A Pointer Forwarding Scheme with Mobility-Aware Binding Update in Hierarchical Mobile IPv6 Networks

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***Abstract*— In this paper, we propose a pointer forwarding scheme with mobility-aware binding update in Hierarchical Mobile IPv6 networks. In the proposed scheme, a pointer chain between access routers (ARs) is established to reduce the binding update (BU) traffic to the mobility anchor point (MAP). In addition, the MN performs a binding update to the correspondent node (CN) depending on its mobility. Specifically, an on-link care-of address (LCoA) is chosen for the MN with low mobility whereas a regional care-of-address (RCoA) is selected for the MN with high mobility. This mobility-aware binding update can reduce the packet delivery overhead in an adaptive manner. We develop analytical models that consider both the binding update cost and the packet delivery cost when route optimization is supported. Numerical results demonstrate that the pointer-forwarding scheme with mobility-aware BU outperforms HMIPv6 and the existing pointer forwarding scheme in terms of binding update and packet delivery costs.**

Key words: Hierarchical Mobile IPv6, pointer forwarding, mobility-aware binding update, performance analysis.

1. Introduction

Mobile IPv6 (MIPv6) is the de-facto mobility support protocol in IPv6-based mobile networks [1]. In MIPv6 networks, a mobile node (MN) sends a binding update (BU) message to its home agent (HA), whenever it changes its point of attachment to the Internet. Therefore, MIPv6 leads to significant signaling traffic. Furthermore, since the HA is typically far from access routers (ARs), a long handoff latency for the HA binding update procedure is expected. To overcome these problems, Hierarchical Mobile IPv6 (HMIPv6) [2] has been proposed by the Internet Engineering Task Force (IETF). HMIPv6 localizes binding update procedures by introducing a local HA called mobility anchor point (MAP).

In HMIPv6 networks, an MN configures two care of addresses (CoAs): a regional care-of-address (RCoA) and an on-link care-of-address (LCoA). The RCoA is an address in the MAP's subnet. An MN obtains its RCoA when it receives a Router Advertisement (RA) message with the MAP option. On the other hand, the LCoA is an on-link CoA attributed to the MN's interface and it is based on the prefix information advertised by an access router (AR). After configuring the LCoA and RCoA, the MN sends a BU message to the MAP, which then maintains the binding information between the RCoA and the LCoA (i.e., local binding update). Also, the MN sends a BU message containing the MN's home address (HoA) and the RCoA to its HA (i.e., home binding update) and correspondent nodes (CNs) (i.e., route optimization). The MN's RCoA is not changed while the MN resides in the MAP domain and therefore the MN needs to send a local BU message only to the MAP (not to its HA) for a movement within the MAP domain. By localizing the binding update traffic, HMIPv6 can reduce the signaling load and the handoff latency. On the other hand, the packet delivery procedure in HMIPv6 networks is as follows. When a CN has some packets to send to an MN, the CN first sends its packets to the MN's HoA, and the HA then intercepts the packets and tunnels to the registered CoA (i.e., the MN's RCoA). The tunneled packets arrive at the MAP and then the MAP re-tunnels them to the MN's current AR (i.e., the MN's LCoA).

Since reducing signaling overhead and handoff latency is a critical issue in large-scale wireless/mobile networks, extensive studies have been conducted in the literature [3] One of the most representative schemes is a pointer forwarding (PF) scheme [4,5]. The basic operations of the PF scheme for cellular networks can be summarized as follows. When a mobile terminal moves between the domains of two visitor location registers (VLRs), a forwarding pointer between the old VLR and the new VLR is established, instead of reporting its new location to its home location register (HLR). By doing so, the signaling traffic to the HLR can be significantly reduced. The forwarding pointer can be extended as a form of a chain as the mobile terminal moves through multiple VLR areas. When a session for the terminal is initiated, the cellular network locates the terminal by first determining the initial VLR (the starting point of the forwarding chain) and then following the pointers to the current serving VLR of the terminal. To limit the excessive delay in locating a terminal, the length of the pointer chain can be extended up to a predefined value *K*. In other words, when the length of the pointer chain reaches K, additional forwarding pointer is not allowed and the new location is reported to the HLR.

As heterogeneous wireless/mobile networks are converged to all-IP networks, IP-based mobility support protocols have been recently investigated [6]. In [7-9], several protocols employing the PF scheme have been introduced to reduce the signaling overhead. However, these works do not consider the effect of route optimization that is a mandatory function in Mobile IPv6. Also, the optimal pointer length is not explicitly derived.

In this paper, we propose an enhanced pointer forwarding scheme with mobility-aware binding update (MBU) in HMIPv6 networks. Since the size of a MAP domain is generally large (i.e., a MAP domain covers a large number of ARs), the movement between MAPs is not a frequent event than intra-MAP handoff. Therefore, unlike the previous works, the proposed pointer forwarding scheme establishes a pointer chain between ARs not MAPs, and it can further reduce the signaling traffic incurred by local movements (i.e., local binding update traffic inside a MAP domain). In addition, MBU is introduced to alleviate the negative effect of PF schemes on the packet delivery procedure. Last but not least, we present an analytical model for the PF scheme with MBU, which considers the packet delivery procedure and the binding update procedure. Based on the analytical model, we evaluate the performance of the proposed schemes against MIPv6, HMIPv6, and the PF scheme without MBU.

The remainder of this paper is organized as follows. In Section 2, we propose the pointer forwarding scheme and MBU. In Section 3, the analytical models are presented and numerical results are described in Section 4. Section 5 concludes this paper.

2. A Pointer Forwarding Scheme with Mobility-Aware Binding Update

In this section, we describe the binding update and packet delivery procedures. Also, mobility-aware binding update (MBU) is introduced.

2.1. Binding Update Procedure

In general, a MAP domain covers a number of ARs and an MN's movements are likely to be bounded within the areas of several ARs. Therefore, the inter-MAP handoffs occur much less frequently than the intra-MAP handoffs. Based on this observation, the proposed PF scheme establishes a forwarding pointer between ARs rather than MAPs or FAs, which is different from the existing studies [7-9]. In addition, the hop distance between ARs (i.e., the old AR (oAR) and the new AR (nAR)) is much shorter than the one between the MAP and the nAR. Therefore, sending a BU message to the oAR (not to the MAP) can significantly reduce the binding update traffic and registration latency in HMIPv6 networks.

In the PF scheme, each AR maintains a pointer table (PT). Each entry in PT includes of three fields: **ID**, **CURRENT**, and **NEXT**. The **ID** field contains the MN's home address. The **CURRENT** field stores the MN's LCoA configured in the corresponding AR subnet, whereas the **NEXT** field is the MN's LCoA used in the next AR subnet. If the **NEXT** field is null, the address in the **CURRENT** field is the currently used LCoA, which indicates the MN resides in the AR subnet.

Figure 1 illustrates the binding update procedure. After the initial registration at the first AR, *AR1*, the **CURRENT** and **NEXT** fields are *LCoA1* and *NULL*, respectively. If the MN moves to a new AR, *AR2*, the MN sends a BU message to the previous AR, *AR1*. The BU message has a flag F, which represents that the BU message is sent to setup a forwarding pointer between the oAR and the nAR. The oAR receiving the BU message then updates its pointer table and responds to the MN, which current LCoA is *LCoA2*, with a BACK message. When the MN receives the BACK message, the MN increases its pointer chain length variable l by one. After the binding update procedure, the **CURRENT** and **NEXT** fields at *AR1* become *LCoA1* and *LCoA2*, respectively. On the other hand, the **CURRENT** and **NEXT** fields at *AR2* become *LCoA2* and *NULL*, respectively.

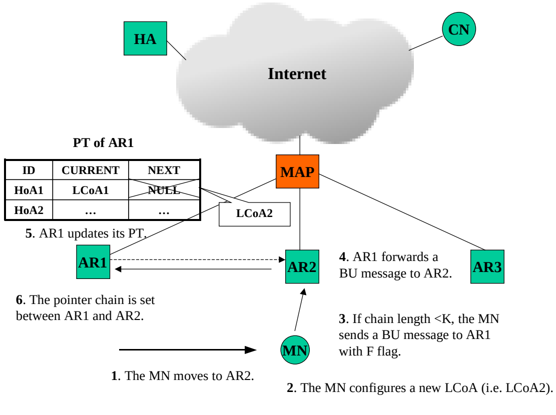

Figure 1: Binding update procedure.

This binding update procedure is performed as long as l is less than a pre-defined threshold K. If an MN hands off within a MAP domain and l becomes K, the MN informs the MAP of its current LCoA and l is reset. Since K has a significant impact on the performance of the PF scheme, it should be set not to incur the excessive packet reception latency [7], which will be investigated in Section 4.1. For an inter-MAP handoff, the MN initializes *l* and performs the local and home binding updates as specified in [2]. In terms of implementation, it can be integrated with Fast Handover for Mobile IPv6 [10], where a bi-direction tunnel is established between the oAR and the nAR for seamless handoff support.

2.2. Packet Delivery Procedure

The packet delivery procedure in the PF scheme is as follows. When a CN has packets to send to an MN, the CN first sends the packets to the MN's home address. Then, the HA intercepts the packets and tunnels them to the registered RCoA of the MN. Since the MAP maintains the mapping information between the RCoA and the LCoA, the MAP re-tunnels the received packets to the most recently registered LCoA of the MN. In the PF scheme, the most recently registered LCoA may not be the LCoA currently used by the MN. For instance, as shown in Figure 2, the most-recently registered LCoA at the MAP is *LCoA1*, whereas the current LCoA is *LCoA3*. Therefore, *AR1* should re-route the packets to the registered MN. To re-route the packets, *AR1* checks the **NEXT** field for the MN. If the **NEXT** field is *NULL*, the AR delivers the packets to the MN directly. Otherwise, *AR1* forwards the packets to the LCoA recorded in the **NEXT** field. This packet forwarding procedure is repeated until an AR with the **NEXT** field of *NULL* is reached. After receiving the packets, the MN should send BU messages to the MAP and CN in order to notify its up-to-date CoA and initialize *l*.

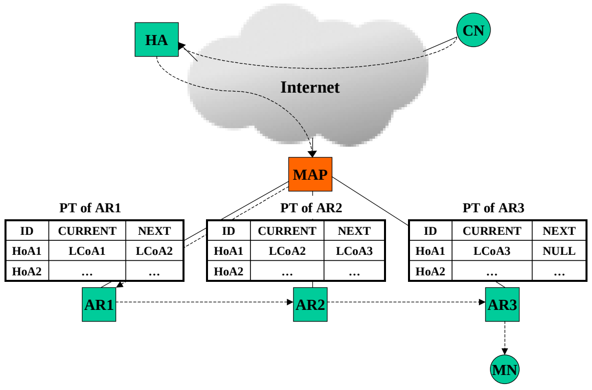

Figure 2: Packet delivery procedure

In the PF scheme, a loop may be formed when the MN enters a previously visited subnet. To avoid the loop formation, each MN maintains the AR list consisting of visited ARs. If the newly visited AR is belonged to the AR list, it implies a loop formation. Then, the MN recalculated its pointer chain length variable *l* as follows: the new AR is the *i*th AR in the AR list, the length variable is set to *i-1*. At the same time, the MN sends a BU message with an *L* flag to the current AR. When the AR receives the BU message with an *L* flag, the AR detects the loop and updates the MN's entry in its PT as (the MN's LCoA, *NULL*).

2.3. Mobility-Aware Binding Update to CNs

In MIPv6 networks, an MN performing route optimization by sending BU messages to CNs after receiving tunneled packets from the HA. Route optimization addresses the triangular routing problem incurred in MIPv4 networks and mitigates the burden on the HA. In HMIPv6 networks, the MN sends BU messages with its RCoA to CNs for route optimization, and then the packet are routed via the MAP bypassing the HA. However, route optimization in HMIPv6 networks needs additional tunneling overhead at the MAP, and therefore it may lead to low throughput for an MN with low mobility and high session arrival [11,12]. For those MNs, route optimization with LCoA is preferable because it can remove the MAP tunneling. Consequently, if route optimization is applied adaptively to the MN's characteristics, both BU traffic reduction and tunneling overhead reduction can be achieved.

This is the motivation of mobility-aware binding update (MBU). In MBU, MNs are classified into two types: fast and slow MNs. The classification can be done by the measured time interval of the received RA messages from different ARs. For example, if an MN listens to an RA message from an AR at time t_1 and it moves and listens to an RA message from another AR at time t_2, the time interval t_2-t_1 is interpreted by the subnet residence time of the MN. When an MN enters a new AR subnet, it estimates the residence time at the new AR subnet using the previously measured subnet residence time. In the estimation, the exponentially weighted moving average (EWMA) technique can be utilized to mitigate the effect of the variations on the measured residence times. After that, the MN compares the estimated residence time with a predefined threshold δ. If the estimated value is smaller than δ, the MN is deemed to be fast. Otherwise, the MN is considered as a slow MN. For a fast MN, the MN sends a BU message with RCoA to the CN whereas the LCoA is notified to the CN for a slow MN. Accordingly, MBU enables the fast MN to reduce the binding update traffic by leveraging the MAP. At the same time, the slow MN can avoid the unnecessary MAP processing cost in the packet delivery procedure.

3. Performance Analysis

In this section, we develop analytical models, which quantify the total cost consisting of the binding update (BU) and packet delivery (PD) costs. We compare the PF scheme with MBU against MIPv6, HMIPv6, and the PF scheme without MBU. Unlike [7], we models the BU and

PD costs during an inter-session time, which is defined as the time interval from the last packet of a data session to the first packet of the next data session [13]. We have the following notations for analytical modeling.

- $E(L_S)$: The average session length (in number of packets)
- B_{HA} , B_{MAP} , and B_{CN} : Unit BU cost to the HA, MAP, and CN, respectively.
- B_F : Unit BU cost to the old AR (i.e., pointer setup cost)
- P_{NRO}^{X} : PD cost over a non-optimized path from the CN to the MN ($X \in$ {MIPv6 or HMIPv6})
- P_{RO}^{X} : PD cost over an optimized path from the CN to the MN ($X \in$ {MIPv6 or HMIPv6})
- P_F : PD cost over a pointer chain from the old AR to the new AR
- P_{LCoA} : Probability that the MN sends a BU message with its LCoA to the CN
- ω : The portion of packets before route optimization to the total number of packets of a data session.

3.1. Mobile IPv6

In MIPv6, an MN sends a BU message to the HA whenever the MN moves to another subnet. Also, if the MN receives tunneled packets from the HA, the MN sends a BU message to the CN for route optimization. Therefore, the BU cost of MIPv6 is given by

$$C_{Total}^{MIPv6} = E(N_C) \cdot B_{HA} + B_{CN}$$

where $E(N_C)$ is the average number of subnet crossings during an inter-session arrival time. For the PD cost, we need to consider two types of packet delivery paths: non-optimized path and optimized path. Before route optimization, packets from the CN visit the HA and then tunneled to the MN. On the other hand, after route optimization, packets can be directly routed from the CN to the MN without bypassing the HA. Then, the PD cost can be computed as

$$C_{PD}^{MIPv6} = \omega \cdot E(L_S) \cdot P_{NRO}^{MIPv6} + (1-\omega) \cdot E(L_S) \cdot P_{RO}^{MIPv6}$$

3.2. Hierarchical Mobile IPv6

In HMIPv6 networks, a BU message is sent to the HA only when an MN moves to another MAP domain. If the MN moves to another subnet within the same MAP domain, the MN sends a BU message only to the MAP. Therefore, the BU cost of the HMIPv6 is given by

$$C_{BU}^{HMIPv6} = E(N_D) \cdot B_{HA} + B_{CN} + E(N_C) \cdot B_{MAP}$$

where $E(N_D)$ denotes the average number of domain crossings during an inter-session arrival time. Before route optimization, all packets are first routed to the MAP. Hence, the PD cost of HMIPv6 is computed as

$$C_{PD}^{HMIPv6} = \omega \cdot E(L_S) \cdot P_{NRO}^{HMIPv6} + (1-\omega) \cdot E(L_S) \cdot P_{RO}^{HMIPv6}$$

3.3. Pointer Forwarding Scheme

In the PF scheme, an MN sends a BU message to the HA when an MN crosses a MAP domain, whereas the MN sends a BU message to the CN and MAP when it receives the first packet of a data session. On the other hand, the MN sends a BU message to the MAP when pointer chain length reaches to the threshold value *K*. If the MN crosses an AR and the pointer chain length is less than *K*, it sends a BU message to the old AR. Let $E(N_C^i)$ denote the average number of subnet crossings in the *i*th MAP domain. Then, $\lfloor E(N_C^i)/K \rfloor$ represents the number of pointer resets and $E(N_C^i) - \lfloor E(N_C^i)/K \rfloor$ refers to the number of pointer updates in the *i*th MAP domain. Then, the BU cost of the PF scheme can be calculated as

$$\begin{aligned} C_{BU}^{PF} &= E(N_D) \cdot B_{HA} + B_{CN} + B_{MAP} \\ &+ \sum_{i=1}^{E(N_D)} \left(\left\lfloor \frac{E(N_C^i)}{K} \right\rfloor \cdot B_{MAP} + \left(E(N_C^i) - \left\lfloor \frac{E(N_C^i)}{K} \right\rfloor \right) \cdot B_F \right) \end{aligned}$$

Even though the PF scheme can reduce the BU cost, it increases the PD cost because packets should be delivered over a pointer chain before route optimization procedure. Since the pointer chain is refreshed every *K* subnet crossings, the average pointer chain length that a data session travels can be approximated to *K/2*. Note that the packet delivery after route optimization is the same as that of HMIPv6. Then, the PD cost of the PF scheme is given by

$$C_{PD}^{PF} = \omega \cdot E(L_S) \cdot \left(P_{NRO}^{HMIPv6} + \frac{K}{2} \cdot P_F \right) + (1-\omega) \cdot E(L_S) \cdot P_{RO}^{HMIPv6}$$

3.4. Pointer Forwarding Scheme with MBU

In MBU, the LCoA can be notified to the CN if the MN is considered as a slow MN and then the LCoA binding update is performed for every subnet crossing during a binding update lifetime T_{BU}. To obtain this additional BU cost, let μ_C be the subnet crossing rate of an MN. Then, the average number of subnet crossings during T_{BU} is given by $\mu_C T_{BU}$. Then, the BU cost in the PF scheme with MBU is given by

$$C_{BU}^{PF+MBU} = C_{BU}^{PF} + P_{LCoA} \cdot \mu_C T_{BU} \cdot B_{CN}$$

The PD cost of the PF scheme with MBU before route optimization is the same as that of the PF scheme without MBU. If the MN's LCoA is informed to the CN by route optimization, the PD cost of the PF scheme with MBU is the same as that of MIPv6. Otherwise, the PF scheme with MBU follows the same operations as HMIPv6. Therefore, the PD cost can be computed as

$$C_{PD}^{PF+MBU} = \omega \cdot E(L_S) \cdot (P_{NRO}^{HMIPv6} + \frac{K}{2} \cdot P_F)$$
$$+ (1-\omega) \cdot E(L_S) \cdot ((1-P_{LCoA}) \cdot P_{RO}^{HMIPv6} + P_{LCoA} \cdot P_{RO}^{MIPv6})$$

4. Numerical Result

Table 1 shows the parameter values used in the numerical analysis. These values are assigned by considering the hop distance between mobility agents and the processing cost at the mobility agent [14]. To investigate the effect of mobility, we define the session to mobility ratio (SMR) as $SMR = \lambda_S / \mu_C$, where λ_S is the session arrival rate and μ_C is the subnet crossing rate. As derived in [15], if the session arrival and subnet residence time processes follow exponential distributions with means $1/\lambda_S$ and $1/\mu_C$, respectively, the expected number of subnet crossings per session ($E(N_C)$) is given by μ_C / λ_S. On the other hand, the MAP domain crossing rate can be represented as a function of the number of subnets in a MAP domain. Specifically, μ_D can be approximated to $\mu_C / \sqrt{n}$, where n is the number of subnets in a MAP domain [16]. Therefore, the expected number of MAP domain crossings per session ($E(N_D)$) is given by $E(N_C)/\sqrt{n}$, when the MAP domain residence time follows an exponential distribution with rate μ_D. In our analysis, n is assumed to be 49 [13]. Let t_C be a random variable for the subnet residence time. Then, P_{LCoA} can be calculated as

$$P_{LCoA} = \Pr(t_C > \delta) = 1 - \Pr(t_C > \delta) = e^{-\lambda_C \delta}$$

where δ is the predefined threshold.

Table 1: Parameter values for numerical analysis

B_{HA}	B_{MAP}	B_{CN}	B_F	ω
20	5	10	1	0.1
P_{NRO}^{MIPv6}	P_{RO}^{MIPv6}	P_{NRO}^{HMIPv6}	P_{RO}^{HMIPv6}	T_{BU}
10	4	15	6	180

4.1. Optimal Pointer Chain Length

Figure 3 indicates the effect of SMR on the optimal pointer chain length *K*. When the SMR is low, the mobility rate is a more dominant factor than the session arrival rate. Therefore, reducing the BU cost is more critical than reducing the PD cost. To accomplish this, the pointer chain should be lengthened because the BU cost to the old AR is much lower than that to the MAP or the HA. On the other hand, when the SMR is high, the mobility rate is relatively lower than the session arrival rate. In this situation, the PD cost has a large portion of the total cost, and hence a short pointer chain is preferable to reduce the packet delivery overhead. Consequently, the optimal pointer chain length decreases as the SMR increases.

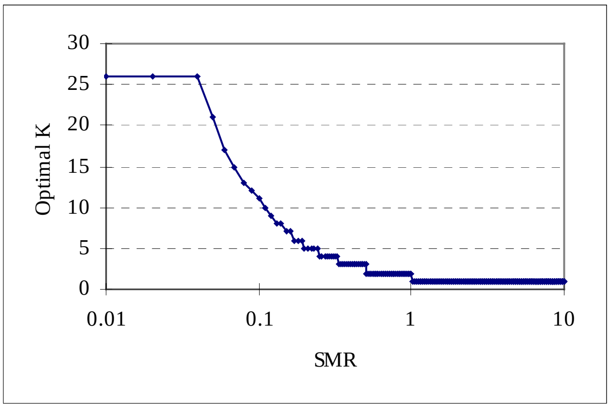

Figure 3: Optimal K vs. SMR.

4.2. Effect of SMR

Figure 4 shows the relative total cost of each scheme when the total cost of MIPv6 is normalized to one. When the SMR is low, HMIPv6 can reduce the total cost of MIPv6 by localizing binding updates. However, as the SMR increases, the relative cost of HMIPv6 increases. Especially, when the SMR exceeds a specific point (0.53 in Figure 4), HMIPv6 exhibits a larger cost than MIPv6. This is because a high SMR represents large session arrivals. Since all packets are processed at the MAP in HMIPv6, HMIPv6 is worse than MIPv6 in terms of the PD cost [11]. Therefore, HMIPv6 has a larger total cost than MIPv6 for large session arrivals, i.e., when the SMR is high.

On the other hand, the PF scheme with or without MBU can further reduce the total cost of HMIPv6 when the SMR is low. However, when the SMR is larger than a specific value (0.66 in Figure 4), the total cost of the PF scheme becomes larger than that of MIPv6. This is because the PF scheme requires an additional cost for the packet delivery over the pointer chain and the cost becomes more significant for a high SMR. One remarkable point in Figure 4 is that the PF scheme with MBU can reduce the total cost even in a high SMR. Consequently, it can be concluded that the overhead in the packet delivery incurred in the PF scheme without MBU can be mitigated by employing MBU.

We have also analyzed the effects of session length and MAP domain size under different SMR values. The results demonstrate that the PF scheme with MBU can reduce the total cost significantly when the SMR is low. In addition, by means of MBU, the PF scheme with MBU can reduce the overhead caused by the PF scheme without MBU even when the SMR is high. More detailed results can be found in [17].

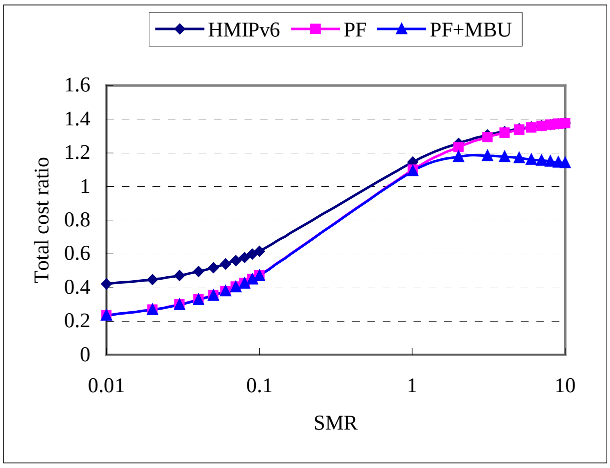

Figure 4: Relative total cost vs. SMR

5. Conclusions

In this paper, we have proposed an enhanced pointer forwarding (PF) scheme with mobility-aware binding update (MBU) in HMIPv6 networks. Through the PF scheme, the binding update cost can be significantly reduced and the MAP overhead is also mitigated. At the same time, MBU enables the MN to register either its LCoA or RCoA to the CN in an adaptive manner to its mobility, and therefore the overhead in the packet delivery can be lowered. We have developed the analytical models and presented various numerical results investigating the optimal pointer chain length and the effect of SMR. The results reveal that the PF scheme with MBU can reduce the total cost over a wide SMR, compared with HMIPv6 and the PF scheme without MBU. Also, it can be shown that the performance of the PF scheme with MBU can be improved as the MAP domain size becomes large.

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