Hierarchical Location Management for Transport Layer Mobility

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Abstract— **IP mobility can be handled at different layers of the protocol stack. Mobile IP has been developed to handle mobility of Internet hosts at the network layer. As an alternative solution, a number of transport layer mobility protocols have been proposed. However, the location management schemes used in these transport layer solutions are not suitable for frequent mobile handovers due to user's high mobility. In this paper, we propose HiSIGMA, a hierarchical location management scheme for transport layer mobility schemes. We used an analytical model to evaluate HiSIGMA using signaling cost as the performance measure, followed by comparison of the signalling cost of HiSIGMA and Hierarchical Mobile IPv6 (an enhancement of Mobile IP) and existing transport layer mobility solutions.**

I. Introduction

There are solutions to IP mobility at different layers of the protocol stack. Mobile IP (MIP) [1] is designed to handle mobility of Internet hosts at the network layer. Several drawbacks exist when using MIP in a mobile computing environment, the most important ones identified to date are high handover latency, high packet loss rate, and requirement for change in infrastructure.

At the transport layer, several mobility protocols have also been proposed, for example, MSOCKS [2] and connection migration solution [3] in the context of TCP, and M-SCTP [4] in the context of SCTP [5]. More recently, a new architecture for supporting low latency, low packet loss mobility scheme called Seamless IP diversity based Generalized Mobility Architecture (SIGMA) was proposed [6]. These protocols implement mobility as an end-to-end service without the requirement to change the network layer infrastructures; they, however, did not thoroughly studied the location management scheme can be used in transport layer mobility solutions. These previous studies mainly focuses on how to provide the mobility support in an end-to-end architecture [2]–[4] or reduce the mobile handover latency utilizing IP diversity [6]. They only briefly outlined the some simple form of location management method. Transport layer mobility solutions proposed in [3], [4], [6] needs to setup a location manager for maintaining a database of the correspondence between MH's identity and its current active IP address.

Take SIGMA proposed in [6] as an example, the basic form of location management in transport layer mobility schemes can be done in the following sequence as shown in Fig. 1, similar location management schemes are also used in [2], [3].

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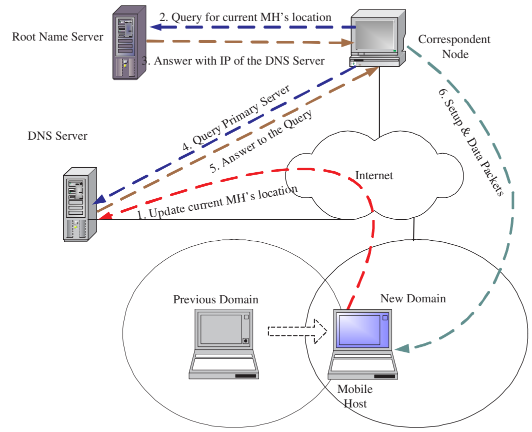

Fig. 1. Basic form of location management in SIGMA

These schemes are not suitable for frequent mobile handovers due to user's high mobility. The reasons are as follows:

- There is a race condition between (Location Manager) LM database update caused by the change of MH's point of attachment and the arrival of association setup request from CN. The higher the Round Trip Time (RTT) between MH and LM is, the larger probability that CN get a stale information from the database at LM, which will result in MH being inaccessible from CN.
- Performing location update on LM whenever MH changes its location may be too costly and time-consuming for LM to process. Too many signaling messages exchanged in the network wastes network bandwidth and may result in unnecessary congestions.
- DNS servers commonly cache DNS replies to reduce the signaling load on network and response time to CN. Each DNS reply is associated with a Time-To-Live (TTL) field indicating the valid period of the cached DNS reply. During the TTL period, the DNS server with cache could answer additional requests for the MH's location from its local cache instead of querying LM again. Thus, even after MH has updated its location with LM, the CN's DNS server could still reply with the old location until the cached entry's TTL expire. This will also lead to MH being inaccessible from CN.

The signaling cost of SIGMA is analyzed in our previous study [7], so it is not repeated here. If we examine the location management procedures used by SIGMA and TCP

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connection migration are very similar in following respects: a) both use DNS server as location manager, b) both need to update location manager and CN after each change of point of attachment. Therefore, the signaling cost analysis of SIGMA [7] also applies to TCP connection migration, and we generalize these two transport layer mobility solutions as Flat Transport Layer Mobility (FTLM) in this paper.

The *objective* of this paper is to propose a hierarchical location management scheme for transport layer mobility solutions to reduce the possibility that MH is inaccessible from CNs and the processing load on LM. The contributions of our paper can be outlined as follows:

- Propose and develop a hierarchical location management scheme for transport layer mobility protocols.
- Evaluate and compare the signaling cost of proposed the hierarchical management scheme with that of FTLM and HMIPv6 [8] using analytical models. We choose HMIPv6 as the benchmark network-layer mobility protocol for signaling cost comparison because HMIPv6 is designed to reduce the signaling cost of base MIPv6, and it has the lowest signaling cost in all versions of MIPv6 enhancements.

The authors are not aware of any *previous studies for hierarchical location management for transport layer mobility solutions*. The rest of this paper is structured as follows: Sec. II describes the hierarchical location management scheme including its architecture, timeline, and state machine. The network structure and modeling assumptions for signaling cost evaluation is presented in Sec. III. The results of signaling cost comparison of `HiSIGMA`, HMIPv6, and FTLM is presented in Sec. IV. Finally, concluding remarks are presented in Sec. V.

II. Hierarchical Location Management of Transport Layer Mobility

In this section, we introduce hierarchical location management for transport layer mobility. Since we use SIGMA as the base architecture for introducing hierarchical location management, we call the proposed scheme as `HiSIGMA`. However, the principle of `HiSIGMA` also applies to other transport layer mobility solutions such as [2], [3].

A. Architecture of `HiSIGMA`

A new entity called Anchor Zone Server needs to be introduced in `HiSIGMA` as shown in Fig. 2. MH only needs to update the Home Zone Server when it enters a new Anchor Zone. Otherwise, MH need only to update the Anchor Zone Server with its current location. Whenever Home Zone Server receives a location query for MH, it will answer with the registered Anchor Zone Server's IP address. This approach will reduce the location update latency and signaling cost while improve the accuracy of the location management. The hierarchical location management can be done in the following sequence as shown in Fig. 2:

1) `a.` When MH enters into a new DNS zone, MH updates the HZS with the IP address of new attached AZS. `b.` When MH moves between IP domains within the region managed by a specific AZS, MH only updates AZS.

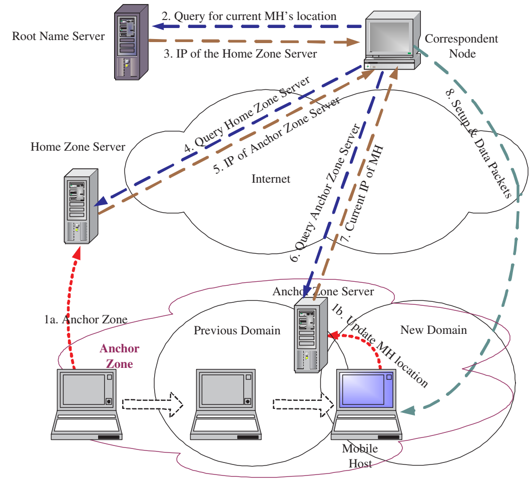

Fig. 2. Hierarchical location management in `HiSIGMA`

2) When CN wants to setup a new association with MH, CN sends a query to the root name server with MH's domain name.
3) Root name server replies to CN with the IP address of the HZS.
4) CN query the HZS referred by the root name server.
5) HZS replies with the IP address of current AZS where MH resides.
6) CN query the AZS referred by the HZS.
7) AZS replies with the current IP address(es) of MH.
8) CN initiates the handshake sequence with MH's current IP address to setup the association.

B. State machine at AZS

During the movement of MH, the IP address used by MH keeps changing. Furthermore, in schemes like SIGMA, the number of IP addresses that MH have also varies, sometimes one and sometimes two [6]. MH may also have its preference on which IP should be used at a particular time based on application characteristics (e.g. VoIP or data) and cost constraints (e.g. satellite links are generally more expensive than WLAN). To support this kind of desirable flexibility and optimize the performance of location management for transport layer mobility solutions that support IP diversity like SIGMA, a state machine is introduced at AZS. *For the schemes in which mobile hosts do not support IP diversity, the hierarchical location management is still useful, but the lack of this state machine may result in non-optimal results.*

It is necessary for AZS to have a clear idea on which IP address(es) should be used and which one has priority when multiple IP are available. In `HiSIGMA`, this goal is achieved by multicasting the IP reconfiguration information of MH to CN and AZS. When MH send IP reconfiguration signaling messages to CN, MH should also send a copy to AZS. These messages could include [6]:

- Add new IP into association between MH and CN (ADD_IP).
- Designate one of the available IP addresses as the primary destination address (SET_PRIMARY).

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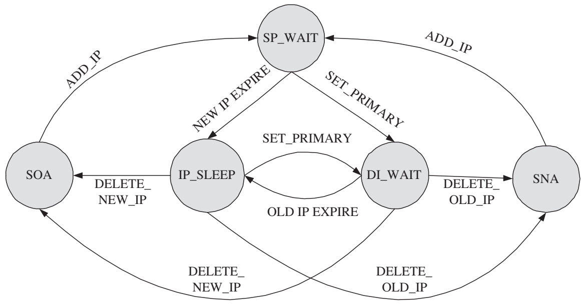

Fig. 3. State machine at AZS

- Delete obsolete IP address (DELETE_IP).

. These signaling messages are used to construct a state machine at AZS to better reflect the current location status of MH. The state machine at AZS is shown in Fig. 3. The state machine works as follows:

- If MH has only one IP address assigned from the old domain or new domain, the AZS is in `SOA` (Single Old Address) or `SNA` (Single New Address) state, respectively.
- If current state is `SOA` or `SNA`, an `ADD_IP` message received from MH will trigger the machine to transfer into `SP_WAIT` state, which means that AZS is waiting for a `SET_PRIMARY` message.
- If current state is `SP_WAIT` or `IP_SLEEP`, a `SET_PRIMARY` message received from MH will trigger the machine to transfer into `DI_WAIT` state, which means that AZS is waiting for a `DELETE_IP` message.
- If current state is `SP_WAIT`, and the timer associated with the new IP just added into the association expires before a `SET_PRIMARY` message is received, the machine transfer into `IP_SLEEP` state, which means that the IP is marked as inactive and should not be advertised to CN.
- If current state is `DI_WAIT` or `IP_SLEEP`, and a `DELETE_IP` message is received from MH with the old IP address as the target IP being deleted, it will trigger the machine to transfer into `SNA` state. Similarly, if a `DELETE_IP` message is received with the new IP address as the target IP being deleted, it will trigger the machine to transfer into `SOA` state.
- If current state is `DI_WAIT`, and the timer associated with the old IP waiting to be deleted expires before a `DELETE_IP` message is received, the machine transfer into `IP_SLEEP` state, which means that the old IP is marked as inactive and should not be advertised to CN.

C. Location query replies sent to CN by AZS

One of the most important objectives of location management is to accurately pointer CN to the current location of MH. We utilize the sate machine at AZS to improve this accuracy. The reply sent by AZS to CN depends on the current state of AZS as described below.

- *SOA or SNA*: Only one IP available at MH, just send MH's IP to CN.
- *SP_WAIT*: Send both MH's new and old IP to CN, old IP has higher priority.
- *DI_WAIT*: Send both MH's new and old IP to CN, new IP has higher priority.
- *IP_SLEEP*: Only one IP active at MH, send current MH's active IP to CN.

When CN receives a location reply with multiple entries of MH's IP address, it will first try the first entry. If the association setup using first entry fails, CN will automatically try the second entry.

III. Signaling Cost Modeling

We compare the signaling cost of `HiSIGMA`, FTLM and HMIPv6 through analytical modeling. In this section, the network structure being considered and assumptions used in the model are presented in Secs. III-A and III-B, respectively. The full analytical models for `HiSIGMA`is presented in [9] due to space restrictions.

A. Network structure

Fig. 4 shows a two dimensional subnet arrangement for modeling MH movement, where $\mathrm{AR}_{1,1}, \cdots \mathrm{AR}_{m,n}$ represent access routers. There are k AZSs, each of which covers R subnets. There are also one HZS (same as HA in the case of HMIPv6) and a number of CNs connected to the Internet. The MHs are roaming in the subnets covered by $\mathrm{AR}_{1,1}, \cdots$ $\mathrm{AR}_{m,n}$, and each MH communicates with one or more of the CNs. Between a pair of MH and CN, intermittent file transfers occur caused by mobile users requesting information from CNs using protocols like HTTP. We call each active transfer period during the whole MH-CN interactivity as a session.

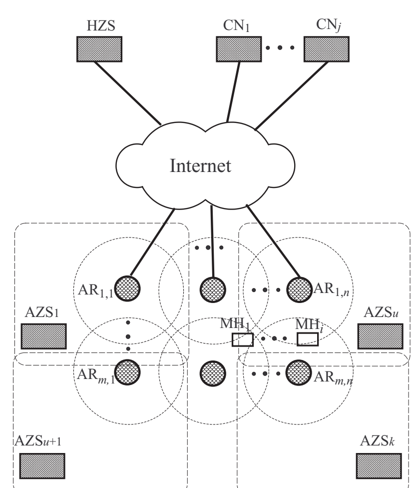

Fig. 4. Network structure considered.

B. Model assumptions

We make the following assumptions for developing the analytical model of `HiSIGMA` signaling cost:

- Both session time and session interval time are of *Pareto* distribution to better model HTTP traffic [10]. The *Pareto* distribution is a heavy-tailed distribution, and it can be characterized with two parameters: minimum possible value, and a heavy-tailness factor.

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- Mobile host moves according to Random Waypoint model [11], which is the most frequently used model in mobile networking research. In this mobility model, a MH randomly selects a destination point in the topology area according to uniform distribution, then moves towards this point at a random speed again uniformly selected between (v_{min}, v_{max}). At destination point, the MH will stay stationary for a period of time, after that a new movement starts.
- Processing costs at the endpoints (MH and CN) are not counted into the total signaling cost since these costs stand for the load that can be scattered into user terminals. Because we are more concerned about the load on the network elements, this assumption enables us to concentrate on the impact of protocol on the network performance. This same assumption was also made by other previous works [12], [13].

IV. Numerical Results for Signalling Cost Comparison of HiSIGMA, FTLM and HMIPv6

As mentioned in Sec. I, and we generalize SIGMAand TCP connection migration as Flat Transport Layer Mobility (FTLM). In this section, we present results showing the effect of various input parameters on total signaling cost of HiSIGMA and compare with that of FTLM and HMIP. The parameter values used in the numerical examples are obtained from previous work [13] and our calculation based on user traffic and mobility models [10], [11], interested reader can refer to our full-sized paper [9] for details.

A. Impact of number of MHs for different MH maximum moving speeds

The impact of number of MHs on total signaling cost of HiSIGMA, FTLM, and HMIPv6 for different MH maximum moving speeds is shown in Fig. 5. From the figure, we can see that under different moving speeds, the signaling cost of both HiSIGMA, FTLM, and HMIPv6 increases with the increase of the number of MHs, which is quite natural. When the moving speed is higher, the subnet residence time T_r decreases, resulting in a increase of the location update and binding update costs per second. We can also observe that the total signaling cost of HiSIGMA is less than FTLM (due to updating LM less frequently) and HMIPv6 (due to high packet delivery cost resulted from tunneling)in this scenario.

B. Impact of average number of communicating CN and location update transmission cost

Next, we set maximum moving speed of MH $v_{max} = 20\text{m/s}$, and number of MHs $N_{mh} = 80$. The impact of the number of average CNs with which an MH communicates with for different per-hop transmission cost for location update cost (δ_U) is shown in Fig. 6. It can be observed from this figure that when the average number of communicating CNs increases, the total signaling cost increases as expected. Also, when δ_U increases, the location update cost per second will increase, which will result in the increase of the total signaling cost of both HiSIGMA, FTLM, and HMIPv6. In this scenario, signaling cost of HiSIGMAis also less than that of FTLM and HMIP in most cases. However, when δ_U is small and number of CNs is small we can see that HiSIGMAhas a higher signaling cost than that of FTLM. This is because when δ_U is small, the advantage of having hierarchical structure for reducing the location update cost is dominated by the overhead of adding AZS which introduces extra processing cost, and packet delivery cost.

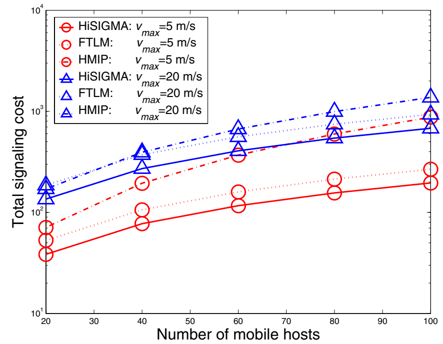

Fig. 5. Impact of number of MHs on total signaling cost of HiSIGMA and HMIPv6 under different moving speeds.

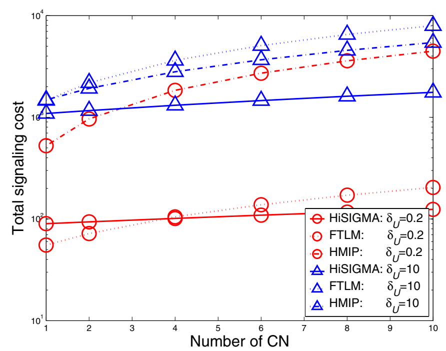

Fig. 6. Impact of number of CNs and per-hop binding update transmission cost

C. Session to Mobility Ratio

Session to Mobility Ratio (*SMR*) is a mobile packet network's counterpart of Call to Mobility Ratio (*CMR*) in PCS networks. We vary MH residence time in a subnet T_r from 75 to 375 seconds with session arrival rate λ_{sa} fixed to 0.01, which yields a *SMR* of 0.75 to 3.75. The impact of *SMR* on total signaling cost for different N_{mh} is shown in Fig. 7. We can observe that a higher *SMR* results in lower signaling cost in both HiSIGMA, FTLM, and HMIPv6. This is mainly because high *SMR* means lower mobility, and thus lower signaling cost due to less location update and binding update.

D. Relative signaling cost of HiSIGMA *to HMIPv6 and FTLM*

Fig. 8 shows the impact of (location update transmission cost) / (packet tunnelling cost) ratio (δ_U/τ) on the relative signaling cost between HiSIGMA and HMIPv6. A higher δ_U/τ ratio means that the location update requires more cost while packet encapsulation/decapsulation costs less. This ratio depends on the implementation of the intermediate routers. We

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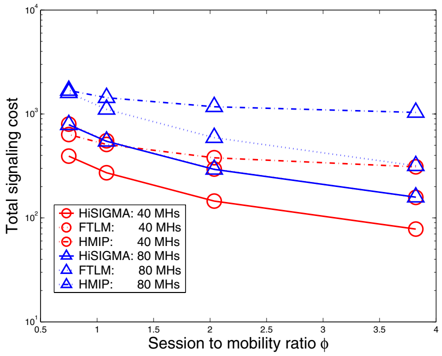

Fig. 7. Impact of *SMR* on total signaling cost for different N_{mh}

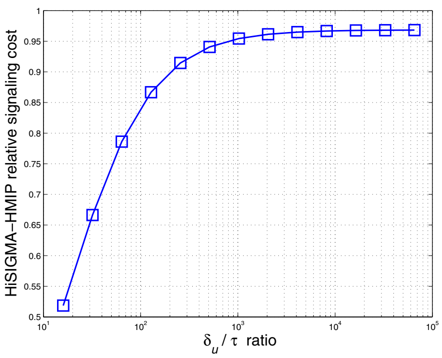

Fig. 8. Impact of δ_U/τ ratio on HiSIGMA to HMIPv6 relative signaling cost

can see that the signaling cost of HiSIGMA is less than that of HMIPv6 in the possible range of δ_U/τ since the relative cost between HiSIGMA and HMIPv6 is always less than one.

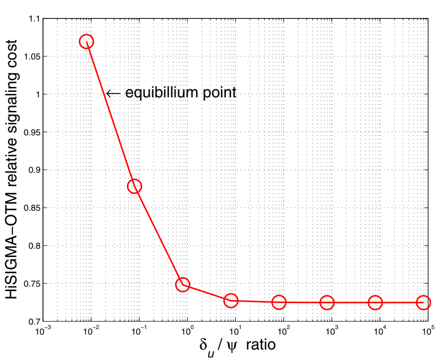

Fig. 9. Impact of δ_U/ψ ratio on HiSIGMA to FTLM relative signaling cost

Fig. 9 shows the impact of (location update transmission cost) / (location database lookup coefficient) ratio (δ_U/ψ) on the relative signaling cost between HiSIGMA and FTLM. A higher δ_U/ψ ratio means that the location update requires more cost while the location database lookup for packet delivery costs less. This ratio depends on the implementation of the intermediate routers and the Data Base Management System (DBMS) at location manager. We can see that the signaling cost of HiSIGMA is less than that of FTLM when this ratio is larger than 2×10^{-2}. The δ_U/ψ ratio reflects the tradeoff introduced by AZS: it can reduce the location update frequency (therefore reduce the location update cost), but on the other hand it increases the system complexity and CN needs query one more time to get the current location of MH (therefore increases the packet delivery cost). So HiSIGMA's advantage is more obvious when the network is more bandwidth limited (high location update cost) and/or location managers' processing power is high (low database lookup cost).

V. Conclusions

In this paper, we presented the hierarchical location management scheme for transport layer mobility protocols. We developed an analytical model to compare the signaling costs HiSIGMA, FTLM and HMIPv6. Numerical results show that, by introducing the concept of Anchor Zone Server into location management of mobile hosts, the signaling cost of HiSIGMA can be greatly reduced and is lower than that of FTLM and HMIPv6. However, there are tradeoffs introduced by the use AZS. HiSIGMAis more suitable for the situations where the network is more bandwidth limited and/or location managers' processing power is high.

References

[1] C.E. Perkins, "Mobile Networking Through Mobile IP," *IEEE Internet Computing*, vol. 2, no. 1, pp. 58–69, January/February 1998.
[2] D. A. Maltz and P. Bhagwat, "MSOCKS: An architecture for transport layer mobility," *INFOCOM*, San Francisco, USA, pp. 1037–1045, March 1998.
[3] A. C. Snoeren and H. Balakrishnan, "An end-to-end approach to host mobility," *ACM MobiCom*, Boston, MA, pp. 155–166, August 2000.
[4] W. Xing, H. Karl, and A. Wolisz, "M-SCTP: Design and prototypical implementation of an end-to-end mobility concept," *5th Intl. Workshop on the Internet Challenge: Technology and Applications*, Berlin, Germany, October 2002.
[5] S. Fu and M. Atiquzzaman, "SCTP: State of the art in research, products, and technical challenges," *IEEE Communications Magazine*, vol. 42, no. 4, pp. 64–76, April 2004.
[6] S. Fu, L. Ma, M. Atiquzzaman, and Y. Lee, "Architecture and performance of SIGMA: A seamless mobility architecture for data networks," *40th IEEE Internationl Conference on Communications (ICC)*, Seoul, Korea, May 2005.
[7] S. Fu, M. Atiquzzaman, L. Ma, and Y. Lee, "Signaling cost and performance of SIGMA: A seamless handover scheme for data networks," *Accepted by Journal of Wireless Communications and Mobile Computing*.
[8] H. Soliman, C. Catelluccia, and K.E. Malki et al., "Hierarchical Mobile IPv6 mobility management (HMIPv6)." IETF DRAFT, draft-ietf-mipshop-hmipv6-04.txt, December 2004.
[9] S. Fu and M. Atiquzzaman, "Hierarchical location management for transport layer mobility," Tech. Rep. TR-OU-TNRL-05-105, University of Oklahoma, Telecommunication & Network Research Lab, www.cs.ou.edu/~netlab, February 2005.
[10] M.E. Crovella and A. Bestavros, "Self-similarity in world wide web traffic: evidence and possible causes," *IEEE/ACM Transactions on Networking*, vol. 5, no. 6, pp. 835–846, Dec 1997.
[11] C. Bettstetter, H. Hartenstein, and X. Perez-Costa, "Stochastic properties of the random waypoint mobility model: epoch length, direction distribution, and cell change rate," *5th ACM International Workshop on Modeling Analysis and Simulation of Wireless and Mobile Systems*, pp. 7–14, September 2002.
[12] Y.W. Chung, D.K. Sun, and A.H. Aghvami, "Steady state analysis of P-MIP mobility management," *IEEE Communication Letters*, vol. 7, no. 6, pp. 278–280, June 2003.
[13] J. Xie and I. F. Akyildiz, "An optimal location management scheme for minimizing signaling cost in Mobile IP," *IEEE International Conference on Communications (ICC)*, New York, pp. 3313–3317, April 2002.

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