

Two-Step Paging for Reducing Signaling Costs in Mobile IP

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Abstract— Recently, Mobile IP has been widely used to support seamless internet user mobility. However, unnecessary registration process of Mobile IP system for tracking mobile users' movement causes large increase of signaling costs, and affects the scalability. Therefore, it is necessary to investigate how to reduce the signaling costs in Mobile IP. This paper proposes a Two-Step Paging Scheme for Mobile IP (TSP-MIP) to reduce signaling costs and the sensitivity of the system with various user parameters. The main concept is to partition the paging area and select the optimal paging sequence. The performance of the proposed TSP-MIP is compared with three conventional schemes, namely, Distributed Local Paging scheme for Mobility Management in Mobile IP (DLP-MIP), Paging Extensions for Mobile IP (P-MIP) and Mobile IP via analysis and simulation results. The reported results show that the total signaling costs of TSP-MIP is the lowest, compared with those three conventional schemes.

Keywords— Mobile IP, Paging, Signaling cost

I. INTRODUCTION

Due to the need of seamless real-time applications, such as voice over IP (VoIP), in wireless communication networks, the networks must be designed to support the user's mobility and to maintain the continuity of ongoing communication services. Mobile IP [1] has been proposed to support a simple mobility mechanism. In Mobile IP, a mobile node's location is tracked by its registration. When a mobile node (MN) moves to a new network, it registers a new address with its home agent (HA). Since the basic Mobile IP only supports registration, the signaling overhead in the registration process of Mobile IP system for tracking mobile user's movement largely increases, and affects its scalability.

In cellular networks, registration and paging process are used to reduce the signaling overhead. Paging is a process that the system searches for an idle MN by broadcasting or multicasting the paging request message in paging areas (PA). Also the authors [2] introduced the paging process to reduce the signaling overhead for Mobile IP. However, the signaling cost of P-MIP is not always less than that of Mobile IP, especially when the PA size is large. Therefore, calculating the optimal PA size has to be calculated.

To solve P-MIP problems, various authors [3]-[5] proposed an adaptive and individual paging scheme in which each MN

computes its optimal PA. Incoming packet rate and mobility parameters are used in the optimization process. Since an MN continuously computes the optimal PA, this solution is not energy-efficient. Furthermore, some of the optimization parameters are time-varying, which is difficult to be tracked by MN.

In [6], the authors proposed Distributed Local Paging scheme (DLP-MIP) that can reduce both the total signaling cost and power consumption of an MN by partitioning the paging area into sub-paging area (SPA). However, DLP-MIP causes large paging signaling cost when each SPA consists of many cells.

In this paper, we propose a two-step paging scheme for Mobile IP, which can further reduce paging signaling cost, compared to DLP-MIP by partitioning the SPA into an inner SPA and an outer SPA together with selecting the optimal paging sequence. This paper is organized as follows. In Section II, we review DLP-MIP and propose TSP-MIP. In Section III, we present the analysis of signaling costs. The performance comparison by mathematical analysis is provided in Section IV. Section V presents the simulation results. Finally, Section VI concludes the paper.

II. OVERVIEW OF DLP-MIP AND THE PROPOSED TSP-MIP

A. Distributed Local Paging scheme (DLP-MIP)

DLP-MIP [6] can reduce the total signaling cost by configuring sub-paging areas (SPA) within a paging area (PA), as shown in Figure 1. In this scheme, each PA contains n foreign agents (FA), and is partitioned into sub-PAs, where each sub-PA (SPA) contains m FAs.

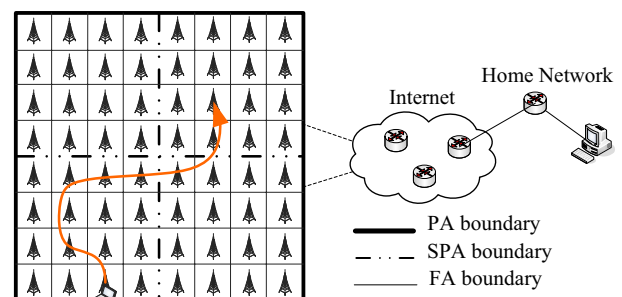


Figure 1. DLP-MIP scheme

This scheme allows a mobile node (MN) to operate in two states: an active state and an idle state. An active MN operates exactly the same as that in Mobile IP, where an MN registers with a home agent (HA) when it crosses a cell boundary. For an idle MN, unlike P-MIP, the idle MN does not always need to register with HA. It registers with HA only when it crosses PA boundary. Otherwise, it sends a location update only when it crosses SPA boundary to the paging FA (pFA), which is the FA that the MN visits first in PA. Therefore, DLP-MIP can reduce the total signaling cost.

B. Two-Step Paging scheme for Mobile IP (TSP-MIP)

This paper proposes a Two-Step Paging scheme for Mobile IP (TSP-MIP), which can further reduce signaling costs, compared to DLP-MIP. In doing so, we further partition each SPA into an inner SPA and an outer SPA, as shown in Figure 2. The first paging step is done in the inner SPA. If MN is found, then the first paging procedure succeeds, and the second paging step is skipped. If not, the second paging step is done in the outer SPA.

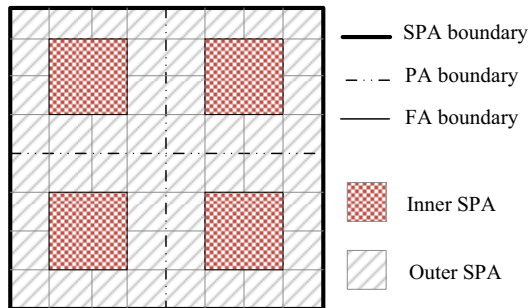


Figure 2. Partitioning in TSP-MIP

This scheme assumes that all FAs support paging, that is all FAs can perform as pFA as in [2]. The first FA in a PA that an MN visited will be registered by an MN as the pFA of that MN. This scheme allows an MN to operate in two states as in [6]. An active MN, it operates exactly the same as that in Mobile IP. For an idle MN, it has to registers its pFA with HA only when it crosses PA boundary. If it moves within the same SPA, it's not need to perform registration. When it had already moved out from the same SPA but still in the same PA, it performs location update with its pFA to inform a new sub-pFA, which is the FA that the MN visits first in SPA. A sub-pFA is responsible for tracking movement of MN when an MN still in the same SPA.

Figure 3 demonstrates a simple scenario of TSP-MIP. When there are packets that are routed to MN, HA forwards them to the pFA. When a pFA received packets, it first checks whether or not a record for an MN exists. If there is a record for the MN, a pFA checks whether the MN lives in the same SPA or not. If the MN still lives in the same SPA, then a pFA checks an MN's state. If the MN is active, a pFA decapsulates packets and forwards them to MN directly. If the MN is idle, a pFA first sends a paging request message to all FAs in the inner SPA. If the MN detects its home address from a paging request message, it will register with HA. When the registration process is complete, then HA routes all packets to

the MN. At the same time, the MN sends paging reply message via its pFA. A pFA forwards buffered packets to the MN. If a system does not receive a response from that MN in the first paging procedure, then a pFA will send a paging request message to all FAs in the outer SPA. If the MN detects its home address from a paging request message, it further registers with HA.

On the other hand, when an MN has already moved out from the same SPA but still in the same PA. A pFA forwards all packets to the sub-pFA. When a sub-pFA receives them, it first checks whether the MN is in a sub-pFA's visitor list or not. If there is a record for the MN in its visitor list, then a sub-pFA checks the MN's state. If the MN is active, a sub-pFA decapsulates packets and forwards them to MN. In the case of the idle MN, a sub-pFA first sends a paging request message to all FAs living in the inner SPA. If the MN is found, then the first paging procedure is terminated. If not, a sub-pFA will further send a paging request message to all FAs in the outer SPA.

Dividing the paging into two-step can reduce signaling cost because skipping the second paging step (when the first paging step succeeds) eliminates flooding in the outer SPA. The probability that MN locates in the inner SPA depends on paging area construction. In this paper, we consider two PA constructions: non-overlapping and overlapping.

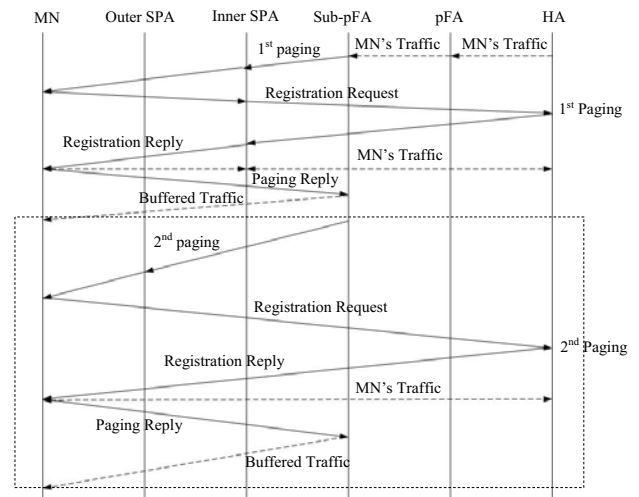


Figure 3. The signaling procedure to page an Idle MN when there is incoming packet data

III. ANALYSIS OF TOTAL SIGNALING COST AND PAGING DELAY

The total signaling cost of Mobile IP, P-MIP, and DLP-MIP are analyzed in [2], [6], and are presented here for convenience. We analyze total signaling cost of TSP-MIP. In addition, we analyze paging delay for DLP-MIP as well as TSP-MIP. The analysis is based on the fluid flow model, and takes into account various system conditions, i.e., paging area size and mobile speed. The signaling cost is defined as the product of the weighted distance signaling message travels and the signaling rate. In this section, we consider only the non-overlapping PA approach.

The shape of the PAs, SPAs and wireless cells is assumed to be square as in [6]. The perimeter of cell is c_l . The perimeter of SPA is $l(=c_l\sqrt{m})$ and the perimeter of PA is $L(=c_l\sqrt{n})$. We assume that MNs move at an average velocity of v (m/sec) in directions that are uniformly distributed over $[0, 2\pi]$ and are uniformly distributed with density ρ . The rate of cell boundary crossing r_c is $\rho v c_l / \pi$. The rate of SPA boundary crossing r_{SPA} is $\rho v l / \pi$. The rate of PA boundary crossing rate r_{PA} is $\rho v L / \pi$.

A. Mobile IP

In Mobile IP, the total signaling cost function as in [2] is

$$C_{MIP} = d_{FA,HA} (R_{core} \omega_{core} + R_{local} \omega_{local}) \left[r_c n + \rho \left(\frac{c_l}{4} \right)^2 n r_r \right] \quad (1)$$

where:

- C_{MIP} is the total signaling cost of Mobile IP (weighted hops•packets/s),
- $d_{FA,HA}$ is the average distance between FA and the HA in terms of the number of hops,
- R_{core} is the ratio of the number of hops in the core, network to the total number of hops between HA and FA,
- R_{local} is the ratio of the number of hops in local access networks to the total number of hops between HA and FA,
- ω_{core} is the weight of each hop in the IP core network,
- ω_{local} is the weight of each hop in access networks,
- r_c is the cell crossing rate (mobile nodes/s),
- ρ is the mobile node density (mobile nodes/m²),
- n is the number of cells in a considered PA,
- v is the MN's velocity (m/sec),
- c_l is the cell perimeter (m),
- r_r is the average mobile node registration refresh rate which is associated with registration lifetime.

B. P-MIP

From [6], the formula used to calculate the total signaling cost for P-MIP is

$$C_{PMIP} = d_{FA,HA} (R_{core} \omega_{core} + R_{local} \omega_{local}) \left[(r_c n - r_{PA}) \alpha + r_{PA} + \rho \left(\frac{c_l}{4} \right)^2 n r_r \right. \\ \left. + \rho \left(\frac{c_l}{4} \right)^2 n (1 - \alpha) (\lambda_a + \lambda_d) \right] + (n - 1) d_{FA,FA} \omega_{local} \rho \left(\frac{c_l}{4} \right)^2 n (1 - \alpha) \lambda_a \\ + \delta_{air} \left[\rho \left(\frac{c_l}{4} \right)^2 n (1 - \alpha) \lambda_a \right] n \quad (2)$$

where:

- C_{PMIP} is the total signaling cost of P-MIP,
- $d_{FA,FA}$ is the average distance between FAs within a PA,
- r_{PA} is the PA crossing rate (mobile nodes/s),

- α is the ratio of active mobile nodes to the total number of mobile nodes,
- L is the paging area perimeter (m),
- λ_a is the incoming data session rate of mobile node, it is also the paging rate for MN, from assumption (1/s),
- λ_d is the outgoing data session rate of MN (1/s),
- δ_{air} is the weight of wireless hop for paging.

C. DLP-MIP

As defined in section II-A, each PA consists of n/m SPAs. The formula used to calculate the total signaling cost for DLP-MIP is [6]

$$C_{DLP-MIP} = d_{FA,HA} (R_{core} \omega_{core} + R_{local} \omega_{local}) \left[(r_c n - r_{PA}) \alpha + r_{PA} + \rho \left(\frac{c_l}{4} \right)^2 n r_r \right. \\ \left. + \rho \left(\frac{c_l}{4} \right)^2 n (1 - \alpha) (\lambda_a + \lambda_d) \right] + (1 - \alpha) d_{FA,FA} \omega_{local} \left[\frac{n}{m} r_{SPA} - r_{PA} \right] \\ + (m - 1) d'_{FA,FA} \omega_{local} \rho \left(\frac{c_l}{4} \right)^2 m (1 - \alpha) \lambda_a \left(\frac{n}{m} \right) \\ + \delta_{air} \left[\rho \left(\frac{c_l}{4} \right)^2 m (1 - \alpha) \lambda_a \right] m \left(\frac{n}{m} \right) \quad (3)$$

where:

- $C_{DLP-MIP}$ is the total signaling cost of DLP-MIP,
- $d'_{FA,FA}$ is the average distance between FAs within a SPA,
- r_{SPA} is the SPA crossing rate (mobile nodes/s),
- m is the number of cells in a sub-paging area,
- l is the sub-paging area perimeter (m).

D. TSP-MIP

Let an inner SPA has k cells, and an outer-SPA has $m - k$ cells, where $k = (\sqrt{m} - 2)^2$ cells. The formula used to calculate the total signaling cost for TSP-MIP is

$$C_{TSP-MIP} = d_{FA,HA} (R_{core} \omega_{core} + R_{local} \omega_{local}) \left[(r_c n - r_{PA}) \alpha + r_{PA} + \rho \left(\frac{c_l}{4} \right)^2 n r_r \right. \\ \left. + \rho \left(\frac{c_l}{4} \right)^2 n (1 - \alpha) (\lambda_a + \lambda_d) \right] + (1 - \alpha) d_{FA,FA} \omega_{local} \left[\frac{n}{m} r_{SPA} - r_{PA} \right] \\ + k d'_{FA,FA} \omega_{local} \rho \left(\frac{c_l}{4} \right)^2 k (1 - \alpha) \lambda_a \left(\frac{n}{m} \right) \\ + \delta_{air} \left[\rho \left(\frac{c_l}{4} \right)^2 k (1 - \alpha) \lambda_a \right] k \left(\frac{n}{m} \right) \\ + (m - k - 1) d'_{FA,FA} \omega_{local} \rho \left(\frac{c_l}{4} \right)^2 (m - k) (1 - \alpha) \lambda_a P_{outer} \left(\frac{n}{m} \right) \\ + \delta_{air} \left[\rho \left(\frac{c_l}{4} \right)^2 (m - k) (1 - \alpha) \lambda_a \right] (m - k) P_{outer} \left(\frac{n}{m} \right) \quad (4)$$

where:

- $C_{TSP-MIP}$ is the total signaling cost of TSP-MIP,
- k is the number of cells in an inner SPA,
- P_{outer} is the probability of locating an MN in an outer SPA.

The third and fourth terms in (4) represent the paging signaling cost caused by the paging initiator sending a first paging request message to all FAs in an inner SPA in wired link and wireless link, respectively. Similarly, the fifth and sixth terms take into account the paging signaling cost in the second paging request message in an outer SPA. Since the fifth and sixth terms are weighted with probability P_{outer} , which is less than 1, the signaling cost of TSP-MIP becomes less than that of DLP-MIP.

To compare among schemes, the registration refresh can be ignored because the registration lifetime, which incurs registration refresh rate, in P-MIP, DLP-MIP and TSP-MIP are equal. Thus, we normalize the signaling cost to the weighted distance between a HA and FA, i.e., $d_{FA,HA}(R_{core}\omega_{core} + R_{local}\omega_{local})$. After normalizing $\delta_{air} / d_{FA,HA}(R_{core}\omega_{core} + R_{local}\omega_{local})$ is newly denoted by σ_{air} .

E. The Average Paging Delay for DLP-MIP and TSP-MIP.

Since the proposed TSP-MIP scheme used a two-step paging scheme for reducing signaling cost, it takes longer average delay, compared to one-step approach. In this section, we analyze the average paging delay to observe the tradeoff of the proposed approach. We define the paging delay of one-step paging scheme (i.e., DLP-MIP scheme) as 1, and the average delay of TSP-MIP could be represented as [7], [8]:

$$\bar{D}_{TSPMIP} = \sum_{i=1}^w i p_i \quad (5)$$

where:

- $\bar{D}_{TSPMIP}$ is the average delay of TSP-MIP,
- w is the total number of paging zone into which the SPA is partitioned. In this scheme, w is equal to 2, including an inner SPA and an outer SPA,
- p_i is the probability that MNs are found in the i^{th} SPA,
- i is a sequence number of paging zone.

IV. ANALYSIS RESULTS

In this section, we present the performance of TSP-MIP compared to three conventional schemes (Mobile IP, P-MIP and DLP-MIP) with varying paging area sizes and the MN velocity. Consider cellular macro systems, which have an average perimeter cell size (c_l) of 4000 m, maximum MN velocity of 28.9 m/s and MN density of 0.0002 MN/m². The parameters used in this analysis are set to typical values as in [6]. (See Table 1.)

A. PAGING AREA SIZES

Figure 4 shows the signaling cost as a function of number of cells in a paging area. It can be observed that Mobile IP linearly increases with the number of cells, as expected from (1). That is the more cells considered, the more cell boundary crossings, which causes more registration signaling cost. P-MIP, DLP-MIP and TSP-MIP have lower total signaling cost than Mobile IP due to the paging procedure. However, when PA has more than 196 cells, the total signaling cost in P-MIP grows rapidly and becomes higher than Mobile IP. DLP-MIP

can reduce the total signaling cost compared with P-MIP. The proposed TSP-MIP has the lowest signaling cost. When PA has a large number of cells, the probability that MNs are found in an inner SPA will increase. Therefore, most first paging step is successful. The improvement of TSP-MIP scheme over Mobile IP, P-MIP and DLP-MIP is in average 74.6%, 78% and 20.3%, respectively.

TABLE 1. INPUT PARAMETERS

Parameter	Value
R_w	8
R_{core}, R_{local}	0.5
n/m	4
σ_{air}	1
$d_{FA,HA}$	16
$d_{FA,FA}$	$\sqrt{n}$
$d'_{FA,FA}$	$\sqrt{m}$
α	5%
v	28.9 m/s, 104 km/hr
$\lambda_a = \lambda_d$	0.0008/s (i.e., 3/hr)
ρ	0.0002 MNs/m ²

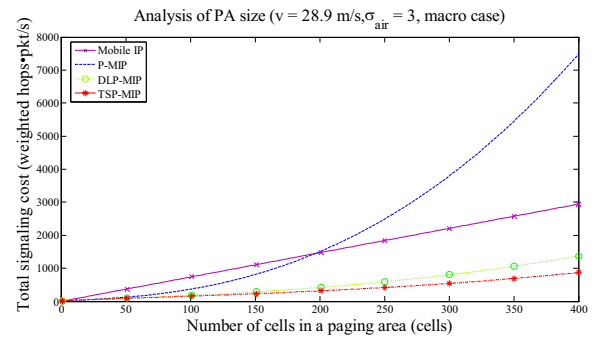


Figure 4. Effect of paging area size on the total signaling cost.

B. MOBILE NODE SPEED

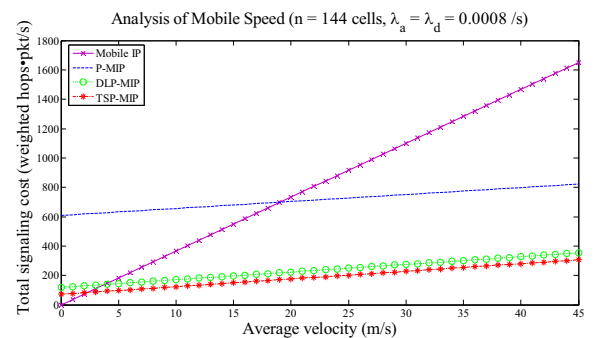


Figure 5. Effect of MN speed on the total signaling cost.

Figure 5 shows the signaling cost as a function of MN velocity. We set a PA size to 144 cells and 36 cells in a SPA, and then the number of cells in an inner SPA is 16 cells. When MNs move faster, DLP-MIP and TSP-MIP perform better

than P-MIP and Mobile IP. However, when MN move slower, the total signaling cost of Mobile IP is slightly lower than P-MIP, DLP-MIP and TSP-MIP. TSP-MIP performs better than P-MIP and DLP-MIP in all speed environments. TSP-MIP can improve the performance up to 77.1%, 73.6% and 19.9% signaling cost saving over Mobile IP, P-MIP and DLP-MIP, respectively.

C. THE AVERAGE PAGING DELAY

Even though TSP-MIP scheme proceeds in two-step paging scheme, its average paging delay is slightly longer than DLP-MIP scheme. Figure 5 shows that the average paging delay of TSP-MIP is 1.36 to 1.89 times of that DLP-MIP scheme.

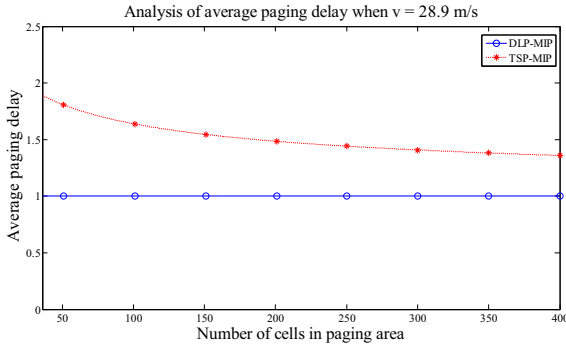


Figure 6. The average paging delay under the variety of PAs size

V. SIMULATION RESULT

Besides the analytical approach, we also evaluate our proposed scheme and the three conventional schemes via simulation results by varying system conditions. The mobility model is assumed to be a random walk on a connected graph model [8]. We consider a single MN in the simulation period (10,000 timeslots), which results in 95% of confidence interval. In the random walk model, MN will change its FA with assigned probability P_{walk} and stay within the same FA with probability $1-P_{walk}$. Hence, P_{walk} depends on the given average velocity of MN, but does not depend on the number of cells in a PA. We apply the same parameters as in Table 1.

A. PAGING AREA SIZES

We simulate the operation of P-MIP, DLP-MIP and TSP-MIP in both non-overlapping (i.e., P-MIP, DLP-MIP and TSP-MIP) and overlapping scenarios (i.e., P-MIP-O, DLP-MIP-O and TSP-MIP-O).

In the non-overlapping scenario, Figure 7 shows the results of three non-overlapping schemes (P-MIP, DLP-MIP and TSP-MIP), which follow the same trends as in Figure 4. Mobile IP does not vary by the number of cells in PA because of random walk assumption. Hence, it only depends on the MN velocity. In the overlapping scenario, TSP-MIP-O has the lowest signaling cost. When an MN locates far away from the previous PA and enters a new PA, the new location of that MN becomes the center of the SPA (i.e., an inner SPA). Also, the probability that MN is found in an inner SPA is higher than TSP-MIP. In other words, a new location of an MN becomes the boundary of SPA (i.e., an outer SPA). Hence

there is a high possibility that an MN moves off the new PA and returns to the previous PA, which causes unnecessary registration to its HA. The average improvements of TSP-MIP-O scheme over Mobile IP, P-MIP-O and DLP-MIP-O are in average 83.1%, 73.3% and 13.5%, respectively.

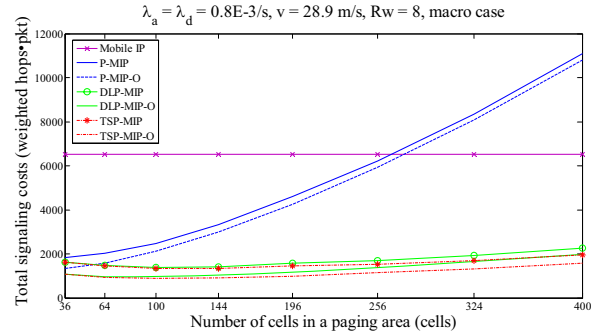


Figure 7. Effect of paging area size on the total signaling cost from simulation.

B. MOBILE NODE SPEED

In Figure 8, the results of four conventional schemes (Mobile IP, P-MIP, DLP-MIP, and TSP-MIP) in the non-overlapping scenario follow the same trends as in Figure 5. In the overlapping scenario, the total signaling cost of TSP-MIP-O is significantly less than the other schemes. TSP-MIP-O improves the performance up to 84.6%, 72.7% and 12.6% over Mobile IP, P-MIP-O and DLP-MIP-O, respectively.

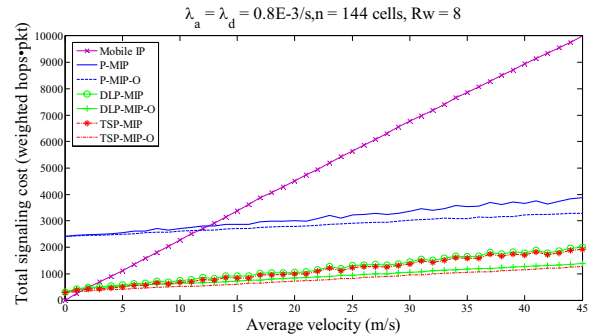


Figure 8. Effect of MN speed on the total signaling cost from simulation.

VI. CONCLUSION

In this paper, we proposed a two-step paging scheme for Mobile IP to reduce the total signaling cost and the sensitivity of the system with various user parameters by partitioning a sub-paging area into an inner sub-paging area and an outer sub-paging area. The first paging attempts to page the inner sub-paging area. If mobile user is found, then the first paging procedure is terminated. If not, the paging initiator continues to send paging messages to the outer sub-paging area, which means the rest of sub-paging area receives paging messages in the second step. High possibility of success in the first paging step improves the signaling cost over the conventional schemes. The proposed scheme also offers adaptability, which improves the performance in terms of the total signaling cost due to the paging procedure, compared with Mobile IP, P-MIP

and DLP-MIP. The performance of TSP-MIP is compared via mathematical analysis and simulation. In addition, we investigate the performance of TSP-MIP in the cases of non-overlapping and overlapping areas. The reported results show that TSP-MIP-O that provides the best performance compared with the other schemes. We also investigate a trade-off between reducing signaling cost and paging delay of TSP-MIP. By analysis in comparison with DLP-MIP, the delay of TSP-MIP is slightly longer than that of DLP-MIP scheme.

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