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Article

SMR-Based Adaptive Mobility Management Scheme in Hierarchical SIP Networks

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Abstract: In hierarchical SIP networks, paging is performed to reduce location update signaling cost for mobility management. However, the cost efficiency largely depends on each mobile node's session-to-mobility-ratio (SMR), which is defined as a ratio of the session arrival rate to the movement rate. In this paper, we propose the adaptive mobility management scheme that can determine the policy regarding to each mobile node's SMR. Each mobile node determines whether the paging is applied or not after comparing its SMR with the threshold. In other words, the paging is applied to a mobile node when a mobile node's SMR is less than the threshold. Therefore, the proposed scheme provides a way to minimize signaling costs according to each mobile node's SMR. We find out the optimal threshold through performance analysis, and show that the proposed scheme can reduce signaling cost than the existing SIP and paging schemes in hierarchical SIP networks.

Keywords: SIP; SMR; paging; location update; location management

1. Introduction

As Internet services are getting more popular, the wideband IP networks are becoming more common in wireless networks, as well as wired networks. One of the most important challenges that IP networks face is mobility support. There are two approaches for mobility support. One is Mobile IP (MIP) [1], the other is Session Initiation Protocol (SIP) [2]. Mobile IP and Mobile IPv6 (MIPv6) enhance the network layer so that IP hosts can change location and retain their communication session [3]. Mobility in IP networks can be alternatively supported by application layer mobility protocols that rely on higher layer signaling to achieve the sought-after results. Some of these efforts include the use of SIP. Recently, most operators deployed the IP multimedia subsystems (IMS), which is working based on SIP [4].

Motivation and description of SIP functionality to support mobility can be found in [5,6]. According to these proposals, SIP can be used to provide terminal mobility to Internet multimedia applications, with the appropriate SIP extensions to the basic SIP specification. Specifically, SIP signaling is used after the handoff for the end-to-end session re-establishment of SIP ongoing sessions between the communicating users in heterogeneous networks [7,8]. The major argument for using SIP to achieve terminal mobility in SIP environments is the reuse of existing SIP infrastructure like SIP proxies, SIP registrars, and SIP back-to-back user agents for the functionality required by mobile nodes. The deployment of mobile IP leads to some extent in a duplicated network functionality and stored user data. Both SIP and Mobile IP have their own mechanism for registration or location update. Additionally, the use of SIP could also compensate for the current lack of wide deployment of Mobile IP.

The need of micro-mobility support in SIP networks has increased recently. Micro-mobility protocol can handle local movement (e.g., within a domain) of mobile nodes without interaction with the SIP registrar. This scheme is defined as a hierarchical SIP (HSIP). HSIP can be achieved by using border router enabled SIP proxy, B2BUA and registrar functionality. This has the benefit of reducing delay and packet loss during handoff and eliminating location updates between mobile nodes and their registrar. As a result, HSIP can reduce the signaling overhead and support seamless handoff [9,10]. Additionally, paging can be supported in HSIP. This scheme is defined as a paging scheme in hierarchical SIP networks (PHSIP). Paging can reduce each mobile node's location update, thus, the signaling cost is reduced and the power of mobile device is saved. However, the signaling cost can be increased according as the MN's session-to-mobility ratio (SMR) is increased because paging and location update are trade-off [11–13]. The SMR represents the relative ratio of the session arrival rate to the user mobility. In order to reduce the total cost, including location update and paging, we propose the adaptive mobility management scheme, which can determine the policy regarding to each mobile node's SMR in hierarchical SIP networks to solve the problem.

The proposed scheme is defined as an adaptive scheme in hierarchical SIP networks (AHSIP). In AHSIP, each mobile node can determine the policy regarding to its SMR whenever it moves. If an MN's SMR is greater than the threshold, the HSIP scheme works, otherwise, the PHSIP scheme works. As a result, AHSIP can reduce the signaling cost regardless of each MN's SMR.

The remainder of this paper is organized as follows: Section 2 describes the architecture of hierarchical SIP and the proposed scheme, AHSIP, in detail. Section 3 describes performance analysis. From performance analysis, signaling cost functions for HSIP, PHSIP, and AHSIP are generated, and the threshold used in AHSIP is determined. Section 4 provides numerical results in detail. Finally, Section 5 concludes the paper.

2. Adaptive Mobility Management Scheme in HSIP

In this section, we provide the overview of the hierarchical SIP. We also describe the paging scheme in hierarchical SIP. Then we propose the adaptive mobility management scheme, which can determine the policy regarding to each mobile node's SMR.

2.1. HSIP Scheme

The Hierarchical SIP scheme is proposed by Dimitr Vali [9,10]. This scheme is a micro mobility management scheme in SIP networks, which is similar to IDMP [11], HMIPv6 [14], and MIP-RR [15]. Figure 1 shows the system architecture of HSIP, which is composed of mobile nodes (MNs), correspondent nodes (CNs), a home registrar (HR), SIP mobility agents (SIP MAs), and access routers (ARs). An HR is responsible for globally handling inter-domain mobility. SIP MAs can be deployed in a domain and they are responsible for locally handling intra-domain mobility and managing routes in its domain. For simplicity, we assume that each domain is controlled by a single SIP MA situated at the domain boundary. An AR is deployed in every cell and is responsible for wireless transmission.

Figure 1. HSIP architecture.

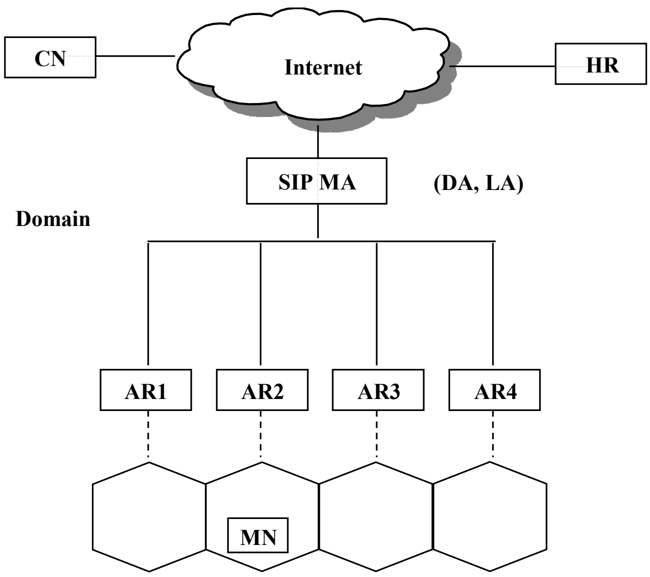
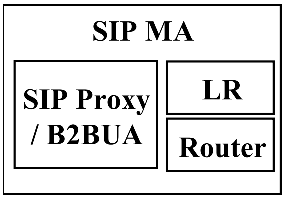


Figure 2 shows the SIP MA, which is a border router enhanced with the functionality of a SIP proxy, a back-to-back user agent (B2BUA), and a local registrar (LR). HSIP can support intra-domain mobility using the SIP MA. HSIP allocates two addresses to each MN. One is local address (LA) and the other is global domain address (DA). The LA is an IP address reflecting the current point of attachment of the MN and it is allocated to the MN by the serving AR. A new LA is allocated to the MN each time it performs an intra-domain movement. The DA is a globally routable IP address that uniquely identifies the MN for the whole duration of moving inside the same access domain. Each MN is allocated a different DA by the SIP MA, which has a pool of globally routable IP addresses associated with it. The SIP MA is responsible for maintaining and managing mappings among the SIP URI, the DA and the LA for each mobile that moves inside the domain. The MN registers locally with its SIP MA in the case of intra-domain movement. However, it registers not only locally with its SIP MA, but also globally with its HR in the case of inter-domain movement [9,10].

Figure 2. SIP MA.

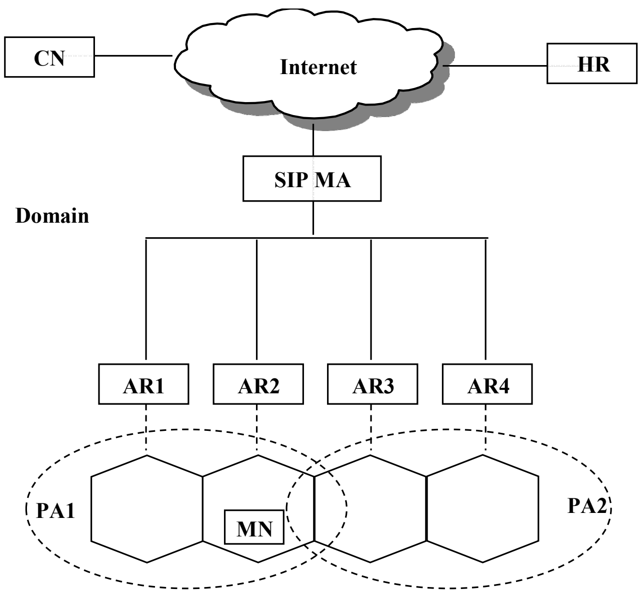


2.2. PHSIP Scheme

In the PHSIP scheme, paging is applied to reduce each MN's location update cost. In Figure 3, the domain can be organized into one or several paging areas, assuming that the SIP MA is in charge of the paging process for its paging areas. In this paper, we assume that each base station acts as an access router for each MN and paging areas are preconfigured. The AR interacts with the radio access network operates independently of the radio access network technology. We also assume that each AR always knows the exact location of an MN so that it can forward all packets destined to the idle MN. Each paging area is identified as having a unique paging area identifier (PAI).

The PHSIP scheme borrows the paging method, which is proposed in IDMP [11], P-MIP [12], and its variations [16,17]. When an idle MN moves a new PA, the MN detects the inter-paging area movement and registers with its serving SIP MA. If the movement is inter-domain movement, the MN should also register globally with HR. When an incoming session request for the MN happens, this request is relayed to the serving SIP MA in the domain and it is paged in the paging area of the MN by the SIP MA. Thus, the MN attaches the AR and then the buffered packets are delivered.

Figure 3. PHSIP architecture.



2.3. AHSIP Scheme

Although the PHSIP scheme can reduce the MN's location update cost, there is the trade-off relationship between the location update cost and the packet delivery cost. Therefore, the performance metric is the total signaling cost which is defined the summation of the location update cost and the packet delivery cost. In the proposed AHSIP scheme, the MN can determine whether paging scheme is applied or not, according to its own SMR. We assume that an MN can recognize its own SMR. An MN really can maintain its SMR because it can recognize its movements and incoming calls and also can compute residential duration in a cell.

The AHSIP scheme is similar to the PHSIP scheme in the case of inter-PA movement. As it were, an MN registers with its SIP MA every inter-PA movement. However AHSIP scheme differs from PHSIP in the case of intra-PA movement. When an MN moves a new cell in the same PA, it computes its own SMR and if the SMR is greater than the predefined threshold, it registers with its SIP MA. It means that the location update of the cell which is expected to an MN's high SMR reduces the total cost. The cell registered in this way is named by a temporary paging area (TPA). A TPA is a paging area including only one cell like an island in a general PA including some cells. When an MN leaves the TPA, it registers to the SIP MA and the TPA is eliminated. And the general paging area is named by a fixed paging area (FPA) to distinguish from TPA. Here, we extend REGISTER message in order to distinguish the location update of a TPA from the location update of inter-PA movement. The field "PA-mode" is an extended header field of REGISTER, which can be assigned two values, a TPA or an FPA in Figure 4. When an MN moves from PA to PA, it sends a REGISTER message with assigning PA-mode to FPA. Although an MN moves within a PA, if its SMR is greater than the threshold, it sends a REGISTER message with assigning PA-mode to TPA. For backward compatibility, if an MN sends a REGSITER message without the extended header field "PA-mode", the SIP MA understands that an MN requests the location update of a general PA, FPA.

Figure 4. Extended header field "PA-mode".

```
REGISTER sip:REGISTRAR.EXAMPLEHOME.COM SIP/2.0
Via: SIP/2.0/UDP192.0.2.4:5060;branch = zhKnashds7
To: sip:UA1@EXAMPLEHOME.COM
From: sip:UA1@EXAMPLEHOME.COM;tag = 456248
Call-ID: 843817637684230@998sdasdh09
CSeq: 1826 REGISTER
Contact: <sip:UA1@192.0.2.4>
PA-mode: TPA
```

Figure 5 shows the data structure which the SIP MA manages MNs. It has a global domain address (DA), a local address (LA), an operation mode, a life time and a PA mode for each MN.

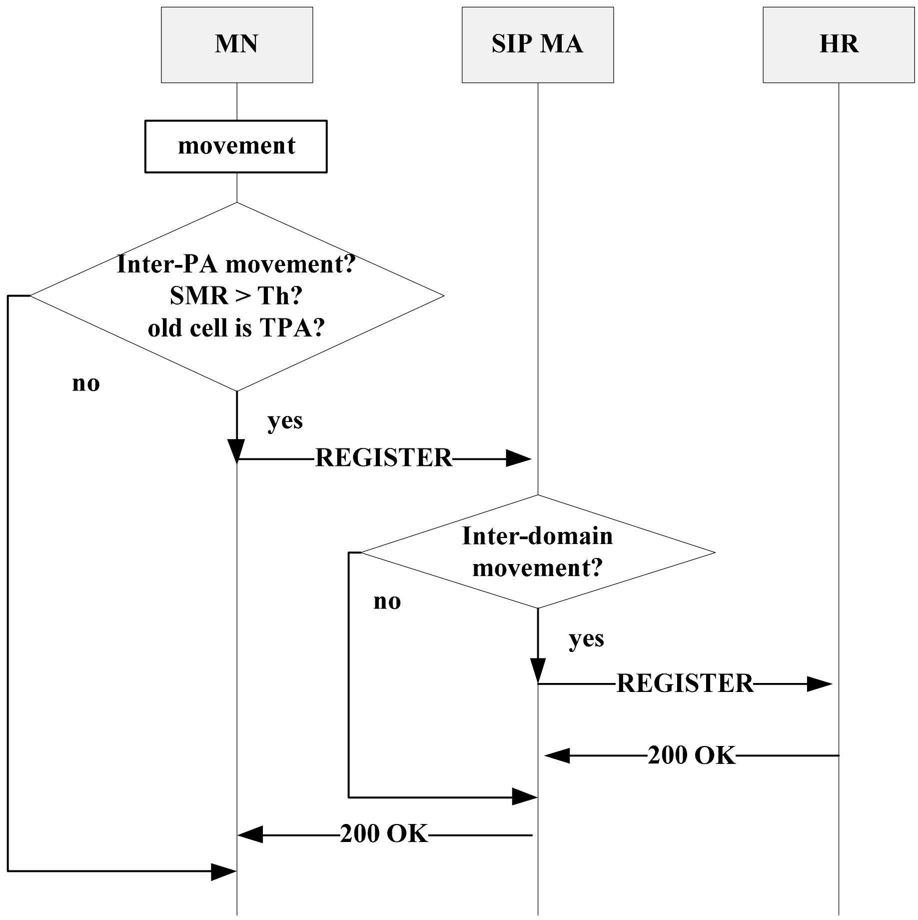
Figure 5. SIP MA's data structure for MN.

MN's DA	MN's LA	MN's operation mode (active / idle)	Life time	PA mode (FPA / TPA)

Figure 6 shows the location update procedure in the AHSIP scheme. When an MN is in active mode, it operates exactly in the same manners with HSIP. However, when the active timer expires, the MN enters idle mode. When an idle MN moves from cell to cell, it sends a REGISTER message to its SIP MA under the following conditions:

- An idle MN crosses the border of PA (inter-PA movement).
- An idle MN's SMR is greater than the threshold value in a new cell.
- An MN leaves a TPA.

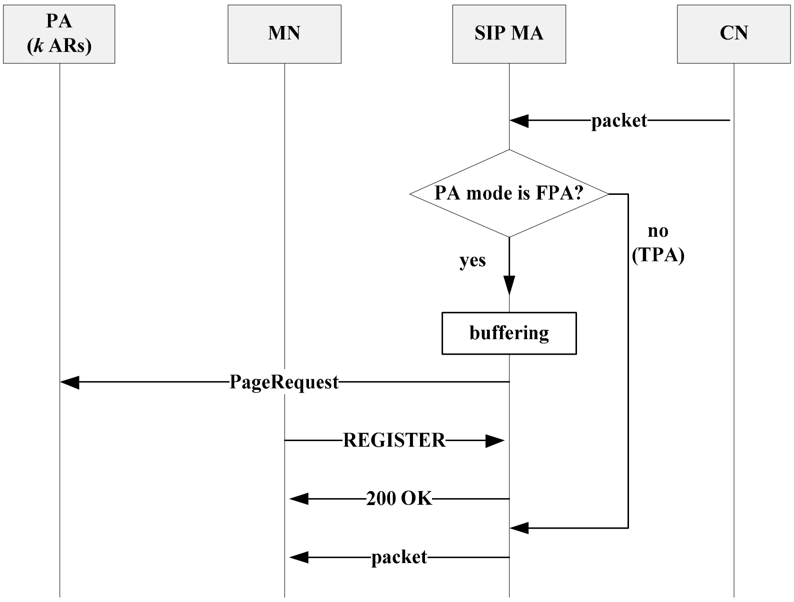
Figure 6. Location update procedure.



The SIP MA receives a REGISTER message for an MN, it updates an LA, a life time and a PA mode for an MN. Then, it determines whether this is an inter-domain movement or not. If inter-domain movement happens, the SIP MA generates new DA and it sends a REGISTER message to the HR. Additionally, the HR responds 200 OK, the SIP MA relays it to the MN. Otherwise, in the case of an intra-domain movement, the SIP MA just responds 200 OK.

Figure 7 shows the packet delivery procedure. A CN sends the data packets to a DA for an MN. These packets are delivered to the SIP MA and it checks the PA mode for an MN. If the PA mode is FPA, the SIP MA buffers the packets and sends a PageRequest message to all ARs in an MN's PA. When an MN receives a PageRequest message, it registers with the SIP MA. And then the SIP MA delivers the packets buffered to an MN. Otherwise (if the PA mode is TPA), the SIP MA delivers the packets to an MN.

Figure 7. Packet delivery procedure.



3. Performance Analysis

In this section, we compare the proposed scheme (AHSIP) with existing schemes (HSIP and PHSIP). We analyze the performance in the aspect of total signaling cost per unit time mathematically. The location update cost and the packet delivery cost are trade-off relationship. Therefore, the metric of performance analysis is the total cost, the summation of location update cost, and packet delivery cost. As mentioned before, although the paging scheme applies to an MN, it updates its location every inter-cell movement in an active mode. However, it only updates its location every inter-PA movement in an idle mode. As it were, if an MN is an active mode, the total cost of all schemes is same. Thus, we consider the total cost if an MN is an idle mode. Similar to [13], we define parameters for performance analysis in Table 1.

Table 1. Parameters for performance analysis.

Parameter	Definition
λ_s	Incoming session arrivals per unit time of the MN
λ_m	Inter-cell movements per unit time of the MN
l_{HM}	Network transmission cost between the HR and the SIP MA
l_{MN}	Network transmission cost between the SIP MA and the MN
α_{HR}	DB processing cost for location update procedure at the HR
α_{MA}	DB processing cost for location update procedure at the SIP MA
β_{HR}	DB processing cost for packet delivery procedure at the HR
β_{MA}	DB processing cost for packet delivery procedure at the SIP MA
N	The total number of cells
n	The total number of cells within a domain
k	The total number of cells within a PA (FPA)
m	The number of times that the MN changes its point of attachment
M	The random variable before each MN moves out of a domain at movement *m*
M'	The random variable before each MN moves out of a PA (FPA) at movement *m*
δ	Threshold to determine a TPA

3.1. Cost in the HSIP Scheme

We derive the location update cost, the packet delivery cost and the total cost in the HSIP scheme. When an MN moves between cells within a same domain (intra-domain movement), the local location update cost is as follows:

$$C_{MA} = \alpha_{MA} + 2l_{MN} \tag{1}$$

When an MN moves between domains (inter-domain movement), the additional cost induced by the global location update procedure is as follows:

$$C_{HR} = \alpha_{HR} + 2l_{HM} \tag{2}$$

Similar to [13], the probability of performing global location update induced by inter-domain movement is as follows:

$$P_{HR}^{m} = \frac{N-n}{N-1}\left(\frac{n-1}{N-1}\right)^{m-2}, \text{where } 2 \le m < \infty \tag{3}$$

Therefore, the expectation of M is:

$$E[M] = \sum_{m=2}^{\infty} mP_{HR}^{m} = 1 + \frac{N-1}{N-n} \tag{4}$$

From (1)–(4), we can get the location update cost per unit time in HSIP as follows:

$$C_{LU} = \left(\frac{C_{HR}}{E[M]} + C_{MA}\right)\lambda_m \tag{5}$$

Additionally, we can get the packet delivery cost per unit time in HSIP as follows:

$$C_{PD} = (\beta_{HR} + \beta_{MA} + l_{HM} + l_{MN})\lambda_S \tag{6}$$

From (5) and (6), we can derive the total cost per unit time in HSIP as follows:

$$C_{TOT} = C_{LU} + C_{PD} \tag{7}$$

3.2. Cost in the PHSIP Scheme

We derive the location update cost, the packet delivery cost and the total cost in the PHSIP scheme. Similar to (3), the probability of performing location update induced by inter-PA movement is as follows:

$$P_{MA}^{m} = \frac{N-k}{N-1}\left(\frac{k-1}{N-1}\right)^{m-2}, \text{where } 2 \le m < \infty \tag{8}$$

Therefore, the expectation of M' is:

$$E[M'] = \sum_{m=2}^{\infty} mP_{MA}^{m} = 1 + \frac{N-1}{N-k} \tag{9}$$

From (1), (2), (8) and (9), we can get the location update cost per unit time in PHSIP as follows:

$$C'_{LU} = \left(\frac{C_{HR}}{E[M]} + \frac{C_{MA}}{E[M']} \right) \lambda_m + C_{MA} \lambda_s \tag{10}$$

where $C_{MA}\lambda_s$ is added because the MN performs location update procedure when a session arrives to the MN.

We can get the packet delivery cost per unit time in PHSIP as follows:

$$C'_{PD} = \left(\beta_{HR} + \beta_{MA} + l_{HM} + (k+1)\ l_{MN} \right) \lambda_S \tag{11}$$

where $k\lambda_S$ is added if compared with (6) because PHSIP should perform packet delivery requests to k cells within a PA every incoming session arrival.

From (10) and (11), we can derive the total cost per unit time in PHSIP as follows:

$$C'_{TOT} = C'_{LU} + C'_{PD} \tag{12}$$

3.3. Cost in the AHSIP Scheme

We derive the location update cost, the packet delivery cost and the total cost in the AHSIP scheme. Basically, the AHSIP scheme works like the PHSIP scheme. However if the SMR of the MN in a new cell after intra-PA movement is greater than a certain threshold, the MN considers this cell as a TPA and performs the local location update procedure.

The difference between the total cost in HSIP and the total cost in PHSIP is as follows:

$$C_{TOT} - C'_{TOT} = \left(1 - \frac{1}{E(M')} \right) C_{MA} \lambda_m - (k\ l_{MN} + C_{MA}) \lambda_s \tag{13}$$

We define the threshold, δ as a SMR, which satisfies that the difference from (13) equals 0.

$$\delta = \frac{\left(E(M') - 1 \right) C_{MA}}{(k\ l_{MN} + C_{MA}) E(M')} \tag{14}$$

If an MN's SMR is equal or less than the threshold δ, AHSIP works like PHSIP. Otherwise it works like HSIP. Therefore, from (7), (12) and (14), we can derive the total cost per unit time in AHSIP as follows:

$$C''_{TOT} = \Pr(SMR \le \delta) \cdot C'_{TOT} + \Pr(SMR > \delta) \cdot C_{TOT} \tag{15}$$

where, similar to [18], the probability which an MN's SMR is greater than the threshold δ, $\Pr(SMR > \delta)$ is as follows:

$$\Pr(SMR > \delta) = \int_0^\infty e^{-\lambda_m \delta \tau} \cdot \lambda_s e^{-\lambda_s \tau} d\tau = \frac{\lambda_s}{\lambda_s + \delta \lambda_m} \tag{16}$$

4. Numerical Results

In this section, we conduct numerical results based on performance analysis between the proposed scheme (AHSIP) and two existing schemes (HSIP and PHSIP). Table 2 shows the used parameter values in our performance analysis that are discussed in [13]. Note that the value of each parameter is given for only a relative comparison among three schemes.

Figure 8 shows the tendency of the threshold in the AHSIP scheme according to PA's size. It means that we should choose relatively a high threshold in the small PA. Because the paging cost of the small PA is relatively lower than that of the large PA. In the contrary, we should choose relatively a low threshold in the large PA.

Table 2. Parameters and their values.

Parameter	Value	Parameter	Value
l_{HM}	4	l_{MN}	2
α_{HR}	12	α_{MA}	6
β_{HR}	12	β_{MA}	6
N	100	n	25
k	5	SMR	0.001~10

Figure 8. SMR threshold according to PA size.

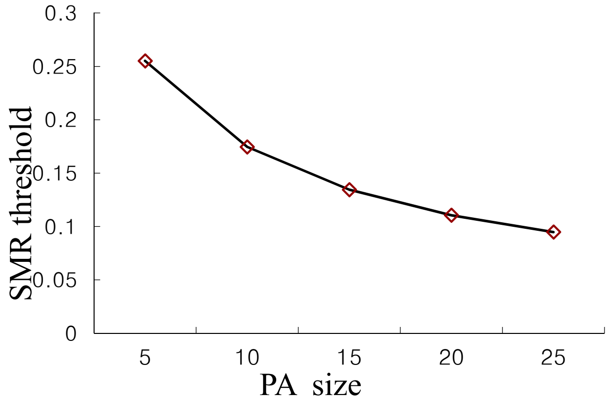


Figure 9 shows the numerical result of total cost in three schemes. As shown Figure 9, HSIP scheme is more cost-efficient for high SMR users and PHSIP scheme is more efficient for low SMR users. Additionally, the AHSIP scheme is efficient for both high SMR users and low SMR users. Because the AHSIP scheme can be adaptive according to each user's SMR, paging is selectively executed and the total cost of AHSIP scheme is equal to that of PHSIP scheme when an MN's SMR is less than the threshold. Otherwise the total cost of AHSIP scheme is equal to that of HSIP scheme.

Figure 9. Total cost according to SMR.

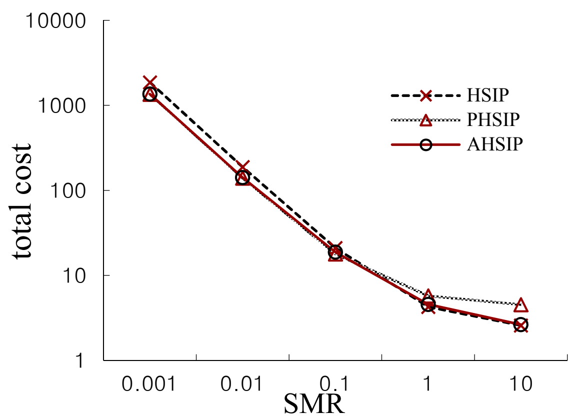
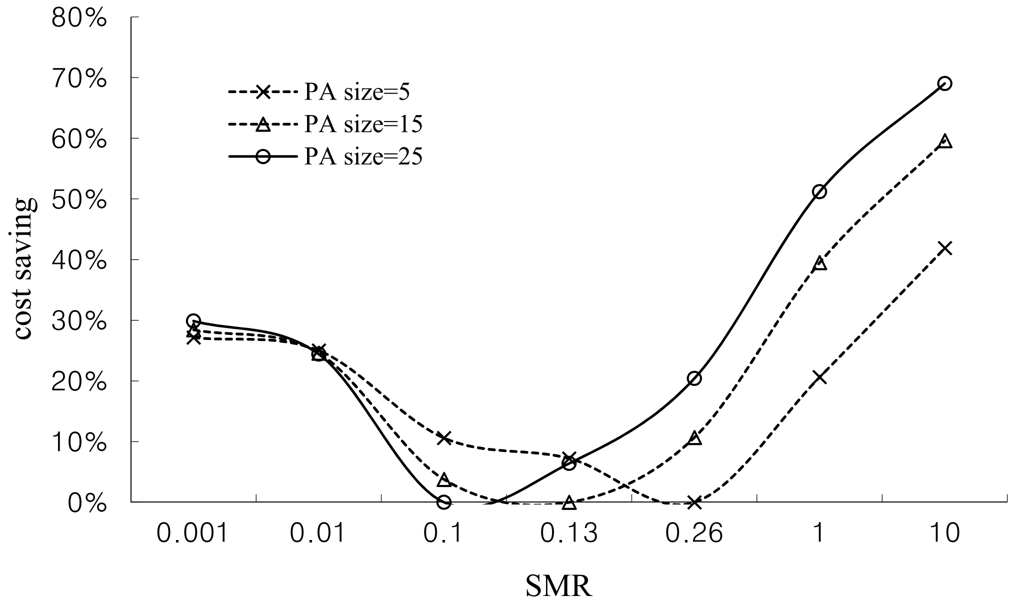


Figure 10 shows the cost-saving percentage of the proposed scheme, AHSIP. Our scheme can reduce signaling costs 27.16% ~ 29.88% than HSIP scheme in the case of low SMR (0.001) and also reduce 41.91% ~ 69.02% than PHSIP scheme in the case of high SMR (10). We can find that the cost-saving is reduced when an MN's SMR is nearly to the threshold. PHSIP scheme is more cost-effective than other two schemes.

Figure 10. Cost saving of AHSIP according to SMR.



However, if the SMR of user is changing near the threshold, the additional overhead of changing the policy can be a problem. This is the ping-pong problem. We can substitute the threshold range for the threshold to prevent the ping-pong problem. We define δ_1, δ_2 in $\delta_1 < \delta < \delta_2$. If the SMR of MN is less than δ_1, the paging scheme can be used. If it is more than δ_2, the MN can set the TPA.

5. Conclusions

Although paging scheme can reduce location update cost, it needs additional paging cost to packet delivery. Particularly, when the SMR of MN highly increases, the paging scheme can spend more signaling cost. In this paper, we proposed an adaptive mobility management scheme in hierarchical SIP networks. We expect that user-based location management policy will be applied owing to enhanced computing power. In our scheme, the SMR of MN is a key parameter to determine the location management policy. If the SMR is more than a given threshold, the MN considers the cell as the TPA to reduce unnecessary paging cost. Otherwise it is working paging scheme. We also provide the threshold range to prevent the ping-pong problem. From performance analysis, we get the optimal threshold and show that the proposed scheme is more cost-effective than the existing SIP scheme or paging scheme in hierarchical SIP networks.

We have focused on cost-effective mobility management in hierarchical SIP networks. In the future, we plan to investigate the performance of our scheme in the aspect of performance factors, such as handover latency, packet loss, and jitter.

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Author Contributions

KwangHee Choi provided main idea and designed the algorithm. Joon-Min Gil wrote the performance analysis and numerical results theoretically. All authors were involved in organizing and refining the manuscript. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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