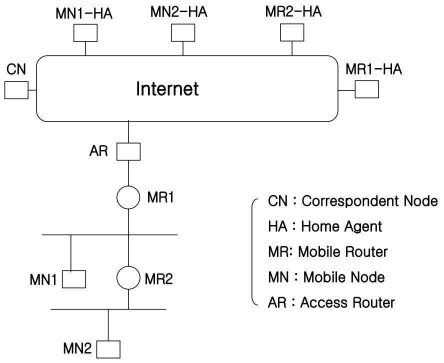

Fig. 1. Nested mobile network.

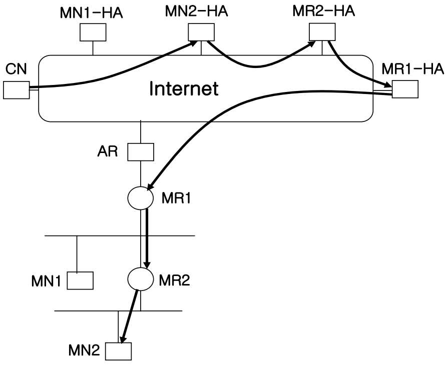

Fig. 2. NEMO basic operation with nested mobile networks.

Multiple solutions presented provide route optimization support for NEMO Basic. A new routing header called the RRH [3] was proposed. RRH is a solution to provide an optimized path for the single tunnel. RRH records the route out of the nested mobile networks. Each MR on the egress path places its CoA in the RRH. By receiving this header, All CNs can construct the chain of MRs to which the first MR is attached where the first MR is connected to MNNs which communicates with the CNs. When applying RRH to Fig. 1, the packets destined to MN2 in MR2's mobile network are transmitted with MR1-CoA, MR2-CoA and MN2-CoA as the Routing Header Option (RHO) in IPv6 [2]. Thus, the major inconvenience of this solution is the additional overhead, introduced by RRH on each packet, which increases with the number of levels of the nested mobile network. When the mobile network moves, it is necessary for the MNNs in the mobile network to inform all CNs of the change in the MR-CoAs on the egress path because all CNs cache them. Conventional mechanisms such as NEMO Basic and RRH assume that the MNP is permanent, which results in the packet overhead and non-optimal routing.

As a solution to resolve these problems, HPD [4] is an extended prefix delegation protocol based on Automatic Prefix Delegation Protocol (APD) [5]. HPD is not limited to a leaf router. It also provides efficient network mobility in a nested mobile network. It allows routers to request any prefix from upper routers. Once a requesting router receives a prefix from its upper router, it can play the role of the delegating router. It provides its lower routers with parts of its address space by delegating longer level prefixes, enabling multiple-level hierarchical prefix delegation. Thus, HPD enables that every node in the mobile network will have a topologically meaningful address. In this way, nodes outside the mobile network can send packets to a MNN inside the mobile network without adding a source routing header or using additional tunnels inside the MR. As an example, when each MR performs HPD in Fig. 1, it gets a prefix from its access router. Each MN behind the MR makes its CoA using the prefix in a Router Advertisement message (RA) and sends BUs to its HA/CNs. Using this information, CN sends packets to MN2 directly.

CN → MR1 → MR2 → MN2

Thus, HPD provides optimal routing between correspondent nodes. However, significant handoff latency is caused when MNNs move frequently within a nested mobile network because they take some time to configure and update new CoA.

[6] proposes that a MNP is changed to adapt to the hierarchical address of the AR to which the mobile network is connected. This method enables packets to be optimally routed to MNs in the mobile network using only MN-CoA created from the MNP. This scheme allows each MN-CoA to be divided into a common information part indicating the location of the mobile network and an individual node information part indicating the location of each MN within mobile network. When handoff occurs, MR in the mobile network sends a BU to Local Anchor Router (LAR) containing the common MNP instead of MNs behind the MR. Thus, this solution reduces the number and the volume of hand- off signals by managing the location addresses of all MNs in a hierarchical manner. However, this scheme is limited to the mobility of a single mobile network and does not support nested mobile networks which can be used to route IP packets for such complex applications as various types of communication devices moving on vehicle or Personal Area Networks (PANs) which is moving between sub-networks. As an example, when applying the mechanism proposed in [6] in Fig. 1, CN can not send packets to MN2 be-hind MR2, and it just sends packets to MN1 behind MR1 via LAR.

Our proposal, Advanced Handoff Scheme (AHS), is a new fast handoff scheme combining HMIPv6 [7] and HPD for nest mobility that overcomes the limitation in reference [6] which only supports the mobility of a mobile network. Our design objective reduces the number of control messages and the handoff latency as it enables a Mobility Management Router (MMR) to update the binding information for MNNs behind a MR, using a BU from the MR instead of the MNNs when the MR moves locally within the

MMR domain. This handoff scheme also enables packets to be optimally routed to MNNs in the mobile network via MMR. The remainder of this paper is organized as follows: Section 2 describes our proposed architecture and provides the detailed routing and handoff procedures. A performance evaluation of the proposed architecture and mechanisms is described in section 3. Finally, in section 4, we present some concluding remarks.

2. PROPOSED ROUTING SCHEME

2.1 Nested Mobile Network Architecture

Fig. 3 shows the nested mobile network structure for proposed routing method to meet the requirements for mobile network mobility management. It consists of an IP network with a MMR and Mobile IP components such as MRs, MNs, HAs, CN, and ARs.

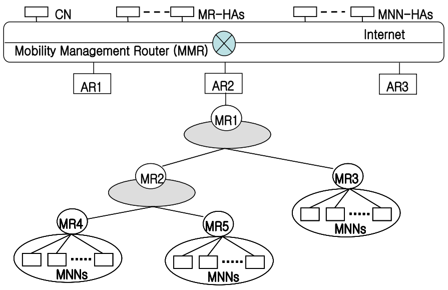

Fig. 3. Nested mobile network architecture for proposed routing method.

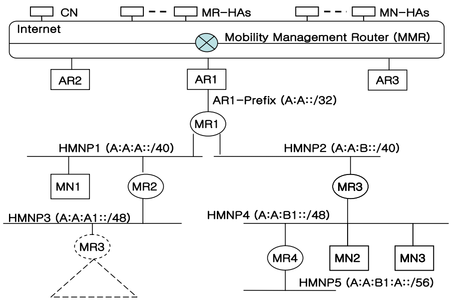

Fig. 4. HMNP assignment.

2.2 Hierarchical MNP Assignment

Our scheme makes the MNP hierarchical to AR, resulting in CoAs which are hierarchical to the nested mobile network. MR acquires a delegated MNP (hereafter referred to as HMNP) from its access router by running HPD method when the MR changes its point of attachment. The HMNP is topologically consistent with the hierarchical structure of the mobile network. The method of allocating the HMNP is shown in Fig. 4. Suppose that the net mask of the AR, which is an edge router of the nested mobile network, is 32 bits long [6]. The mobile network is allocated a HMNP with a $32 + 8 * (n + 1)$ bits mask as the nesting level n increases where $n = 0$ to 3, to form a hierarchical structure with the AR. Then, each MNN creates a CoA using this HMNP. Thus, CoAs hierarchical to the nested mobile network are achieved, which makes it possible to meet route optimization requirements.

2.3 Hierarchical Address Configuration

The CoA for each MNN, which is created using the HMNP assignment in the proposed scheme, is divided into a node locator and a node identifier. The node locator is a 64-bit network prefix made from HMNP advertised in a RA, which indicates the location of the mobile network in the nested mobile network. In the case of handoff, it is changed. On the other hand, the node identifier is a globally unique IPv6 64-bit interface ID [8] which remains unchanged even when handoff occurs.

2.4 Mobile Router Operation

When a MR changes its point of attachment, the MR gets a HMNP from access router by running HPD method [4] introduced in our scheme and makes topologically correct CoA from the HMNP. If the MR has multiple link, it request multiple HMNPs of its access router, gets HMNPs from the access router and advertises each HMNP on a separate subnet. In this scheme, MMR is introduced to have the functionality of a Mobility Anchor Point (MAP) in HMIPv6.

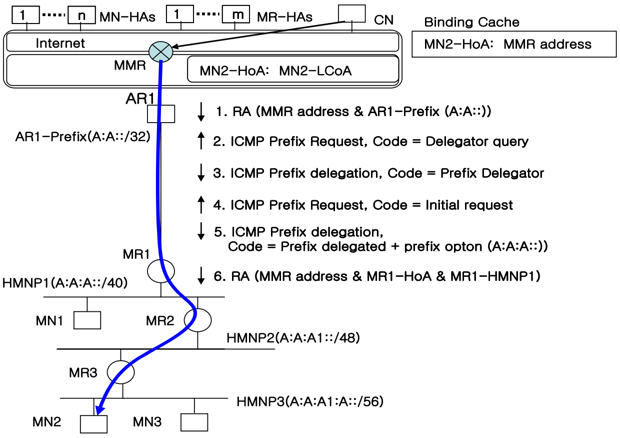

Fig. 5. Mobile router operation.

Fig. 5 shows the signaling procedure to allow MRs to request any prefix from their upper router. First, MR1 receives a RA from AR1, containing AR1-prefix and MMR address. MR1 creates its local CoA (LCoA) using AR1-prefix and sets MMR address as its Regional CoA (RCoA). Second, MR1 sends a prefix request message of code “Delegator Query” to the AR1, specifying the number of prefixes it wishes to receive. Third, AR1 is willing to delegate prefixes to MR1 and unicasts a Prefix Delegation message of code “Prefix Delegator” back to MR1. Fourth, MR1 requests an HMNP from AR1 and sends a Prefix Request with the code “Initial Request” to AR1. Fifth, AR1 sends a Prefix Delegation message with the code “Prefix Delegated” to MR1, and prefix information is contained in the Pre-fix Information option. The option contains the length and lifetime of the prefix (HMNP1). AR1 also updates its routing table based on the HMNP1. This means that all traffic related to HMNP1 is directed to MR1. Sixth, MR1 receives the Prefix Delegation message and updates its routing table. This means that AR1 is designated as the MR1’s default router (::/0 → AR1 address).

Then, MR1 sends a BU to MMR, containing the Home Address (HoA) of MR1

(MR1-HoA), MR1-LCoA, its upper router address (AR1 address), and HMNP1. After this, MR1 sends a BU to MR1-HA to register the MMR address as its RCoA with its HoA. MR1 then advertises a RA to its mobile network, containing MMR address, MR1-HoA and HMNP1. Then, when MR2 moves to MR1's mobile network, MR2 creates MR2-LCoA using HMNP1 and sets the MMR address as its RCoA. MR2 gets HMNP2 from its upper MR (MR1) using the same signaling procedure as MR1 gets HMNP1 from AR1, and it sends a BU to MMR, containing MR2-HoA, MR2-LCoA, MR1-HoA, and the HMNP2. MR2 then sends a BU to MR2-HA to register the MMR address as its RCoA. Then, MR2 sends a RA to its subnet, containing HMNP2, MMR address and MR2-HoA. Finally, when MR3 moves to MR2's mobile network, it repeats the same procedure as MR2 performs the procedure to get a HMNP after the MR2 moves to MR1's mobile network.

Each MNN behind a MR makes its LCoA (MNN-LCoA) using a HMNP, sets MMR address as its RCoA and the MR-HoA as the address of the MR connected to it. The MNN then sends a BU to MMR, containing MNN-HoA, MNN-LCoA and the MR-HoA. Then, each MNN sends BUs to its HA/CNs, containing MNN-RCoA (MMR address) and its HoA. As an example, Fig. 5 shows that packets from a CN are optimally routed to a MNN (MN2) via MMR, using a RHO. MMR encapsulates the packets with MNN-LCoA (MN2-LCoA) after searching for it in its binding cache and sends the packets to the MNN (MN2). On the other hand, when packets contain MNN-LCoA as its source address, CN address as its destination address and MNN-HoA in its Home Address Option (HAO), the packets have no problem in egress filtering, and directly reach CN with route optimization.

2.5 MMR Functionality

To localize handoff signals and support route optimization in this scheme, the MMR maintains binding information for all MNNs in its domain in its binding cache. Table 1 shows MMR's binding cache that is composed of HoA, CoA, upper-MR, and HMNP fields based on Fig. 4. The CoA field contains LCoAs of MNNs which are divided into the node locator and the node identifier. The upper-MR field contains the home address of a MR associated with the MNNs in the MR's network. The HMNP field contains a HMNP which represents the location of each subnet of the MR. Assume that the location registrations of all the MNs and MRs are already done appropriately in Table 1.

Table 1. MMR's binding cache.

HoA	CoA (locator + identifier)	upper-MR	HMNP
MR1-HoA	MR1-LCoA (AR1-prefix + mr1)	AR1	HMNP1, HMNP2
MN1-HoA	MN1-LCoA (HMNP1 + mn1)	MR1-HoA1	–
MR2-HoA	MR2-LCoA (HMNP1 + mr2)	MR1-HoA1	HMNP3
MR3-HoA	MR3-LCoA (HMNP2 + mr3)	MR1-HoA2	HMNP4
MR4-HoA	MR4-LCoA (HMNP4 + mr4)	MR3-HoA	HMNP5
MN2-HoA	MN2-LCoA (HMNP4 + mn2)	MR3-HoA	–
MN3-HoA	MN3-LCoA (HMNP4 +mn3)	MR3-HoA	–

As an example, MMR holds the binding information of MR1, that is, MR1-HoA in HoA field, MR1-LCoA created using AR1-prefix in CoA field and HMNPs (HMNP1, HMNP2) in HMNP field. MMR also stores MN2-HoA, MN2-LCoA and the upper MR's HoA (MR3-HoA) of MN2 when it receives a BU from MN2. When a mobile network moves locally within the MMR domain, each MNN in the mobile network updates its MNN-LCoA using a HMNP in RA from the MR associated with the MNN. However, the MNNs need not send the handoff signals to MMR as the MR sends a BU only to MMR containing the HMNP information. When MMR receives a BU from the MR, it updates the binding information for the MR and for each MNN behind the MR in its binding cache where MNNs can be found using the HoA of the MR in upper-MR field. Thus, MMR reduces handoff signals significantly as well as localizes them because MMR is closer to the mobile network compared to the MR-HA.

2.6 Protocol Operation

In this section, the proposed solution describes the detailed operations to solve the limitations of other routing schemes such as pinball routing, overhead and handoff latency.

Fig. 6 shows that a MR1 moves to a foreign network and directly accesses AR1. MMR periodically sends its address to AR1 and AR2. MR1 sends a Router Solicitation message (RS) to AR1 to ask for immediate advertisement. AR1 sends a RA to MR1, containing AR1-prefix and MMR address. Then, MR1 creates its LCoA (A::mr1) by combining the AR1-prefix (A::) in RA with 64-bit MR1's interface ID (mr1), and sets the MMR address as its RCoA. MR1 then performs step 5 to step 8 to acquire a HMNP (HMNP1) from AR1 by running HPD method [4]. Then, MR1 receives HMNP1 and updates its routing table (::/0 → AR1). MR1 then sends a BU to MMR, containing MR1-HoA, MR1-LCoA, HMNP1 and AR1 address. MMR registers the binding information for MR1 in its cache. After this, MR1 sends a BU to MR1-HA to register its RCoA. MR1 then sends a RA to its mobile network, containing MMR address, HMNP1 and MR1-HoA.

Fig. 7 shows the procedure for connecting MR3 to MR2 due to inter-domain handoff. MR3 sends a RS to MR2. Next, MR2 sends a RA to MR3, containing MMR address,

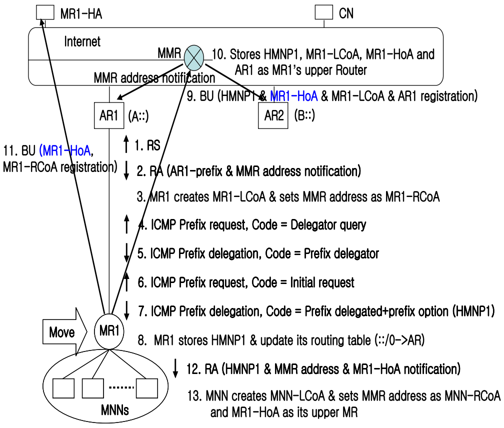

Fig. 6. MR joins (Macro-mobility).

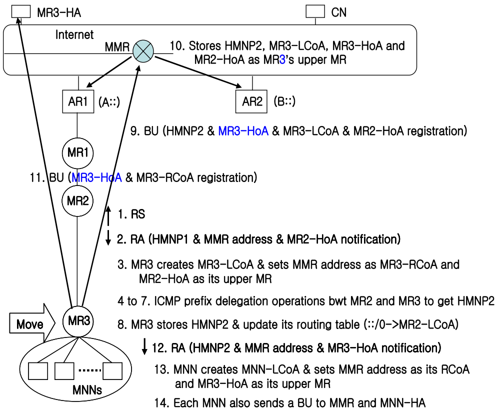

Fig. 7. MR joins inside of mobile network.

MR2-HoA, and HMNP1. MR3 creates its LCoA (MR3-LCoA) using HMNP1, sets its RCoA (MMR address) and its upper MR's HoA (MR2-HoA), after getting RA from MR2. MR3 then performs step 4 to step 7 to acquire a HMNP (HMNP2) from MR2, such as HPD [4]. This new HMNP2 is a longer HMNP than HMNP1. Then, MR3 receives HMNP2 and updates its routing table (::/0 → MR2-LCoA). MR3 sends a BU to MMR, containing MR3-HoA, MR3-LCoA, HMNP2 and MR2-HoA. MMR then registers the information to bind the MR3-LCoA, MR3-HoA, HMNP2 and the upper MR of MR3 (MR2-HoA). Then, MR3 sends a BU to its HA, containing its RCoA. Next, the MR3 sends a RA to MNNs in its mobile network, containing MR3-HoA, HMNP2 and MMR address. Each MNN behind MR3 also updates its LCoA based on the HMNP2 and sets its RCoA as the MMR address. Next, Each MNN then sends a BU to MMR, containing its LCoA (MNN-LCoA) and its upper MR's HoA (MR3-HoA). MMR then registers the information to bind MNN-LCoA, MNN-HoA, and MR3-HoA for each MNN. Thus, MMR caches the related information, that the LCoA of each MNN is divided from the HMNP2 of MR3, and the upper MR of MNN is MR3 from MR3-HoA. After this, the MNNs should send BUs to their HA/CNs. In cases where a MNN is a MR, the MNN repeats the same procedures as the inter-domain handoff procedures performed by MR3.

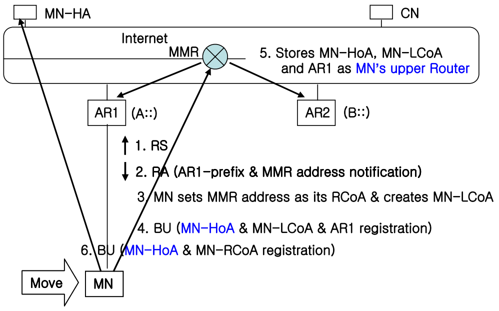

Fig. 8. MN joins (Macro-mobility).
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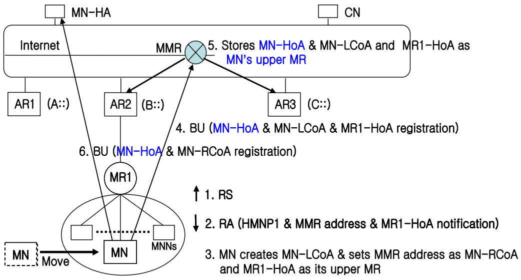

Fig. 9. MN joins inside of mobile network

Fig. 8 shows the procedure for connecting MN to AR1 due to inter-domain handoff. MN creates MN-LCoA and sets its RCoA (MMR address) from the RA received from AR1. Then, MN sends a BU with MN-HoA, MN-LCoA and AR1 address to MMR, and a BU with MN-RCoA to MN-HA.

Fig. 9 shows the procedure for connecting a MN to a MR (MR1) as a result OF the movement of the MN. The MN detects the fact that inter-domain handoff occurs when it receives a different MNP (HMNP1) and a new MMR address (MMR address) from a RA received from the MR1. Then, the MN creates its LCoA using HMNP1, sets MMR address as its RCoA and stores its upper MR's HoA (MR1-HoA) from the RA. Next, the MN should send a BU to MMR, containing MN-HoA, MN-LCoA and MR1-HoA. After this, the MN should send a BU containing the MMR address to its HA.

Fig. 10 shows an intra-domain handoff when MR4's network moves locally within a MMR domain. MR4 sends a RS to MR2. Then, MR2 sends a RA to MR4, containing HMNP1, MMR address and MR2-HoA. After receiving a RA from MR2, MR4 detects its movement within the same MMR domain in case its upper MR's HoA changes from

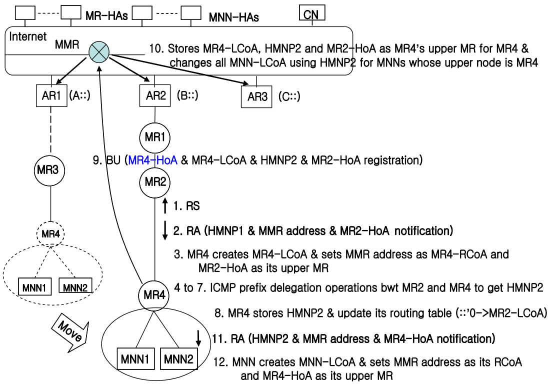

Fig. 10. MR joins inside of mobile network (Micro-mobility).

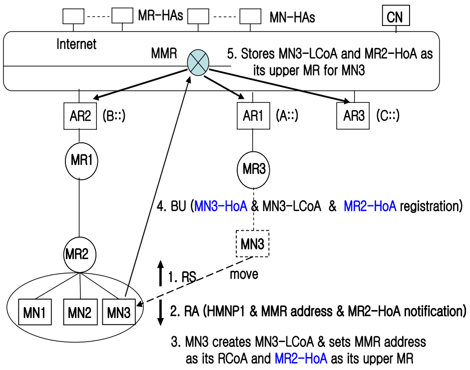

Fig. 11. MN joins inside of mobile network (Micro-mobility).

MR3-HoA to MR2-HoA but its RCoA (MMR address) does not change. Then, MR4 creates its LCoA and performs ICMP prefix delegation operations from step 4 to step 7 to acquire a HMNP (HMNP2) from MR2, such as HPD [4]. MR4 then sends a BU to MMR, containing MR4-HoA, MR4-LCoA, its upper MR's HoA (MR2-HoA) and HMNP2.

Then, MMR registers the information to bind the MR4-HoA, MR4-LCoA, MR2-HoA, and HMNP2. After this, MMR searches the binding entries for MNNs behind the MR4 using MR4-HoA in the upper-MR field of its binding cache. Thus, when MMR updates MR4's binding information, MMR also updates all MNN-LCoAs within MR4's network by changing the common information, that being the node locator, to HMNP2. Then, MR4 sends a RA to MNNs within its mobile network, containing MR4-HoA, HMNP2, and MMR address. Each MNN within MR4's network creates its new LCoA (MNN-LCoA) using HMNP2, and also sets its RCoA as MMR address and MR4-HoA as its upper MR. Each MNN behind the MR4 does not need to send a BU to the MMR, because MNN-LCoA (which MMR manages) has already been updated.

If the handoff of a mobile network is caused by the movement of the parent mobile network within a nested mobile network, the MR (MR4 in Fig. 4) repeats the above-mentioned handoff procedure for MNNs within its mobile network, which is performed by its upper MR (MR3) for MNNs within MR3's network. Thus, if a mobile network moves locally within the nested mobile network, MR in the mobile network and all nested MRs on lower levels connected to the MR send BUs on behalf of MNNs within their mobile networks. On the other hand, in case that MR4 moves to AR3 within MMR domain, MR4 performs the similar procedures with AR3 as it does one with MR2 when it moves to MR2's network from MR3's network.

Fig. 11 shows the procedure for connecting MN3 to MR2 when MN3 moves locally between mobile networks within a MMR domain. MN3 receives a RA containing the HMNP1, MMR address, and MR2-HoA from MR2 where MR2 is already connected to MMR through intermediate MRs (IMRs). The MN3 detects its movement within the same MMR domain in case its upper MR's HoA changes from MR3-HoA to MR2-HoA but its RCoA (MMR address) does not change. Then, MN3 creates its LCoA (MN3-

LCoA) based on the HMNP1 and sets MR2-HoA as its upper MR's address. MN3 sends a BU to MMR, containing MN3-HoA, MN3-LCoA and MR2-HoA. Then, MMR updates the binding information for the MN3. On the other hand, in case that MN3 moves to AR3 from MR3's network within MMR domain, MN3 sends a RS to AR3. AR3 sends a RA with MMR address and AR3-prefix to MN3. Then, MN3 sends a BU with MN-HoA, MN-LCoA and AR3 address to MMR, because its upper MR's address only changes from MR3-HoA to AR3 address with its RCoA (MMR address) unchanged.

3. PERFORMANCE ANALYSIS

We have evaluated AHS, NEMO Basic, RRH and HPD, using the Network Simulator (NS-2), in a nested mobile network environment. We defined that MR under AR is zero-level (*i.e.*, AR-MR). Therefore, AR-MR-MR means one nested-level. Fig. 12 shows the network model for simulation where there may be at least one MR per level in a nested mobile network. In order to simulate real traffic, we set up the CN as a traffic source at a Constant Bit Rate (CBR) over a User Datagram Protocol (UDP), producing fixed length packets of 1,500 bytes every 10 ms. Then the MNN acts as a sink node receiving packets from CN. The setup link topology consists of wired link and wireless link. The wired link is fixed and used at the connection of CN to MMR, CN to HA, HA to MMR, and MMR to the AR. The wired link bandwidth is set to 100 Mbps. The wireless link bandwidth is set to 11 Mbps with the wireless link latency set to 2 ms. The packet service rate was 100 packets/second corresponding to data rates of 1.2 Mbps. The hand- off interval was set to 2 seconds. We evaluated each scheme assuming 5, 10, 100 MNNs in the mobile network. The simulation assumes that delay between HA and HA is 100 ms, delays between CN and HA, CN and MMR and HA and MMR are the same, 50ms and delay between MMR and AR is 5ms. Furthermore, packet header size, BU size and BACK size are also predefined: 40 bytes, 112 bytes and 96 bytes respectively.

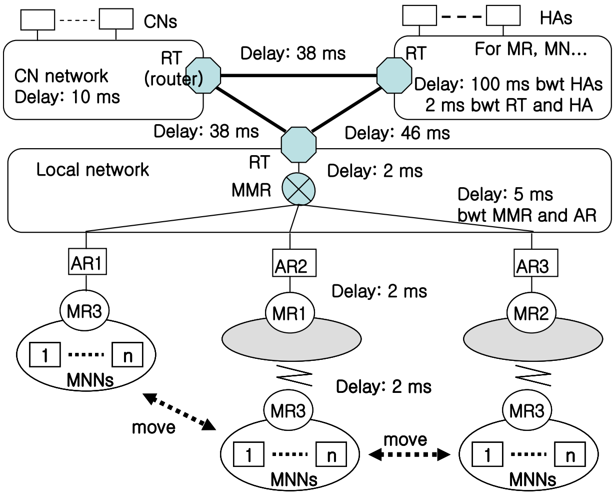

Fig. 12. Network model for simulation.

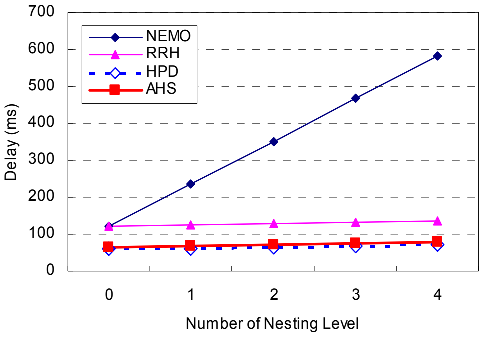

Fig. 13. Inter-domain data transmission.

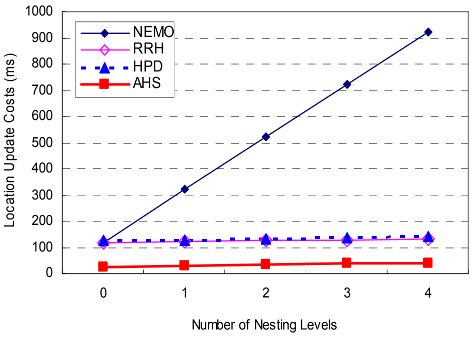

Fig. 14. Location update cost.

3.1 End-to-End Packet Delay

Packet transmission delay measurements from a CN to a MN in the mobile network are depicted in Fig. 13. This is related to the reduction of the number of nested tunnels. Indeed, the proposed solution requires only a unique tunnel from MMR to MN regardless of the number of nested levels in the mobile network. The packets, in NEMO Basic, must pass through multiple tunnels from the MN to MN-HA. The packet transmission delay saving time between AHS and RRH method is 56.33 ms at level 0 and 56.92 ms at level 4. RRH method is superior to NEMO Basic but is inferior to AHS. AHS and HPD offer similar levels of performance since both optimize routing.

3.2 Location Update Costs

Fig. 14 shows the location update costs for each scheme as the nested-level increases. In the case of macro-mobility handoff, AHS has the same level of performance as HPD. However, when MNN moves within MMR domain, AHS requires that MNN only sends a BU to MMR, compared to its HA/CNs in other schemes. The difference of the location update cost between NEMO Basic and AHS is 90.43 ms at level 0 and 882.05 at level 4. The difference between RRH and AHS is 91.49 ms at level 0 and 92.89 ms at level 4.The difference between HPD and AHS is 100.85 ms at level 0 and at level 4. So, our scheme is superior to NEMO Basic, RRH and HPD. The proposed scheme has more efficient location update costs than other schemes, because 69% of user mobility is contained within a local domain (an attribute of micro-mobility [9]).

3.3 Handoff Latency

Handoff latency is the mean time from handoff initiation to completion. Fig. 15 shows the handoff latency for each scheme when a mobile network is assumed to move locally at nesting level 2 within MMR domain. NEMO Basic requires that MR only performs a registration operation to its HA/CNs instead of MNNs connected to the MR. However, AHS requires that MR also performs a registration operation to MMR instead of MNNs behind the MR. The performance ratio of AHS to NEMO Basic is 0.07 regardless of the number of MNNs in the mobile network because this difference depends on

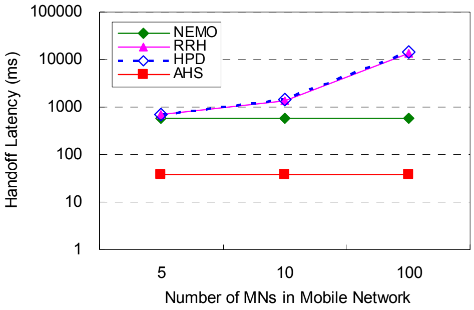

Fig. 15. Handoff latency.

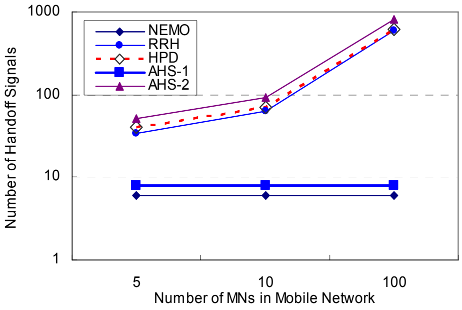

Fig. 16. Number of handoff signal.

the BU destination. The performance ratio of AHS to RRH depends on the number of MNNs, *i.e.*, 0.06 with 5 MNNs, and 0.003 with 100 MNNs. HPD has slightly longer handoff latency than RRH because HPD requires the prefix delegation operations to get a HMNP due to the handoff of a MR. HPD and RRH also require each MNN in the mobile network to send BU messages to its CNs/HA when handoff occurs. As the number of MNNs in the mobile network is increased, the handoff latency of RRH and HPD increases enormously. Therefore, when compared to other schemes, AHS is the most efficient.

3.4 Handoff Signals

Fig. 16 shows the number of handoff signals required in each scheme whenever handoff occurs. The handoff signals are – RS, RA, BU and binding acknowledgement message (BACK) [2]. At this point we consider that two ICMPv6 message types, *i.e.*, the Prefix Request and the prefix Delegation, used in HPD and AHS are included in addition to the handoff signals. We assume that each MNN in mobile network has 1 CN. We also assume that AHS-1 means that mobile network moves within the same MMR domain, whereas AHS-2 means that mobile network moves to a different MMR domain. RRH and HPD have similar AHS-2 characteristics in which each MNN in the mobile network sends a BU to its HA/CNs. However, both AHS-1 and NEMO Basic offer a lower, constant number of handoff signals. When the number of MNNs in a mobile network is 100, AHS-1 requires about 600 fewer handoff signals than RRH and HPD. Therefore, AHS provides better performance compared to other schemes when intra-domain handoff occurs; such as an attribute of micro-mobility [9] or as the number of CNs with which the MNNs in the mobile network communicate increases.

3.5 Amount of Packet Losses

Fig. 17 shows the comparison of total packet losses occurring in each scheme when a mobile network with ten MNs moves locally within a nested mobile network from nested level 0 to 3. The number of packet losses increases as the nesting level or handoff latency increases. All MNs as well as a MR in a mobile network should send BUs to their HAs/CNs in HPD and RRH, which result in longer handoff latency than AHS and NEMO Basic because the MR only sends a BU to MMR in AHS or MR-HA in NEMO

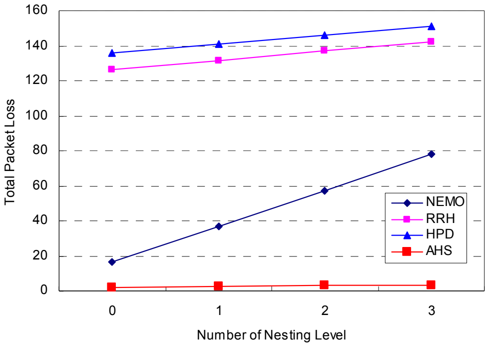

Fig. 17. Amount of packet loss.

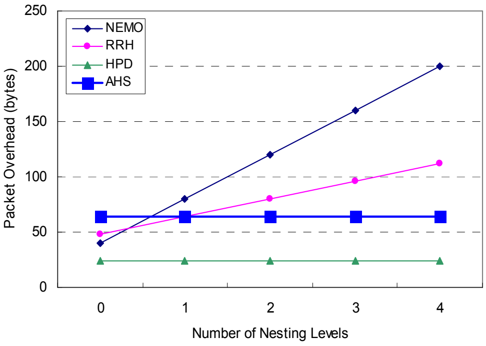

Fig. 18. Overhead.

Basic instead of MNs when the MR moves locally within the MMR domain. However, although packet overhead in RRH increases compared to HPD when nesting level increases, HPD results in similar but slightly longer handoff latency than RRH because each MR, to get a

HMNP to be used its subnet, performs prefix delegation operations with its upper MR. The difference of packet losses between the RRH and HPD is about 7 packets regardless of the nesting levels. On the other hand, the difference of packet losses in AHS and NEMO Basic is due to the BU destination. Thus, the discarded packets in AHS are the fewest of the four methods.

3.6 Packet Overhead

Fig. 18 shows the packet overhead for each scheme when the level of nesting increases. NEMO Basic adds a tunnel (40 additional bytes) between the MR and its HA for each level of nesting. RRH sets up a unique tunnel (40 bytes) between the first MR on the egress path and its HA, and additionally needs the slots to put the CoA of each MR on the egress path. HPD does not have any tunnels. It only adds a HAO or RHO (24 bytes), no matter how many nesting levels are involved. In AHS, packets are transmitted from the CN to the MMR with an RHO that sets MNN-HoA. They are only sent by encapsulation (40 bytes) from the MMR to the MNN. The packet overhead in both NEMO Basic and RRH increases as the nesting level increases, whereas both AHS and HPD offers low and constant packet overhead. Although AHS requires that MMR encapsulates the packets to MNNs within MMR domain, it is better than other methods except HPD.

4. CONCLUSION

In this paper, we have proposed a scheme to perform fast handoff for mobile networks with micro-mobility management. Fast handoff is achieved by getting the MMR to update LCoA for each MNN behind a MR using a HMNP in a BU from the MR. Thus, the proposed scheme reduces handoff latency, the number of handoff signals, and packet losses incurred when a mobile network moves locally in a MMR domain. It also reduces packet delay with hierarchical re-routing, which optimizes routing through MMR.

We verified the effectiveness of our scheme compared to conventional solution, using NS-2. The packet delay from CNs to MNNs in a mobile network obtained using AHS was similar to using HPD, but a little better than RRH. With regard to the location update costs, the results using AHS are better than those using HPD and RRH, due to the destination of BUs. The handoff latency in AHS was much shorter than that in RRH and HPD. The performance ratio of AHS to NEMO Basic is 0.07 at nesting level 2 regardless of the number of MNNs in the mobile network. HPD has similar but slightly longer handoff latency than RRH. The performance ratio of AHS to HPD depends on the number of MNNs, *e.g.* 0.003 with 100 MNNs. The number of discarded packets in AHS is the smallest among the four solutions, regardless of the number of MNs. In the case of a mobile network with 10 MNs, the use of AHS results in about 140 fewer discarded packets than HPD and RRH at nesting level 3. The packet loss difference in AHS and NEMO Basic is about 14 packets at level 0 and about 74 packets at level 3 as the packet loss is affected by the BU destination. In terms of the number of handoff signals per handoff event, the results using AHS and those using NEMO Basic show low and constant values, with about 600 fewer signals than HPD and RRH in the case of 100 MNs through micro-mobility support. The number of handoff signals increases as the number of CNs, with which MNNs in the mobile network communicate, increase. However, although the packet overhead in AHS is higher than in HPD, it remains constant at the low value (64 bytes) while packet overhead in both NEMO Basic and RRH grows with nesting levels.

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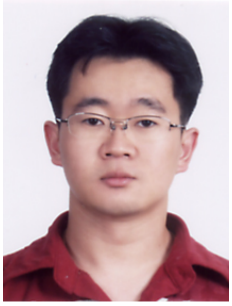

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