Delayed Location Management in Network Mobility Environments

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Abstract. Network mobility basic support (NEMO-BS) supports efficient group mobility. However, when NEMO-BS is applied to public transportation systems where mobile nodes (MNs) frequently get in/off the public transportation, significant signaling overhead owing to frequent and unnecessary binding updates can occur. To address this problem, we propose a delayed location management (DLM) scheme where an MN postpones its binding update for a pre-defined timer to mitigate the binding update overhead. To evaluate the performance of DLM, we develop an analytical model for the binding update cost and the packet delivery cost during the boarding time. Evaluation results demonstrate that DLM can reduce the binding update cost and packet delivery cost by choosing an appropriate timer.

Keywords: Network mobility (NEMO) · Mobility management · Location management · Public transportation

1 Introduction

Network mobility basic support (NEMO-BS) is a mobility support protocol where a collective mobility of multiple mobile nodes (MNs) is handled as a single unit [1,2]. When MNs are connected to a mobile network (MONET), a mobile router (MR) broadcasts a router advertisement (RA) message with its mobile network prefix (MNP) and then MNs configure their care of addresses (CoAs) based on the MR's MNP. After that, MNs conduct binding updates to their home agents (HAs). Then, when the MONET moves to a new access router (AR), only MR conducts the binding update to its HA while MNs in the MONET do not need to execute any binding updates.

However, when NEMO-BS is applied to a public transportation, unnecessary signaling overhead due to binding updates can occur since MNs frequently get in/off the public transportation. Specifically, when an MN gets off before the

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public transportation moves to another AR (i.e., an MN has a short boarding time), the binding update for MN's CoA based on the MR's MNP can be unnecessary. Figure 1 shows an example of the unnecessary binding update. When an MN gets in a public transportation (Step 1 in Fig. 1), the MN configures its CoA based on the MR's MNP and conducts a binding update to its HA (Steps 2–3 in Fig. 1). Then, when the public transportation moves to another bus station (Step 4 in Fig. 1), the MN gets off the public transportation (Step 5 in Fig. 1). In this case, the binding update in Step 3 for supporting collective mobility is useless. Note that the distance between two bus stops in local bus service is typically 300–400 m [3] and the maximum diameter for one macro-cell is 3 km in urban areas [4]. In such environments, there is non-negligible probability that an MN gets off before the public transportation moves to another AR.

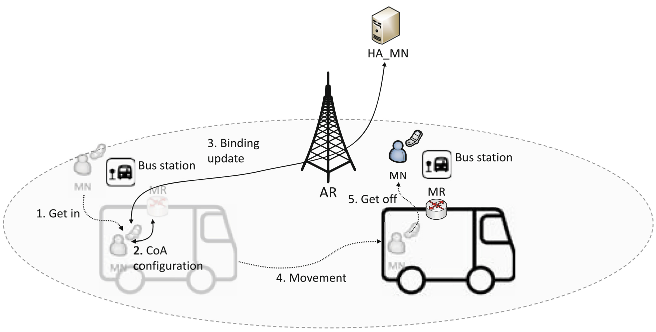

Fig. 1. Example of the wasting binding update.

Intuitively, if an MN with short boarding time does not conduct instantly the binding update when the MN gets in the public transportation, such unnecessary binding update can be reduced. Based on this idea, we propose a delayed location management (DLM) scheme where an MN postpones its binding update until a pre-defined timer T expires. In DLM, the mobility of the MN is managed by mobile IPv6 (MIPv6) before the timer expiration. On the other hand, after the timer expiration, the mobility of the MN is handled by the MR. Therefore, the packets to the MN are forwarded through MN's HA, MR's HA, and MR. Also, the MN does not need to conduct any binding update when the public transportation handovers to another AR. To evaluate the performance of DLM, we develop an analytical model for the binding update cost and the packet delivery cost during the MR attachment time. Evaluation results demonstrate that DLM can reduce the binding update cost and packet delivery cost by choosing an appropriate timer.

The remainder of this paper is organized as follows. The related works are summarized in Sect. 2. The detailed operation of DLM is described in Sect. 3. The performance analysis model is illustrated in Sect. 4. Evaluation results and concluding remarks are given in Sects. 5 and 6, respectively.

2 Related Works

To improve the performance of NEMO-BS, a number of schemes have been proposed in the literature [5–10]. Qiang *et al.* [5] suggested an adaptive route optimization scheme which consists of the mobility transparency sub-scheme and the time saving sub-scheme, and a threshold is introduced to determine which sub-scheme is used in the current situation. In [6], Kim *et al.* proposed a simple route optimization (S-RO) scheme where a correspondent node (CN) maintains binding information of MRs to obtain the optimal path to the MN. Cho *et al.* [7] introduced a routing optimization scheme using a tree information option (ROTIO). In this scheme, each MR sends two binding update messages to the top-level MR (TLMR) and its HA, respectively. Then, the packets to the MN in the public transportation are transmitted only through the HA of the MR and the TLMR. Calderon *et al.* [8] introduced a mobile IPv6 route optimization for NEMO (MIRON) scheme based on the carrying authentication for network access (PANA) and the dynamic host configuration protocol (DHCPv6) by modifying the software in the MR. Chuang and Lee [9] proposed a domain-based route optimization (DRO) scheme which incorporates ad-hoc routing techniques and uses a double buffer mechanism to achieve route optimization. Barman *et al.* [10] suggested a route optimization method by introducing two new IPv6 extension headers named as anchor point request (APR) and anchor point grant (AGR). However, the binding update cost for the CoA derived from the MR's MNP is not considered in these works [5–10].

3 Delayed Location Management (DLM)

In this section, we explain the operations of DLM, which is dependent on whether the timer T expires or not. For example, before the timer T expires, the packets destined to the MN are transmitted through only HA_MN and the MN conducts the binding update whenever the public transportation moves to another AR. On the other hand, after the timer expiration, when a CN sends packets to the MN, the packets are transmitted through HA_MN, HA_MR, and MR. Also, since the mobility of the MN is managed by the MR after the timer expiration, the MN needs not to conduct any binding update even though the public transportation moves to another AR.

Figure 2 shows the operation example of DLM when MN 1 and MN 2 have short and long boarding times, respectively. At the first time, when MN 1 and MN 2 get in the public transportation at τ_0, the MR sends a RA message to MNs (Step 1 in Fig. 2). Then, MN 1 and MN 2 start their timers. Since MN 1 does not conduct any binding update to its HA before the timer expiration, packets are forwarded to MN 1 only through HA_MN when the CN sends the packets to MN 1 at τ_1 (Step 2 in Fig. 2). When MN 1 gets off the public transportation before the timer expires at τ_2 (i.e., short boarding time), MN 1 does not conduct the binding update for its CoA based on MR's MNP, which can save the binding update cost.

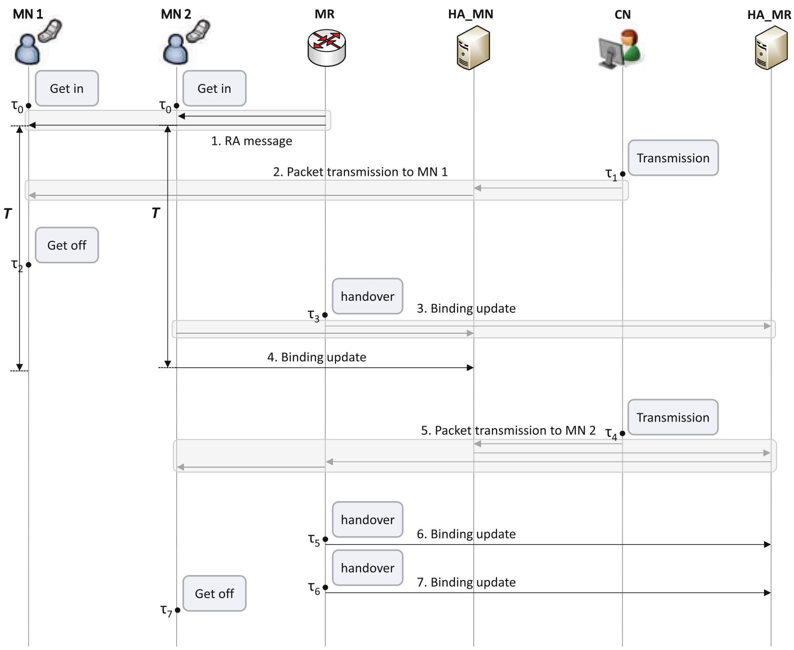

Fig. 2. Operation of DLM.

Meanwhile, since MN 2 with long boarding time does not yet conduct the binding update when the public transportation handovers to another AR at τ_3, both MN 2 and MR should execute binding updates to their HAs (Step 3 in Fig. 2). In other words, MNs conduct their binding updates individually before the timer expiration whenever the public transportation handovers to another AR, which increases binding update cost. After the timer expires, MN 2 executes a binding update for its CoA based on MR's MNP to HA_MN (Step 4 in Fig. 2). From this time, the mobility of MN 2 is managed by MR. Therefore, when the CN sends the packet to MN 2 at τ_4, the packets are forwarded to MN 2 through the detour path, i.e., HA_MN, HA_MR, and MR (Step 5 in Fig. 2). On the other hand, when the MR handovers to another AR at τ_5 and τ_6, only MR sends a binding update message to HA_MR whereas MN 2 does not conduct any binding update (Steps 6–7 in Fig. 2).

4 Performance Analysis

In this section, we develop an analytical model for the total cost that consists of the binding update cost and the packet delivery cost during the MR attachment time. The MR attachment time represents the period between when an MN gets on and when it gets off the public transportation (i.e., the boarding time of the MN). Important notations for the analytical model are summarized in Table 1.

Table 1. Summary of notations.

Notation	Description
t_M	MR attachment time
$t_{S,k}$	kth inter-session arrival time
$t_{R,k}$	kth residence time
T	Timer value
C_{total}	Total cost during the MR attachment time
C^I	Cost for case I
C^{II}	Cost for case II
C_B^I	Binding update cost for case I
C_P^I	Packet delivery cost for case I
C_B^{II}	Binding update cost for case II
C_B	Unit cost for the binding update
C_P	Additional unit cost for the packet delivery
$\alpha_S(k)$	Probability that the MN has k sessions during t_M
$\alpha_R(k)$	Probability that the MR moves across k ARs

4.1 Total Cost of DLM

In DLM, the total cost during the MR attachment time, t_M, can be derived from the following two cases: case (I) t_M is larger than the timer value T (see MN 2 in Fig. 2) and case (II) t_M is equal to or smaller than T (see MN 1 in Fig. 2). Then, the total cost, C_{total}, can be represented by

$$C_{total} = P[t_M > T]C^I + P[t_M \leq T]C^{II} \tag{1}$$

where C^I and C^{II} represent the total cost for cases I and II, respectively.

When we assume that t_M follows an exponential distribution with mean $1/\lambda_M$, $P[t_M > T]$ and $P[t_M \leq T]$ are respectively derived as

$$P[t_M > T] = \int_T^\infty \lambda_M e^{-\lambda_M t} dt_M = e^{-\lambda_M T} \tag{2}$$

and

$$P[t_M \leq T] = \int_0^T \lambda_M e^{-\lambda_M t} dt_M = 1 - e^{-\lambda_M T}. \tag{3}$$

Meanwhile, C^I consists of the binding update cost and the packet delivery cost, i.e., $C^I = C_B^I + C_P^I$ where C_B^I and C_P^I denote the binding update cost and the packet delivery cost in case I, respectively.

In case I (i.e., $t_M > T$), the MN conducts the binding update to its HA whenever the MR handovers to another AR before the timer expiration. Also, when the timer expires, the MN executes another binding update to its HA. Therefore, C_B^I can be represented by

$$C_B^I = C_B\left(E[N_R] + 1\right) \tag{4}$$

where $E[N_R]$ is the expected number of MR handovers during T and C_B represents the unit cost for the binding update. When we assume that the kth residence time, $t_{R,k}$, is drawn from a Gamma distribution with mean $1/\lambda_R$ and variance V_R [11,12], $E[N_R]$ can be computed as $E[N_R] = \lambda_R T$ by Little's law [13].

On the other hand, the packets are transmitted only through HA_MN before the timer expiration. On the contrary, the packets are transmitted through HA_MN, HA_MR, and MR after the timer expiration. That is, additional packet delivery cost incurs for sessions after the timer expires. When $\alpha_S(k)$ denotes the probability that the MN has k sessions during t_M, the expected number of sessions during t_M can be calculated as $\sum_{k=1}^{\infty} k\alpha_S(k)$. Therefore, the number of sessions which result in additional packet delivery cost (i.e., sessions after the timer expiration) can be obtained by $\sum_{k=1}^{\infty} k\alpha_S(k) - E[N_S]$ where $E[N_S]$ is the expected number of sessions during T. Then, C_P^I can be represented by

$$C_P^I = C_P\left[\sum_{k=1}^{\infty} k\alpha_S(k) - E[N_S]\right] \tag{5}$$

where C_P represents the unit cost for the additional packet delivery. If $C_{P,B}$ and $C_{P,A}$ denote the unit costs for the packet delivery before and after the timer expiration, respectively, C_P can be obtained from $C_{P,A} - C_{P,B}$.

When we assume that the kth inter-session arrival time, $t_{S,k}$, is drawn from a Gamma distribution with mean $1/\lambda_S$ and variance V_S, as similar to $E[N_R]$, $E[N_S]$ can be computed as $E[N_S] = \lambda_S T$ [13]. Also, $\alpha_S(k)$ is obtained as [14]

$$\alpha_S(k) = \frac{\lambda_S}{\lambda_M}\left[1 - f_S^*(\lambda_M)\right]^2 \left[f_S^*(\lambda_M)\right]^{k-1} \tag{6}$$

where $f_S^*(s)$ denotes the Laplace transforms of t_S, which is given by $f_S^*(s) = \left(\frac{\lambda_S\gamma_S}{s+\lambda_S\gamma_S}\right)^{\gamma_S}$ where $\gamma_S = \frac{1}{V_S{\lambda_S}^2}$ [11].

In case II (i.e., $t_M \leq T$), since the timer does not expire during t_M, there is no packet that needs additional packet delivery cost. Therefore, C^{II} includes only the binding update cost, i.e., $C^{II} = C_B^{II}$ where C_B^{II} is the binding update cost for case II. Since the expected number of handovers during t_M can be computed as $\sum_{k=1}^{\infty} k\alpha_R(k)$ where $\alpha_R(k)$ is the probability that the MR moves across k ARs during t_M, C^{II} can be derived from

$$C^{II} = C_B \sum_{k=1}^{\infty} k\alpha_R(k). \tag{7}$$

As similar to (6), $\alpha_R(k)$ is given by [14]

$$\alpha_R(k) = \frac{\lambda_R}{\lambda_M}\left[1 - f_R^*(\lambda_M)\right]^2 \left[f_R^*(\lambda_M)\right]^{k-1} \tag{8}$$

where $f_R^*(s)$ denotes the Laplace transforms of t_R which is represented by $f_R^*(s) = \left(\frac{\lambda_R \gamma_R}{s+\lambda_R \gamma_R}\right)^{\gamma_R}$ where $\gamma_R = \frac{1}{V_R {\lambda_R}^2}$ [11].

4.2 Total Cost of Conventional Schemes

Total Cost of NEMO-BS. In NEMO-BS, the MN conducts only one binding update right after the MN gets in the public transportation and configures its CoA. On the other hand, every packet is transmitted through HA_MN, HA_MR, and MR. Therefore, additional packet delivery cost for every packet incurs during the MR attachment time. Therefore, the total cost for NEMO-BS, C_{NEMO}, can be expressed as

$$C_{NEMO} = C_B + C_P \sum_{k=1}^{\infty} k\alpha_S(k). \tag{9}$$

Total Cost of MIPv6. In MIPv6, since the MN does not execute any binding update for CoA based on the MR's MNP, there is no additional packet delivery cost. Meanwhile, each MN conducts a binding update to its HA whenever the public transportation moves across another AR. Therefore, the total cost for MIPv6, C_{MIPv6}, is given by

$$C_{MIPv6} = C_B \sum_{k=1}^{\infty} k\alpha_R(k). \tag{10}$$

5 Evaluation Results

For performance evaluation, we compare DLM against MIPv6 and NEMO-BS. Default parameter settings are described in Table 2.

5.1 Effect of T

Figure 3 shows the total cost as the timer T increases. It can be seen that the total costs of NEMO-BS and MIPv6 are constant regardless of the timer T. This is because NEMO-BS and MIPv6 do not use any timer. Also, it can be shown that

Table 2. Default parameter setting.

Parameter	λ_M	λ_S	λ_R	C_P	C_B
Value	1	5	2	1	1.5

the total cost of NEMO-BS is higher than that of MIPv6. This can be explained as follows. In the default parameter setting, session arrival events occur more frequently than handover events (i.e., $\lambda_S > \lambda_R$). Therefore, the packet delivery cost is more influential to the total cost than the binding update cost. In this situation, since MIPv6 forwards the packets only through the HA of the MN, it has an advantage of reducing the total cost.

Meanwhile, in DLM, it can be found that there is an optimal timer that minimizes the total cost (e.g., 2.75 in Fig. 3). This can be explained as follows. When the timer is set to a too small value, the probability that the binding update of the MN is simply wasted is high. On the other hand, when the timer is set to a too large value, all MNs should individually conduct binding updates to their HAs before the timer expires, which can increase the total cost. Consequently, setting the timer to an appropriate value is important to achieve better performance.

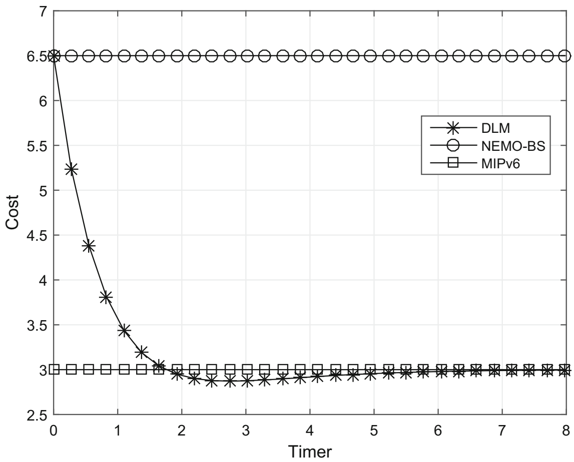

Fig. 3. Effect of T.

6 Conclusion

To reduce unnecessary binding update for MN's CoA based on the MR's MNP, we have proposed an delayed location management (DLM) scheme where an MN postpones its binding update until a pre-defined timer T expires. Evaluation results demonstrate that DLM outperforms existing schemes when the timer is set to an appropriate value. In our future work, we will investigate how to choose the optimal timer.

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