Reducing Location Update Cost Using Multiple Virtual Layers in HMIPv6

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Abstract. Hierarchical Mobile IPv6 (HMIPv6) guarantees to reduce handoff latency, because the MN only registers the new addresses at mobility anchor point (MAP) when the MN moves around access routers (ARs) in the same MAP domain. HMIPv6 still has packet loss problem when the MN moves from one MAP to another. In this paper, a novel location update scheme which further reduces signaling traffic for location update by employing virtual MAP (VMAP) on top of overlapped MAP in HMIPv6, is proposed. This proposed scheme significantly improves performance compared to HMIPv6, in terms of location update rate per user. Also it makes the mobile nodes (MNs) moving around the boundary ARs of adjacent MAP's become to move within a VMAP. It is certain that this scheme reduce the network resources efficiently by reason of removing the location update. In conclusion, this scheme greatly reduces the packet loss and delay, due to Inter-MAP handoff not occurring.

1 Introduction

Mobile IPv6 (MIPv6) [1,2] of Internet Engineering Task Force (IETF) Mobile IP Working Group [4], is the main protocol supporting IP mobility [3]. This protocol provides connectivity with the Internet from the MN's movement. When the MN moves away from its home link, it configures a new care-of-address (CoA) at a visited network. The MN registers new CoA at the Home Agent (HA) and the Correspondent Node (CN) to indicate its current location. However, MIPv6 has weak points, such as handoff latency resulting from movement detections, IP address configurations and location updates which is unacceptable in real-time application.

The purpose of Hierarchical Mobile IPv6 (HMIPv6) [5] is to reduce the amount of signaling to CNs and the HA. However, this does not satisfy the requirements of real-time services which are susceptible to delay, because HMIPv6 also uses MIPv6 for Inter-MAP handoff. Furthermore, HMIPv6 is managed by several MAPs to solve the Single Point of Failure (SPOF) and bottleneck state of traffic. Thus, Inter-MAP handoff is increasingly expanding.

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In this paper, the Inter-MAP handoff scheme is proposed, in order to improve HMIPv6 performance. This scheme is based on a virtual layer employing the VMAP (virtual MAP). The virtual layer consists of virtual MAP's, each of which is managed by a VMAP. This proposed scheme significantly improves performance compared to HMIPv6, for location update rate per users. The proposed scheme allows the mobile terminals moving around the boundary ARs of adjacent MAP's to move within either a VMAP or an overlapped region. This greatly reduces the packet loss and delay, due to the Inter-MAP handoff not occurring.

This paper is organized as follows. In Section 2, we reviewed the analytic models for location update, the basic operation of HMIPv6 and its MAP discovery. The motivation of this work and the new proposed scheme is presented in Section 3 based on HMIPv6. In Section 4, the performance of the proposed scheme is evaluated. Finally, this paper is concluded in Section 5, presenting future direction.

2 Related Works

This section provides a brief overview of analytic approaches for performance improvement of mobile network. Recently, Xie et al. proposed an analytic model for regional registration [6], which is a derivative of a hierarchical mobility management scheme [7]. The proposed analytic model focuses on the determination of the optimal size of regional networks, given the average location update and packet delivery costs. In this study, the existence of one-level regional networks is assumed where there is a single Gateway Foreign Agent (GFA).

In addition, Woo proposed an analytic model, in order to investigate the performance of Mobile IP regional registration [8]. In [8], Woo measured registration delay and CPU processing overhead loaded on the mobility agents to support regional registration. Although this model is a well-defined analytic model, it is based on MIPv4 and not MIPv6. Furthermore, in this study, a spatial-oriented Internet architecture was used for performance analysis. Currently, the Internet is based on the spatial-oriented location area model, which specifies that the distance between two end points situated on the Internet is unrelated to the geographic locations of these two points. However, the ARs used in next-generation wireless and mobile networks may utilize a cellular architecture, in order to maximize utilization of the limited radio resources. Therefore, it is more appropriate to analyze network performance in the context of IP-based cellular networks [9].

HMIPv6 [5] is the extension of MIPv6 and IPv6 Neighbor discovery protocols to support local mobility. Therefore, the introduction of a hierarchy only makes sense if the MAP is located between the MN and HA/CNs. It also reduces the signaling traffic for handoff due to transmitting a BU (Binding Update) regardless of the number of CNs. MN receive the Router Advertisement (RA) having the MAP information from AR. This creates the Regional Care-of-Address (RCoA) and On-link Care-of-Address (LCoA) with received MAP and AR's subnet prefix,

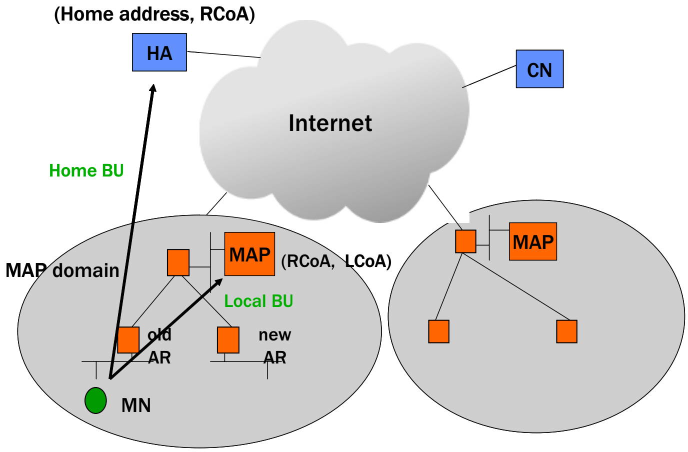

Fig. 1. HMIPv6 Operation

registering them to MAP and HA/CNs. In the case of moving the ARs in the same MAP, MN only registers a changed LCoA to MAP. The MAP intercepts all packets directed to MN in MAP, performing the local HA's role that encapsulates and delivers them.

Fig.1 depicts the basic operations which are performed in HMIPv6. An MN entering a MAP domain will receive RA message containing information on one or more local MAPs. Then, the MN selects the most suitable MAP by a number of criteria (distance, mobility, preference, *etc.*). However, the question of how to select a MAP is the beyond the scope of this paper. We simply assume that a specific MAP selection scheme is used and that the MN sends a BU message to the selected MAP. The MN can bind its current location (*i.e.*, LCoA) with an address on the MAP's subnet (*i.e.*, RCoA). Acting as a local home agent (HA), the MAP will receive all packets on behalf of the MNs it is serving and will decapsulate and forward them to the MN's current address. If the MN changes its current address within a local MAP domain, it only needs to register the new address to the MAP. The RCoA does not change as long as the MN moves within the MAP domain. This makes the MN's mobility transparent to the correspondent nodes (CNs).

The MAP option newly reconfigured for MN to recognize the MAP, to configure the RCoA and to receive the necessary information of basic HMIPv6 operation. The Preference field is 4 bit and indicates the MAP preference. It also consists of a Valid Lifetime field, Distance field, Global IP Address field and several flags. MAP discovery is the procedure of discovering the MAP for ARs and acquiring the MAP subnet prefix. It is possible to pre-configure the Routers for MAP options from MAP to MN over the specified interfaces. All ARs in the same MAP are configured for receiving MAP options with the same MAP address.

3 The Proposed Scheme

3.1 Virtual Layer Scheme

The proposed scheme is configured to receive MAP options from all the adjacent MAPs, for ARs in the boundary area of its MAP. In addition, when a MN is connecting with a boundary area's AR in the overlapped MAP, it should perform MAP switching prior to the Inter-MAP handoff. This MAP switching performs identical procedures to Inter-MAP handoff operation. However, no packet loss occurs or additional handoff latency occurs, because of MAP switching on receiving the packet from previous MAP. One of important facts motivating the proposed design is that the cost of the location update for HA is much greater than that of MAP. A disadvantage is that since every location request in addition to the location registration, is serviced through a HA, in addition to the HA being overloaded with database lookup operation, the traffic on the links leading to the HA is heavy. Therefore, the traffic required for updating HA is required to be minimized, and the principle employed in the proposed scheme is to distribute the signaling traffic heading to HA and MAPs.

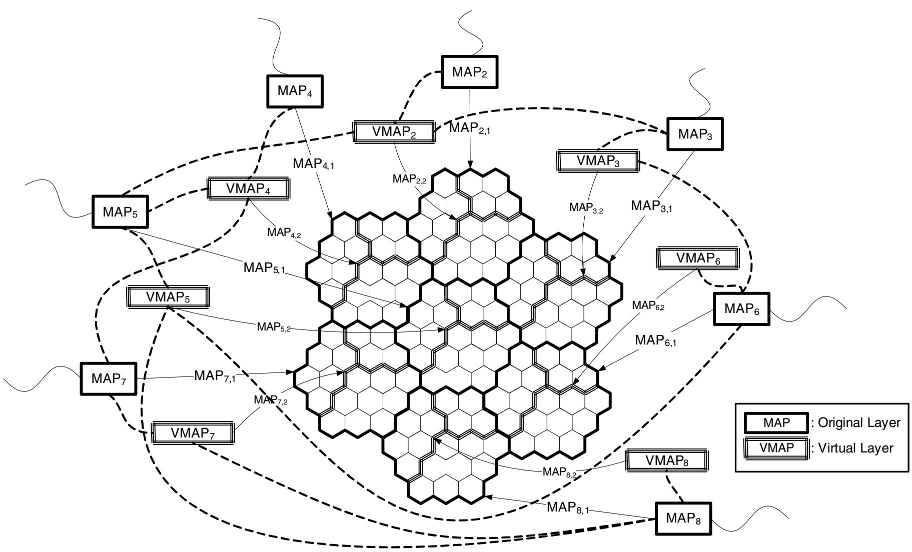

Fig. 2. Proposed Virtual Layer Structure

The enhanced location management scheme proposed in this paper employs virtual layer in part as presented in Fig. 2. Layer-2 MAPs represented as thick lines are in a virtual layer. It can be observed that the entire area is partitioned into seven MAP's ($MAP_2 \sim MAP_8$), which are drawn by dotted MAP boundary lines. In addition, this scheme combines three neighboring MAP's as an expanded cluster in the original layer, an expanded MAP. As previously mentioned, each

MAP has an associated VMAP. This original layer of MAP's is called Layer-1 and the expanded MAP's overlap each other. It is important to note that another portion of the area exists, using bold lines as mentioned above, which is in a virtual layer and are called in Layer-2. Each MAP of Layer-2 also has a VMAP. Each virtual MAP, which is of equal size, is laid upon the center of the combined three MAP's of each expanded MAP. As a result, the mobile terminals' moving around the boundary ARs of adjacent MAP's increasingly move within either a virtual MAP or an overlapping region. VMAPs, which manage the original layer, take charge of the management for the entire area. However, MAPs, which manage the virtual layer, take charge of the management for the partial areas. In what follows, $MAP_{i,j}$ the MAP_i of Layer-j, are denoted. For example, $MAP_{5,1}$ consists of part of $MAP_{2,2}$, $MAP_{4,2}$, and $MAP_{9,1}$. The MAP of Layer-2 is connected to three VMAPs representing the MAP's of Layer-1. For example, MAP_5 is connected to $VMAP_2$, $VMAP_4$ and $VMAP_5$. The proposed structure effectively avoids the ping-ponging effect, occurring when a mobile user travels along the boundary of two adjacent MAP's and distributes the location update signaling traffic over many ARs using the virtual layer.

3.2 Operational Mechanism

The proposed scheme can be implemented by assigning a unique ID to each MAP of Layer-1 and 2. It is important to note that the proposed scheme covers the service area with homogeneous MAP's. The original MAP's are partially overlapped with the MAP's of the virtual layer, and expanded clusters combine three neighboring MAP's in the original layer so they overlap each other. The ARs of layer-1 used to be entirely in one, two, or three MAP's, and the ARs of layer-2 managed by two or three MAP's. Even though each AR belongs to one, two, or three MAP's, the mobile user in an AR registers with only one MAP at any moment. The preference field of MAP options is used to cache the location information of each ARs in the MAP domain. If they are delivered the preference field values of MAP options to all ARs of the same MAP domain, they have exactly the same value. As ARs own location is close to the boundary AR from the center AR, the preference field value is reduced by 1 and then delivered to MN over the Router Advertisement (RA). MN recognizes that it arrived at the boundary ARs of MAP, using the preference field value from AR.

If two MAPs domains overlap other boundary ARs, AR_5, AR_6 and AR_7 receive all the MAP options that are composed MAP_1 and $VMAP_1$. The preference field of MAP options is used for caching AR's location information in the MAP domain and AR transmits the preference field value through Router Advertisement (RA) to MN after decreasing by 1. MN is going to obtain a response that is the value of a preference field, and then obtains boundary ARs. In Fig. 3, when AR_6 is moved to an area of AR_7, Intra-MAP handoff occurs and has received a packet coming from CN through MAP_1 and AR_7 (path 1). AR_7 is located at the outer AR in the overlapping area, so MN is going to turn into its own MAP from MAP_1 to $VMAP_1$. MN transmits Local Binding Update (LBU) to $VMAP_1$, then obtains an Ack, and transmits BU again to HA/CNs. After

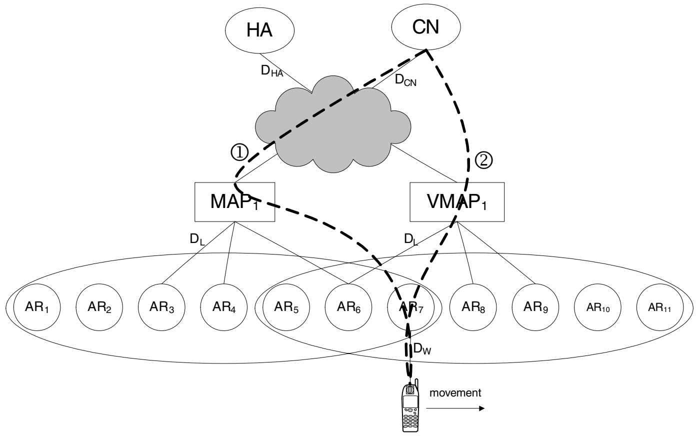

Fig. 3. Operation Procedure

CN receives BU, it transmits data packets with Ack to MN through AR_7 and $VMAP_1$ (path 2). AR_7 does not initiate Inter-MAP handoff if it does not move to AR_5, because AR_7 is located inside of the domain. Considering all of ARs incurring additional overhead for MAP switching are located in MAP domain, the main problem of HMIPv6, SPOF and traffic bottleneck state, are going to have a solution, therefore it can prevent performance downgrade using Inter-MAP handoff.

4 Performance Evaluation

This section presents processing of two kinds of performance analysis in the proposed scheme. First, comparison between the proposed scheme and HMIPv6 for Inter-MAP handoff, is presented. Second, a formula of Average Inter-MAP handoff latency and Total Average handoff latency will be obtained. The handoff latency can be multiplied respectively after an average Intra-MAP handoff probability and Inter-MAP handoff probability occurs, through movement and modeling of handoff procedures. The process for performance comparison when obtaining each value of proposed scheme and HMIPv6 is presented.

4.1 Inter-MAP Handoff Performance Comparison

This consists of topology identical to Fig. 3, for performance comparing of Inter-MAP handoff from the proposed scheme and HMIPv6. AR_5, AR_6, and AR_7 have received all MAP options from MAP_1 and $VMAP_1$. As already mentioned, if the mobile node moves AR_6 to AR_7, and processes the local binding update to MAP_1 in AR_7, then the mobile node in AR_7 is going to process MAP selection algorithm and MAP switching. Parameters for performance evaluation are defined in Table 1.

Table 1. Parameters for Performance Analysis

Parameter	Time
L2 Handoff Latency (Wireless LAN)	80 *ms*
Receipt of Router Advertisement (Mobility Detection)	20 *ms*
D_W (Wireless Part Delay)	2 *ms*
D_L (Wired Part Delay	10 *ms*
D_{CN} (Delay among MAP and CN)	50 $\sim$ 130 *ms*

In this case, for performance comparison the following is assumed. First, On-link CoA Test and Return Routability Test are compared. This does not consider operation time for security in local BU and global BU. Second, it does not consider Duplicated Address Detection (DAD) operation in Address Auto-configuration (AA). Third, if CN delivers packets to MN directly without the HA, mobile node would transmits a binding update to CN first, after checking the local BU. Therefore, if a mobile node does not require the response acknowledgement message, the BA will not return and will transmit data packets with the request. Fourth, CN always transmits packets for moving MN during performance analysis. Fifth, Intra-MAP handoff and MAP switching is always completed during mobile node and stays with a single AR.

In case of moving AR_6 to AR_7, HMIPv6 is $2(D_W+D_L)$ for Intra-MAP handoff latency, proposed scheme is identical. In case of moving AR_7 to AR_8, HMIPv6 is $2(2D_W + 2D_L + D_{CN})$ for Inter-MAP handoff latency, the proposed scheme is $2(D_W + D_L)$for Intra-MAP handoff latency.

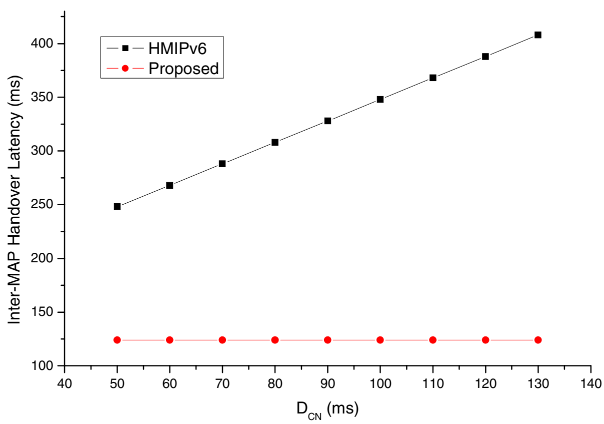

Fig. 4. Inter-MAP Handoff Latency Comparison

As presented in Fig. 4, Inter-MAP handoff latency is identical with Intra-MAP handoff latency for the proposed scheme, these are always the same values regardless of D_{CN} value. Otherwise, HMIPv6 handoff latency is larger, according to D_{CN} because the Inter-MAP handoff latency time should process a local binding update and additional BU to CNs.

4.2 Total Average Handoff Latency

The proposed scheme is only able to improve performance of Inter-MAP handoff. Therefore, it is required to grasp all Inter-MAP handoff probability, in order to decide improvement of the proposed scheme exactly. Given the MAP's radius, Inter-MAP handoff probability is obtained through mobility modeling, and the general formula of average Inter-MAP handoff latency is created after multiplying it by the handoff latency value. In addition, in the same manner, the average Intra-MAP handoff latency is obtained, the sum of the two values and the general formula of total average handoff latency is then obtained. For the proposed scheme, after Inter-MAP and Intra-MAP handoff latency value is input in this general formula. Average Inter-MAP handoff latency and total average handoff latency can be calculated, comparing these values. In this paper, the Markov Chain [10] used for handoff procedures is modified for the Location Update procedures, five formulas are also derived from this Markov Chain. For modeling of border crossing to be used for handoff procedures, the following is assumed.

1. MN's moving direction is distributed equally to $[0,2\pi)$ in AR.
2. Residence time is when MN remains in AR, and has negative exponential distribution.
3. All ARs have identical shape and size, form an adjacent area with each other, and are approximately a circular shape.

The Border-crossing rate can be calculated when MN moves away from MAP [11], as $V_{MAP} = \frac{\pi V}{4R_{MAP}}$. where, $R_{MAP}$is MN's average movement velocity and is the radius of the circular MAP. Similarly, the Border-crossing rate when MN moves away from AR, is $V_{AR} = \frac{\pi V}{4R_{AR}}$. Accordingly, the MN always passes by AR when it crosses MAP and the rate of crossing only AR's border in the same MAP, is calculated [10] as $V_{AR\_in\_MAP} = V_{AR} - V_{MAP} = \frac{\pi V(R_{MAP}-R_{AR})}{4R_{AR} \cdot R_{MAP}}$.

The MN's handoff procedures are modeling the Imbedded Markov Chain as Fig. 5. Markov chain's state is defined as the number of visiting ARs in the same MAP for MN. In other words, it means the number of Intra-MAP handoff until Inter-MAP handoff.

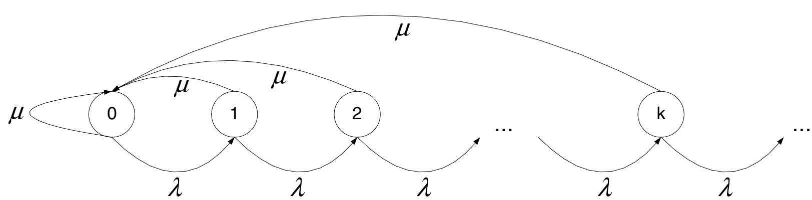

Fig. 5. Markov Chain for Handoff Procedure

where, $\lambda(= V_{AR\_in\_MAP})$ is the transition rate, moving from state k to $k+1$ (Intra-MAP handoff) and $\mu(= V_{MAP})$ is the transition rate, moving from state k to state 0 (Inter-MAP handoff) for MNs.

The steady state probability (P_k) of State k using the global balance equation is $P_0 = \frac{\mu}{\mu+\lambda}$, $P_k = (\frac{\mu}{(\mu+\lambda)})^k P_0 = (1-P_0)^k P_0$. The Inter-MAP handoff probability is $\alpha = P_0 \times 1 = \frac{\mu}{\mu+\lambda} = \frac{R_{AR}}{R_{MAP}} = AMR$. Where, AMR is the ratio for the radius of MAP and AR. Similarly, the Average Intra-MAP handoff probability is $\beta = \sum_{k=1}^{\infty}(1-P_0)^k P_0 = \frac{1}{P_0} - 1 = \frac{R_{MAP}}{R_{AR}} - 1$.

For the topology shown in Fig. 3, the Average Inter-MAP handoff latency is found my multiplying the average Inter-MAP handoff probability by Inter-MAP handoff latency, and the average Intra-MAP handoff latency is achieved similarly. Therefore, the total average handoff latency (L_{T_Av}) is the sum of average Inter-MAP handoff latency (αL_R) and average Intra-MAP handoff latency (βL_A). Handoff latency for the HMIPv6 and proposed scheme are compared in Table 2.

Table 2. Handoff Latency Comparison for HMIPv6 and Proposed schemes

-	**HMIPv6**	**Proposed**
αL_R	$AMR(2D_{CN}+48)$	$24AMR$
βL_A	$24(\frac{1}{AMR}-1)$	$24(\frac{1}{AMR}-1)$, $(\Theta L_R = L_A = 2D_W + 2D_L)$
L_{T_Av}	$AMR(2D_{CN}+48)+24(\frac{1}{AMR}-1)$	$24AMR+24(\frac{1}{AMR}-1)$

Fig. 6 presents the appearance of average Inter-MAP handoff latency according to the AMR and D_{CN} value. For HMIPv6, average Inter-MAP handoff latency increases in proportion to the D_{CN} value, however, the proposed scheme always has same average Inter-MAP handoff latency for all D_{CN} values. As reviewed earlier, in the case of the Inter-MAP handoff of HMIPv6,the Local BU and Global BU are performed respectively. However, in the case of the proposed

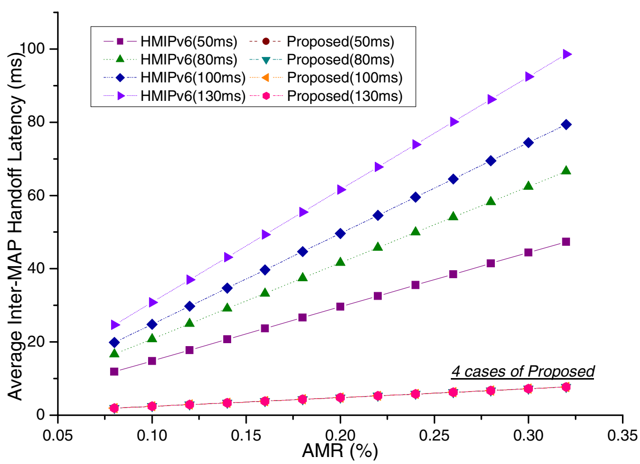

Fig. 6. Average Inter-MAP handoff latency

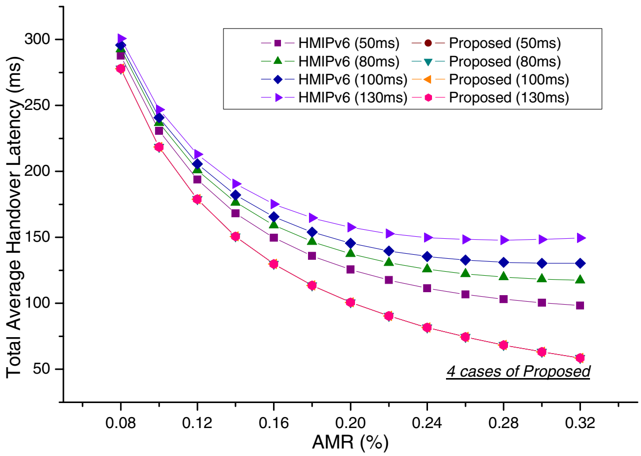

Fig. 7. Total Average handoff latency

scheme, a local BU is always required, this local BU does not change latency according to D_{CN}, which is the distance between MAP and CNs.

AMR's value is the ratio of MAP's radius to AR's radius, actually average Inter-MAP handoff probability based on the formulas as mentioned earlier. When the AMR value close to 1, Inter-MAP handoff probability is greater for HMIPv6 and the proposed scheme, and the Inter-MAP handoff latency also increases. Therefore, when the AMR value is close to 1, there is greater Inter-MAP handoff latency improvement in the proposed scheme.

As presented in Fig. 7, when AMR is 0.32, average handoff latency improved between 40.3% and 55% in accordance with D_{CN}. However, when AMR is 0.08, it is only improved between 5.4% and 9.3%. There is reason to rapidly increase the Inter-MAP handoff probability when there are too many ARs in MAP.

5 Conclusion

In this paper, an efficient location update scheme employing a partial virtual layer to reduce the update signaling traffic in HMIPv6, is proposed. The system has a two-layer architecture and is configured by homogenous MAP's. Conceptually, the proposed scheme is a combination of grouping, overlapping, and local updating in MAP. This scheme yields significant performance improvement over the overlapping and fully virtual layer scheme in terms of the average location update rate per user. Moreover, the new method offers considerable enhancement in utilizing the network resources which otherwise will be wasted by mobile users causing frequent update in HMIPv6. The signaling traffic concentrated on boundary ARs in the HMIPv6 is also distributed to many ARs.

In addition to the mobile users at the boundary ARs, the location update is required to consider other factors such as mobility pattern, dwell time, call to movement ratio, and so on. The relationship between the factors will be investigated, and included in the model of the update rate. This will present good measure by which efficient location management policy can be derived.

Acknowledgment

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