An Adaptive Route Optimization Scheme for Nested Mobile IPv6 NEMO Environment

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***Abstract*—We address the route optimization problem for a nested mobile IPv6 NEtwork MObility (NEMO) environment. We propose an adaptive scheme which can optimize the routing process of the data communication, and minimize the end-to-end delay. The adaptive scheme consists of two sub-schemes: mobility-transparency sub-scheme and time-saving sub-scheme. The mobility-transparency sub-scheme performs well for the high mobility scenarios, while the time-saving sub-scheme performs well for the low mobility and large communication traffic scenarios. A threshold is used to determine which sub-scheme should be applied for the current situation. Theoretical analysis and simulation results demonstrate that the proposed scheme can reduce the end-to-end delay of data communication for nested mobile IPv6 NEMO environment significantly.**

Keywords*—*Adaptive scheme, end-to-end delay, nested mobile IPv6 NEMO, pinball routing problem, route optimization.

I. Introduction

As ubiquitous computing proliferates, more and more electronic devices emerge in wireless networks. Some devices could connect together to construct a small wireless network, which moves as a unit. Mobility of this unit is called the NEtwork MObility (NEMO) [1]. The Network mobility Basic Support Protocol (NBSP) [2] is the primary protocol of NEMO, which defines the core architecture of mobile IPv6 NEMO environment. In this paper, we study the route optimization problem for nested mobile IPv6 NEMO environment based on NBSP.

In the architecture defined by NBSP, there are many mobile routers (MRs) in a mobile network (Fig.1). Some MRs may connect together to construct a tree-configured network. The root of the tree is called Top Level Mobile Router (TLMR), and the region of TLMR is called domain. Each MR has a Home Agent (HA) to maintain its current location. If a Corresponding Node (CN) wants to send packets to an MR, these packets have to pass through the HA of MR at first (Fig.1(a)). This transmission method will incur the packet routing problem in the nested structure. As an example shown in Fig.1(b), CN wants to send some packets to MR_3. Since MR_3 appends to MR_1, packets will pass through MR_1 before reaching MR_3. In order to determine the current locations of MR_1 and MR_3, packets have to pass through two home agents HA_MR_1 and HA_MR_3 at first. Each time when the packets pass through a home agent, these packets are encapsulated once, then be decapsulated by the corresponding mobile router. As a result, packets will experience several times encapsulation and decapsulation in a nested structure. This process increases the packet size and end-to-end delay. The situation gets worse as nesting levels increase (Fig.1(c)). This routing problem is called the "pinball routing problem" [3].

Since the pinball routing problem will increase the packet size and end-to-end delay, some related work has been considered for the route optimization for nested mobile IPv6 NEMO environment. S.Pack *et al*. [4] proposed an adaptive network mobility support scheme, which has to make some changes in the architecture of mobile networks. A.Banno *et al*. [5] proposed χLIN6-NEMO, which will suffer from a lot of location update overhead as the mobile network moves. K.Humayun *et al*. [6] optimized the routing process of packets exchange between CN and MR (*inter-domain communication*). However, the routing process of packets between two MRs (*intra-domain communication*) has not been optimized.

An interesting scheme is proposed by H. Cho *et al*. [7], called the Route Optimization scheme using Tree Information Option (ROTIO). ROTIO provides the optimal routes for both inter-domain and intra-domain communication. Moreover, it does not require any change in the architecture of mobile network. For inter-domain communication, ROTIO requires the home agent of each MR to maintain an information of TLMR. This information indicates that the MR is locating at a mobile network below TLMR. Packets which are destined for an MR will be intercepted by the home agent of this MR, and then encapsulated and forwarded to the home agent of TLMR directly. For intra-domain communication, ROTIO requires TLMR to maintain the structure of nested mobile network. The packets which are sent from a mobile node to another one will be forwarded to TLMR at first. Then, the TLMR forwards these packets to their destinations. However, there are some problems in ROTIO. Packets of inter-domain communication still need to pass through two home agents, the number of passed home agents should be further reduced. Moreover, packets of intra-domain communication should be limited in smaller scope.

In this paper, we propose a novel adaptive route optimization scheme for nested mobile IPv6 NEMO environment. The proposed scheme consists of two sub-schemes: *mobility-transparency sub-scheme* and *time-saving sub-scheme*. The *mobility-transparency sub-scheme* performs well for the high mobility scenario, which ensures the packets of inter-domain communication need to pass through only two home agents, no matter where the destinations are. While the *time-saving sub-scheme* performs well for the low mobility and large communication traffic scenario, which ensures the packets of inter-domain communication need to pass through only one home agent, no matter where the destinations are. A threshold is used to determine which sub-scheme should be adopted for current situation. Furthermore, we extend the proposed adaptive route optimization scheme for intra-domain communication. In the extended route optimization scheme, each MR maintains the structure of its subnet. After receiving some packets, MR will check whether the destinations of received packets belong to its

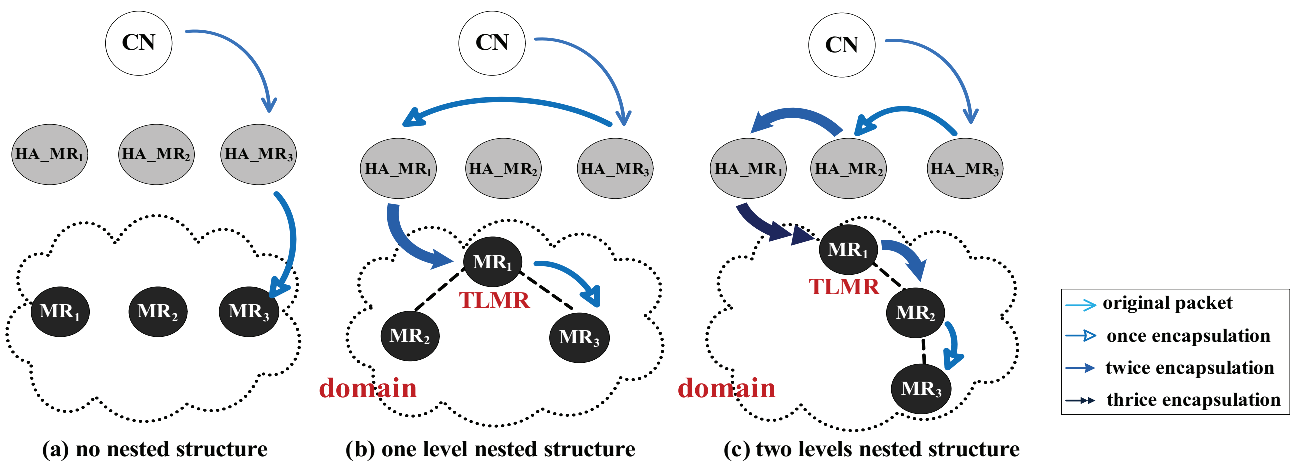


Fig. 1: Illustration of the pinball routing problem

subnet or not. Finally, we compare our proposed scheme with two famous schemes: NBSP [2] and ROTIO [7]. Comparison results demonstrate that, the proposed scheme has the least end-to-end delay for both inter-domain communication and intra-domain communication.

The rest of this paper is organized as follows. System description and problem statement are presented in section II. Section III presents the problem formulation. Section IV gives an adaptive route optimization scheme for inter-domain communication. In section V, the proposed adaptive scheme is extended for intra-domain communication. Section VI shows the performance evaluation. Section VII concludes this paper.

II. System Description and Problem Statement

In this paper, we consider the nested mobile IPv6 NEtwork MObility (NEMO) architecture defined by NBSP [2]. In the architecture, Mobile Nodes (MNs) are divided into two classes: Local Fixed Nodes (LFNs) and Visiting Mobile Nodes (VMNs) [8]. Each LFN attaches to a Mobile Router (MR) and never changes its attachment point. On the contrary, VMNs move around independently and do not belong to any mobile network. We focus on LFNs in our research.

Each MR has two kinds of addresses: 1) Home-Address (HoA) which is an identifier, never changes once obtained; 2) Care-of-Address (CoA) which is a locator, updates as MR moves. Whenever an MR moves into a new Access Point (AP) region, it will obtain a new CoA. As soon as the MR obtains a new CoA, it sends a Binding Update (BU) message [9] to its HA immediately. After receiving this BU message, the HA creates an entry in the binding cache [10]. This entry contains the relationship between HoA of MR and CoA of MR. In order to send some packets to the MR, these packets have to be forwarded to the HA of MR at first. After receiving these packets, HA of MR encapsulates the packets, and forwards them according to the binding cache information.

For example shown in Fig.2, a cell phone, a laptop and a PDA connect together to construct a simple Personal Area Network (PAN) [11], which is a small mobile network. As the person gets on a bus, the PAN nests inside a bigger mobile network. The cell phone (LFN_3) can get internet service through the laptop (MR_1) and a mobile router on the bus (TLMR). When the CN attempts to send some packets to the cell phone, CN sets the destinations of packets to the HoA

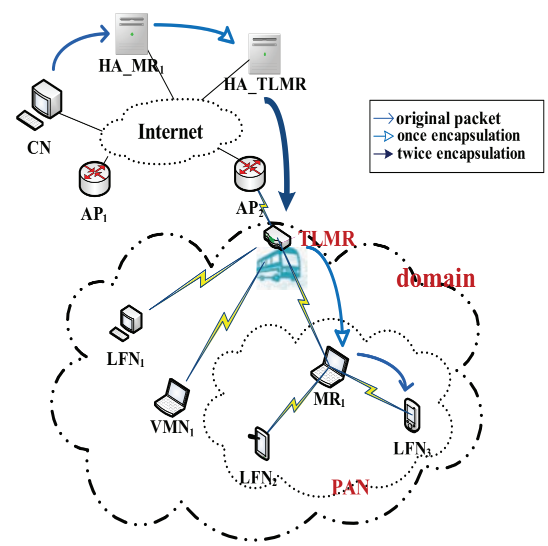


Fig. 2: An example of nested mobile network

of MR_1, and then sends the packets out. These packets will be intercepted by the HA of MR_1. HA of MR_1 searches its binding cache for destinations, then encapsulates these packets and sends them out again. HA of TLMR will intercept these packets and take the same actions as HA of MR_1 did. After several times encapsulation and relay, packets arrive at the bus. Inside this bus, packets will be decapsulated by TLMR and MR_1, then forwarded to the cell phone in the end.

As the example shown in Fig.2, in nested mobile IPv6 NEMO environment, packets sent from source to destination have to pass through several home agents and mobile routers. During this process, packets will be encapsulated and decapsulated for several times. This process will increase the packet size and end-to-end delay. The situation gets worse as nesting levels of mobile network increases. This is called the pinball routing problem [12]. We will solve this problem by proposing an adaptive route optimization scheme.

III. Problem Formulation

In this section, we formulate the routing process of inter-domain communication and calculate the end-to-end delay. Considering the scenario shown in Fig.3, AP divides the nested mobile network into wired part and wireless part. From CN to AP is the wired part, there are a lot of Home Agents (HAs) in this part. Meanwhile, wireless part refers to the region between the AP and LFNs, there are a lot of Mobile Routers (MRs). The other notations are as follows:

- $R_{(a,\ b)}$ refers to the route from a to b, and the end-to-end delay of this route is $D_{(a,\ b)}$. According to the definition, we use $R_{(CN,\ LFN)}$ to represent the route of an inter-domain communication.

$$R_{(CN,\ LFN)} = R_{(CN,\ AP)} + R_{(AP,\ LFN)}. \quad (1)$$

- The Top Level Mobile Router (TLMR) is the gateway of a mobile network to the Internet, and also is the first level of a nested structure. We suppose that the TLMR locates at level 0, and the intermediary mobile router MR_m locates at the LMR_m th level, where $0<m<M$. M is the number of mobile routers.
- C_i denotes the i th inter-domain communication, where $1\leq i\leq C$. C is the total number of inter-domain communications. The destination of C_i is LFN_{C_i} which locates at the $LLFN_{C_i}$th level. The arrival time of inter-domain communications follows an exponential distribution.
- B_w and B_{wl} denote the bandwidth of wired channel and wireless channel respectively, S_P is the size of a packet.

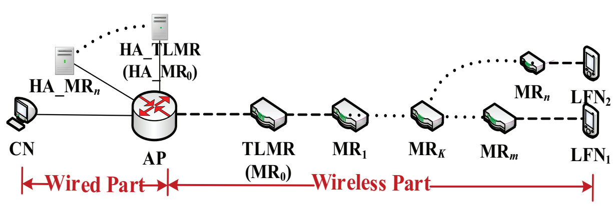


Fig. 3: Structure of nested mobile network

Considering an inter-domain communication C_i, where CN attempts to send a packet to LFN_{C_i}. The end-to-end delay of C_i is $D_{(CN,\ LFN_{C_i})}$, which is calculated as follows,

$$D_{(CN,\ LFN_{C_i})} = D_{(CN,\ AP)} + D_{(AP,\ LFN_{C_i})}. \quad (2)$$

$D_{(CN,\ AP)}$ is the end-to-end delay of wired part. In the wired part, each time when a packet passes through an HA, this packet will be encapsulated once. HA adds an IPv6 header [13] to the received packet, and then sends the packet out. Let n denote the number of passed HAs, and S_H denote the size of an IPv6 header (S_H=40 bytes). As a result, $D_{(CN,\ AP)}$ is calculated by the following equation,

$$D_{(CN,\ AP)} = \frac{\sum_{j=0}^{n}(S_P + j \cdot S_H)}{B_w}. \quad (3)$$

$D_{(AP,\ LFN_{C_i})}$ is the end-to-end delay of wireless part. In the wireless part, each time when a packet passes through an MR, this packet will be decapsulated. MR removes an IPv6 header from the received packet, then sends the packet out. As a result, $D_{(AP,\ LFN_{C_i})}$ is calculated by the following equation,

$$D_{(AP,\ LFN_{C_i})} = \frac{\sum_{j=0}^{n}[S_P + S_H \cdot (n-j)]}{B_{wl}}. \quad (4)$$

Comparing with storage space, computing time and other factors, the impact of end-to-end delay which is incurred by the pinball routing problem is obviously more serious [14]. In order to alleviate the pinball routing problem, we need to minimize the value of end-to-end delay. For this objective, we propose an adaptive route optimization scheme, which is presented as follows.

IV. Proposed Schemes for Inter-domain Communication

The end-to-end delay of inter-domain communication $D_{(CN,\ LFN_{C_i})}$ can be reduced by decreasing the value of n, where n is the number of HAs that packets will pass through during transmission. In NBSP, n equals to the nesting levels of destination. While in our proposed adaptive scheme, n equals to 1 or 2 no matter where the destination locates at. In this section, we will explain our proposed scheme in details.

A. Adaptive Route Optimization Scheme

The adaptive route optimization scheme consists of two sub-schemes: *time-saving sub-scheme* and *mobility-transparency sub-scheme*. If the time-saving sub-scheme is applied, the value of n is 1. Otherwise, if the mobility-transparency sub-scheme is applied, the value of n is 2. A threshold μ is used to determine which sub-scheme should be applied for current scenario. The computing method of μ will be presented in the last subsection.

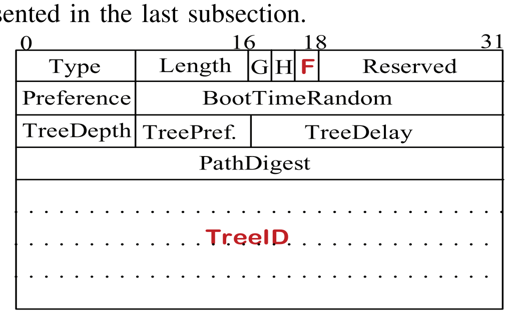


Fig. 4: Format of revised tree information option

As the preparation of adaptive scheme, we revise the Tree Information Option (TIO) [15]. The format of revised TIO is shown in Fig.4, where **TreeID** field is redefined, and **F** field is new added. The value of **TreeID** is Care-of-Address of Top Level Mobile Router (CoA_TLMR) or Home-Address of Top Level Mobile Router (HoA_TLMR). Meanwhile, the value of **F** indicates the address categories of **TreeID**. If the value of **TreeID** is CoA_TLMR, **F** equals to 1. Otherwise, **F** is 0. In addition, we define the Call-to-Mobility Ratio (CMR) [16][17] of a mobile network as follows.

Definition 3.1 (*The Call-to-Mobility Ratio (CMR) of a mobile network*). In the time slot t_i (i=1,2,$\cdots$), there are nc_{t_i} calls coming to a mobile network. Meanwhile, this mobile network passes through nm_{t_i} AP regions. The CMR of the mobile network in t_i is $CMR(t_i) = nc_{t_i} / nm_{t_i}$.

For each time slot, TLMR calculates the $CMR(t_i)$ and compares it with the threshold μ. According to the comparison result, TLMR sets the **TreeID** field and **F** field of a TIO, then appends this TIO to a Route Advertisement (RA) message [18]. As the RA message is propagated downwards, each MR can get the information of **TreeID**, then notify its HA of this information [19]. Different values of **TreeID** direct to the different sub-schemes.

- If $CMR(t_i) \leq \mu$, **TreeID** is set to the HoA_TLMR, and the *mobility-transparency sub-scheme* will be adopted. In this situation, the mobile network moves frequently. Each time when the location of mobile network changes, it will lead to once location update. Since the standard location update process will cost a lot of management overhead, mobility transparency becomes the most important requirement.
- If $CMR(t_i) > \mu$, **TreeID** is set to the CoA_TLMR, and the *time-saving sub-scheme* will be adopted. In this situation, the mobile network is relatively stable and a large amount of calls come to it. The delay incurred by packets transmission is bigger than the delay incurred by location update. Reducing the transmission delay becomes more urgent.

B. Mobility-transparency Sub-scheme

In order to explain how the mobility-transparency sub-scheme works, we consider the scenario shown in Fig.5, where CN attempts to send packets to LFN_3. CN sets the destinations of the packets to HoA_MR_4, then sends the packets out. These packets will be intercepted by the Home Agent of MR_4 (HA_MR_4). HA_MR_4 searches its binding cache for destinations, and finds out the destinations can be achieved through **TreeID**. As a result, HA_MR_4 encapsulates the packets with **TreeID**, then sends these packets out.

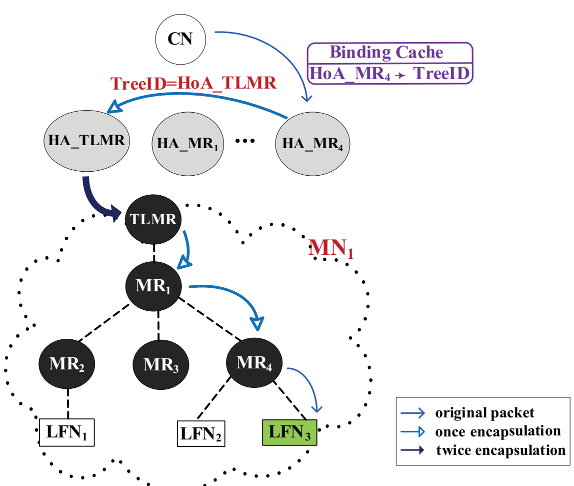


Fig. 5: Illustration of the mobility-transparency sub-scheme

Since the value of **TreeID** is HoA_TLMR, these packets will be intercepted by HA_TLMR. HA_TLMR takes the same actions as HA_MR_4 has done, encapsulates the received packets and sends them out. These packets will be intercepted by TLMR. After receiving the packets, TLMR decapsulates these packets and forwards them to MR_1. MR_1 just forwards the received packets to MR_4. Then, MR_4 decapsulates these packets, and forwards the original packets to their destinations.

As this example demonstrates, the mobility-transparency sub-scheme ensures the packets of inter-domain communication need to pass through only **two** home agents, no matter where the destinations locate at.

C. Time-saving Sub-scheme

Here we also consider the same scenario, the transmission process of the time-saving sub-scheme is shown in Fig.6. CN sets the destinations of packets to HoA_MR_4, then sends the packets out. These packets will be intercepted by HA_MR_4. HA_MR_4 encapsulates these received packets with **TreeID**, then sends them out. Since the value of **TreeID** is CoA_TLMR which indicates the current location of TLMR, packets can be received by TLMR directly. TLMR and MR_1 just forward the received packets without decapsulating. When the packets arrive at MR_4, these packets will be decapsulated and forwarded to their destinations.

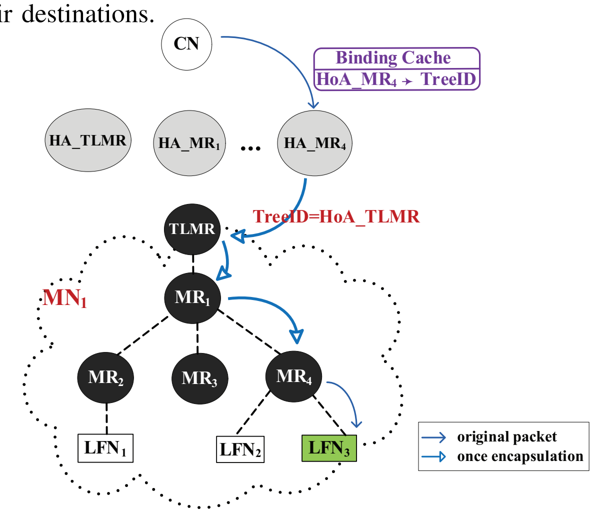


Fig. 6: Illustration of the time-saving sub-scheme

In the time-saving sub-scheme, the packets of inter-domain communication need to pass through only **one** home agent, no matter where the destinations locate at. However, it does not mean the time-saving sub-scheme is better than the mobility-transparency sub-scheme. The reason is: when the mobile network MN_1 moves from an AP region to another one, the TLMR will obtain a new care-of-address. In the time-saving sub-scheme, information maintained by HAs (CoA_TLMR) need to be updated when MN_1 is moving. If MN_1 moves frequently, the update overhead will be very large. While in the mobility-transparency sub-scheme, since the home-address of TLMR will not change as MN_1 moves, information maintained by HAs (HoA_TLMR) do not need to be updated. In a word, transmission overhead of the time-saving sub-scheme is smaller than the mobility-transparency sub-scheme. However, the location update overhead of the time-saving sub-scheme is bigger than the mobility-transparency sub-scheme. Given a scenario, we make use of a threshold μ to determine which sub-scheme should be adopted.

D. Optimal Threshold μ

Let T_{MT} and T_{TS} denote the time overhead of the mobility-transparency sub-scheme and the time-saving sub-scheme respectively. Both T_{MT} and T_{TS} consist of two parts: transmission part and location update part. Transmission part is the end-to-end delay of transmitting packets. Location update part is the required time for updating the information maintained by home agents, when the mobile network moves into a new AP region [20]. If the Call-to-Mobility Ratio (CMR) of a mobile network is very close to the threshold μ, we have the following equations:

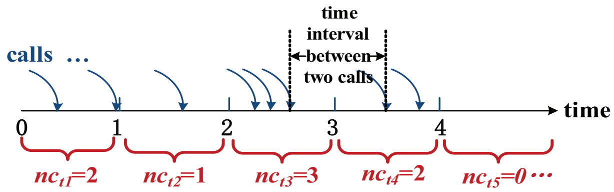


Fig. 7: Calls destined for the mobile network

$$T_{MT}^{trans} + T_{MT}^{update} = T_{TS}^{trans} + T_{TS}^{update}, \tag{5}$$

$$T_{MT}^{trans} - T_{TS}^{trans} = T_{TS}^{update} - T_{MT}^{update}. \tag{6}$$

For simplicity but without losing generality, we assume the time interval between two calls follows an exponential distribution [21] with rate λ_c (Fig.7). Therefore the mean of time interval between two calls is $\int_0^\infty x\lambda_c e^{-\lambda_c x}dx = 1/\lambda_c$. As a result, the average number of calls per unit time *ncall*=λ_c. We also assume the number of AP regions which are crossed by the mobile network per unit time, follows a Poisson distribution [22] with rate λ_m. As a result, the mean of crossed AP regions per unit time *nmob*=λ_m.

As Fig.5 and Fig.6 indicate, after packets arrive at the mobile network, transmission process has no difference between the mobility-transparency sub-scheme and the time-saving sub-scheme. As a result, when we compare the transmission parts between two sub-schemes, we only need to consider the part outside the mobile network. In the mobility-transparency sub-scheme, each packet will pass through two home agents in the wired channel. While in the time-saving sub-scheme, each packet will pass through only one home agent in the wired channel. Whenever a packet passes through a home agent, it will be encapsulated once. For *ncall* packets, the difference of transmission parts between two sub-schemes T_{MT}^{trans}-T_{TS}^{trans} is calculated as follows,

$$T_{MT}^{trans} - T_{TS}^{trans} = ncall\left(\frac{S_P + 2S_H}{B_w} + \frac{S_H}{B_{wl}}\right). \tag{7}$$

Each time the mobile network moves from an AP region to another AP region, the TLMR will obtain a new care-of-address. In the time-saving sub-scheme, since all of home agents maintain the care-of-address of the TLMR in their binding caches, these addresses should be updated when the mobile network moves. In the standard location update process [23], each mobile router will send a BU message to its home agent, which contains the latest care-of-address of TLMR. Since the mobile network passes through *nmob* AP regions per unit time on average, the location update delay for the time-saving sub-scheme T_{TS}^{update} is calculated by the following equation, where S_B denotes the size of BU message (S_B=22 bytes in this paper),

$$T_{TS}^{update} = nmob\sum_{i=0}^{M-1}\left[\frac{S_B}{B_w} + \frac{S_B(LMR_i + 1)}{B_{wl}}\right]. \tag{8}$$

In the mobility-transparency sub-scheme, only the home agent of TLMR maintains the care-of-address of the TLMR. While other home agents maintain the home-address of TLMR, and the home-address will not change once obtained. As a result, only the home agent of the TLMR needs to be updated when the mobile network is moving. Let T_{MT}^{update} denote the location update delay for the mobility-transparency sub-scheme, which is calculated as follows,

$$T_{MT}^{update} = nmob\left(\frac{S_B}{B_w} + \frac{S_B}{B_{wl}}\right). \tag{9}$$

As a result, the difference of location update part between two sub-schemes $T_{TS}^{update} - T_{MT}^{update}$ is calculated as follows,

$$T_{TS}^{update} - T_{MT}^{update} = nmob\sum_{i=1}^{M-1}\left[\frac{S_B}{B_w} + \frac{S_B(LMR_i + 1)}{B_{wl}}\right]. \tag{10}$$

When the call-to-mobility ratio is very close to the optimal threshold μ, the time overhead of mobility-transparency sub-scheme equals to the time overhead of time-saving sub-scheme. Based on the Eq. (6), Eq. (7) and Eq. (10), we obtain the following equation,

$$ncall\left(\frac{S_P + 2S_H}{B_w} + \frac{S_H}{B_{wl}}\right) = nmob\sum_{i=1}^{M-1}\left[\frac{S_B}{B_w} + \frac{S_B(LMR_i + 1)}{B_{wl}}\right]. \tag{11}$$

In this situation, the optimal value of threshold μ equals to $ncall$ divided by $nmob$, which is calculated as the following equation. We will evaluate this theoretical result in section VI.

$$\mu = \frac{B_w B_{wl}\sum_{i=1}^{M-1}[S_B(LMR_i + 1)/B_{wl} + S_B/B_w]}{(S_P + 2S_H)B_{wl} + S_H B_w}. \tag{12}$$

V. Extension for Intra-domain Communication

The optimal route for inter-domain communication is achieved in the adaptive scheme. However, the intra-domain communication also needs to be optimized. For example in the scenario shown in Fig.2, the communication between the cell phone and the PDA should be limited inside the PAN. According to the transmission method defined by NBSP [2] (packets destined for a mobile router have to pass through the home agent at first), packets sent from the cell phone to the PDA have to pass through the home agent of the laptop at first. This means packets of intra-domain communication will be sent out of the mobile network, then sent back. These processes increase the end-to-end delay of intra-domain communication greatly. In this section, we extend the adaptive route optimization scheme for optimal intra-domain communication.

In a mobile network, if an MR can receive an RA message from another one, the MR which sends this RA message is called the parent mobile router [24]. The extended scheme requires that, each MR sends a local BU message which contains its CoA information to the parent mobile router. After receiving the local BU message, parent mobile router makes a record in the binding cache, then overwrites the CoA information with its own CoA. The local BU message will be transmitted upwards, until it arrives at the TLMR. Through this initialization process, each MR can construct the topology of its subnet. In the transmission process, when an MR receives some packets, the MR searches its binding cache for destinations. If there are corresponding entries, the MR will forward the received packets according to indications. Otherwise, the MR will send these packets to its parent mobile router.

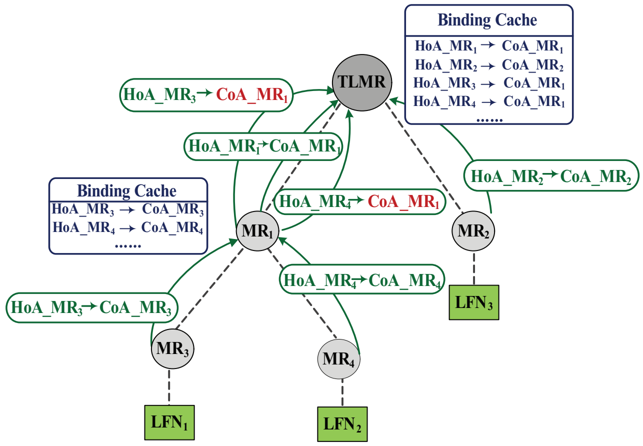


Fig. 8: Route optimization for intra-domain communication

In order to explain the extended scheme more clearly, we consider the scenario shown in Fig.8. In the initialization process, MR_3 puts the CoA_MR_3 into a local BU message, and sends this message to its parent mobile router MR_1. After receiving the local BU message, MR_1 makes a record in its binding cache. This record indicates that, MR_3 can be reached through CoA_MR_3. Then, MR_1 overwrites the CoA_MR_3 with CoA_MR_1, and sends the local BU message upwards. As the parent mobile router of MR_1, the TLMR will receive this local BU message. The local BU message indicates that, MR_3 can be reached through CoA_MR_1. In the routing process, if LFN_1 wants to send some packets to LFN_2, MR_3 will set the destinations to HoA_MR_4, then send these packets out. These packets will be received by MR_1. MR_1 checks its binding cache and finds out that, the destinations HoA_MR_4 can be reached through CoA_MR_4. According to this indication, MR_1 forwards these packets to MR_4 directly.

If the destination is LFN_3 instead of LFN_2, MR_3 will set the destinations to HoA_MR_2, then send the packets out. After receiving packets, MR_1 checks its binding cache for destinations. Since there is no corresponding record, MR_1 will forward these packets to its parent mobile router TLMR. There is a record maintained by TLMR, which indicates HoA_MR_2 can be achieved through CoA_MR_2. According to this indication, packets can be forwarded to their destinations.

As these examples indicate, the extended scheme can limit packets of intra-domain communication in a small scope. This achievement not only reduces the end-to-end delay of intra-domain communication, but also protects the data privacy [25] even though it will cost MRs some storage space.

VI. Performance Evaluation

In this section, we provide the performance evaluation with only adopting the mobility-transparency sub-scheme, the time-saving sub-scheme or the adaptive scheme at first. Then, we evaluate our theoretical derivations toward the optimal threshold μ. Thirdly, we compare the Adaptive Route Optimization Scheme (AROS) with the two existing schemes: the Network mobility Basic Support Protocol (NBSP) [2] and the Route Optimization scheme using Tree Information Option (ROTIO) [7]. The performance metric is the end-to-end delay.

Over a 400m $\times$ 400m rectangular flat space, we consider the typical inter-domain communication scenario and intra-domain communication scenario as shown in Fig.9. HA_i (i=0,1,2 $\cdots$) is the home agent of MR_i, MR_0 is the Top Level Mobile Router (TLMR) of the nested mobile network. As the mobile network moves, MR_0 will attach to different Access Points (APs). Based on the NS-3-UMIP [26], simulation experiments are repeated thirty times and the average result is presented with 95% confidence interval. Some important experimental parameters are presented in Table I.

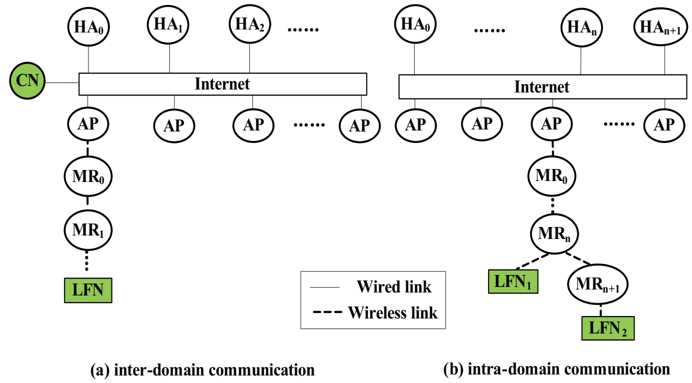


Fig. 9: Network topology for simulation

TABLE I: Experimental Parameters

Parameter	Definition
B_w	100 Mbps
B_{wl}	12 Mbps
Size of a packet	512 bytes
Simulation area	400*400 m^2
Simulation time	30 sec

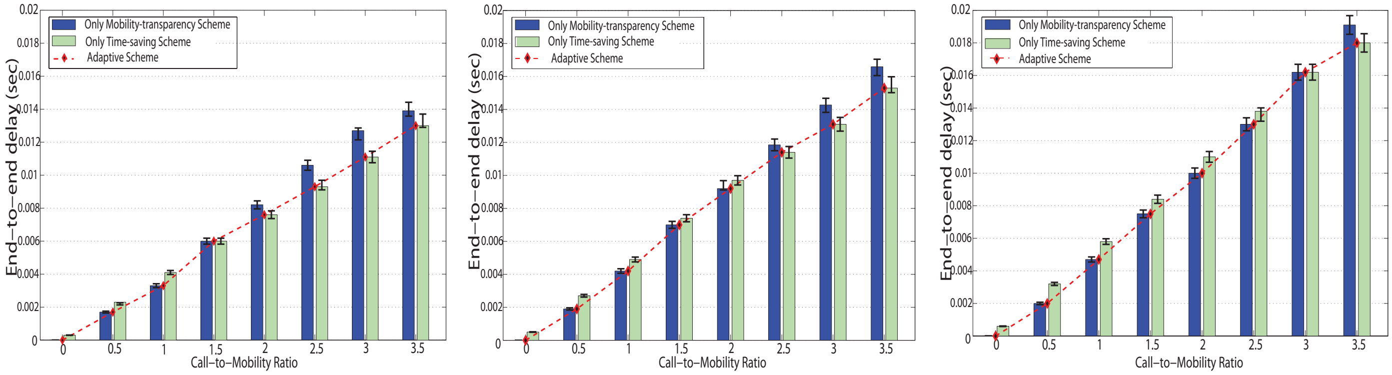
A. Comparison among Proposed Schemes

We compare the end-to-end delay of the only mobility-transparency scheme, the only time-saving scheme and the adaptive scheme for a serious of call-to-mobility ratios. In a scenario shown in Fig.9 (a), CN and LFN are the source and destination of an inter-domain communication respectively. We assume that the mobile network passes through two AP regions per unit time. We increase the nesting levels of LFN from 4 to 6, and calculate the end-to-end delay of the three schemes. Simulation results are shown in Fig.10.

As the value of call-to-mobility ratio varies from 0 to 3.5, the end-to-end delay of the only mobility-transparency scheme, the only time-saving scheme and the adaptive scheme are all increasing. The increase speed of the only mobility-transparency scheme is faster than the only time-saving scheme. When the call-to-mobility ratio is small, the only mobility-transparency scheme has less end-to-end delay. As the call-to-mobility ratio increases to a certain value, the only mobility-transparency scheme will incur higher end-to-end delay than the only time-saving scheme. According to our previous theoretical analysis, this certain value of call-to-mobility ratio equals to the optimal threshold. As Fig.10 shows, the adaptive scheme always has the minimum end-to-end delay.

B. Effects of the Threshold μ

We assume that the mobile network passes through two AP regions per unit time. Considering a scenario as shown in Fig.9 (a), where CN attempts to send some packets to LFN. LFN



(a) nesting levels of LFN = 4 (b) nesting levels of LFN = 5 (c) nesting levels of LFN = 6

Fig. 10: End-to-end delay of proposed schemes versus call-to-mobility ratio

locates at the 5th level of a nested mobile network. According to our previous theoretical derivations, we can calculate the optimal threshold μ (Eq.12) for this scenario. The value of the theoretical optimal threshold is 2.8689. We implement some simulation experiments to evaluate this theoretical value. The simulation results are shown in Fig.11.

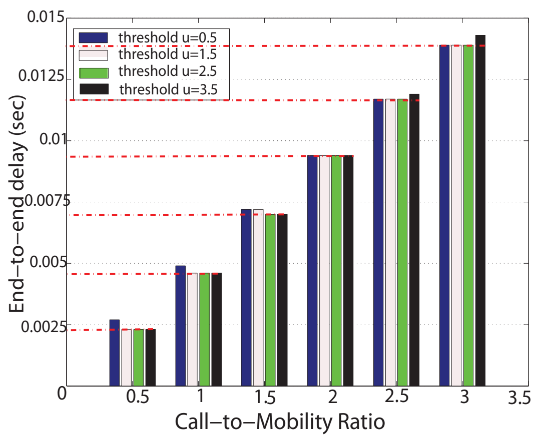


Fig. 11: End-to-end delay of the adaptive scheme for different thresholds

We calculate the end-to-end delay in the adaptive scheme for a series of thresholds. When the call-to-mobility ratio is smaller than 2, the end-to-end delay with the threshold value of 0.5 is larger than the results with the other three values. It means, 0.5 is not the optimal value of threshold. When the call-to-mobility ratio is 1.5, using 1.5 as the threshold is also suboptimal. When the ratio is larger than 2, setting the threshold to 3.5 will incur a higher end-to-end delay, so 3.5 is not the optimal value of threshold. Simulation results in Fig.11 indicate that the optimal threshold is close to 2.5, which accords with our theoretical deviations.

C. Comparison with NBSP and ROTIO

1) End-to-end Delay of Inter-domain Communication: We compare our proposed scheme AROS with two existing schemes NBSP [2] and ROTIO [7]. NBSP is the primary protocol of network mobility environment, and ROTIO is an effective protocol which makes use of the tree information option as AROS. We assume that the mobile network passes through two AP regions per unit time. Considering the scenario shown in Fig.9 (a), where CN wants to send some packets to LFN. We increase the nesting levels of LFN from 4 to 6, and calculate the end-to-end delay in AROS, NBSP and ROTIO for a series of call-to-mobility ratio. The simulation results are shown in Fig.12.

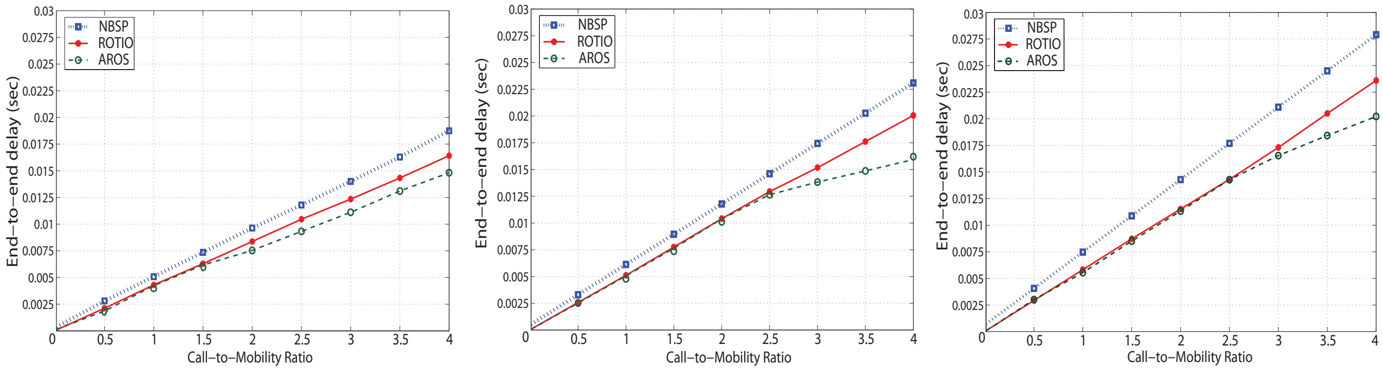
In NBSP, the number of passed HAs is proportional to the nesting levels of destination. As a result, the end-to-end delay in NBSP gets larger as the nesting levels of destination increase. While in ROTIO, since the HAs of intermediary MRs maintain the home-address of TLMR, packets only need to pass through two HAs no matter where the destination LFN locates at. This means in ROTIO, the transmission delay incurred by wired channel will not change when the nesting levels of destination increase. Therefore, the increase of end-to-end delay in ROTIO is smaller than in NBSP. In the proposed AROS, the number of passed HAs is one or two, which is less than ROTIO. As a result, AROS has the minimum end-to-end delay. As shown in Fig.12, after the call-to-mobility ratio increases to a certain value, the increasing speed of the end-to-end delay in AROS slows down. This is because AROS switches the adopted sub-scheme.

2) End-to-end Delay of Intra-domain Communication: Considering a scenario shown in Fig.9 (b), where LFN_1 wants to send some packets to LFN_2. We increase the nesting levels of MR_n, and compare the end-to-end delay in AROS, NBSP, and ROTIO. The comparison results are shown in Fig.13.

In NBSP, packets will be sent outside the mobile network at first, then pass through some HAs and be forwarded to LFN_2 at last. While in ROTIO, TLMR maintains the topology of the whole mobile network. Packets sent from LFN_1 will be sent to TLMR (MR_0) at first, and then forwarded to the destination LFN_2. As a result, the end-to-end delay in ROTIO is smaller than that in NBSP. In the proposed AROS, packets sent from LFN_1 to LFN_2 will be limited in the subnet of MR_n. Since the topology of MR_n subnet will not change during the simulation, the end-to-end delay in AROS is a fixed value. As Fig.13 shows, AROS always has the minimum end-to-end delay, and the value of end-to-end delay will not change when the nesting levels of MR_n are increasing.

VII. Conclusion

In this paper, we focused on addressing the route optimization problem for nested mobile IPv6 network mobility environment. The main contribution of this paper is to propose an adaptive route optimization scheme, which can alleviate the pinball routing problem effectively. Through theoretical analysis and simulation we demonstrated that, the proposed



(a) nesting levels of LFN = 4 (b) nesting levels of LFN = 5 (c) nesting levels of LFN = 6

Fig. 12: End-to-end delay of inter-domain communication versus call-to-mobility ratio

scheme can reduce the end-to-end delay of both intra-domain and inter-domain communications for nested mobile IPv6 network mobility environment significantly.

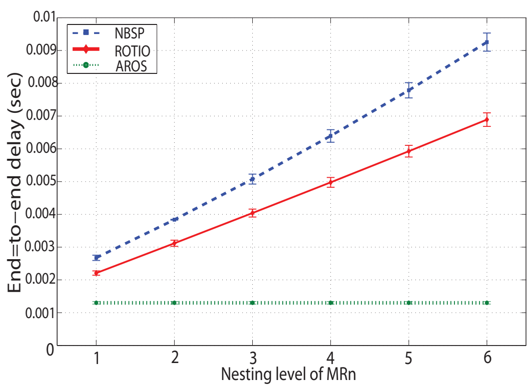


Fig. 13: End-to-end delay of intra-domain communication for different nesting levels

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