

Performance Analysis of Route Optimization Scheme in Proxy Mobile IPv6

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Abstract— This paper describes implementation details and performance comparison of route optimization scheme for Proxy Mobile IPv6 (PMIPv6). The implementation details presented in the paper leverages route optimization mechanism defined in [5], which is based on Mobile IPv6 and extends the procedures in order to apply for PMIPv6. We also show the analytical performance comparison result of route optimization scheme for PMIPv6.

Keywords— IPv6, Mobility, Proxy Mobile IPv6, Route Optimization

I. INTRODUCTION

The Proxy Mobile IPv6 (PMIPv6) protocol describes a mobility management solution without a mobile node's participation in mobility management related signaling process. The PMIPv6 document considers IPv6 home address mobility over IPv6 transport network. The IPv4 extension document specifies amendment so that it can support IPv4 home address mobility and IPv4 transport network [1][2].

The Mobile IPv6 and Enhanced Route Optimization specify route optimization procedures that allow a mobile node (MN) to register its binding information to a corresponding node (CN). The correspondent node can directly send and receive packets from the mobile node's care-of address by completing route optimization procedures. In PMIPv6, packets originated from or sent to a mobile node are routed through bidirectional tunnelling between Mobile Access Gateway (MAG) and Local Mobility Anchor (LMA) by default, thus packets from/to the mobile may be experience longer path than the optimized route, especially when the mobile node and a correspondent node are in topologically close location and local mobility anchor is away from the mobile node. Hence, route optimization is useful, when PMIPv6 domain spans large area. The function of route optimization is to enable the mobile node and the correspondent node to communicate through a path that is shorter than the path chosen by PMIPv6. The benefit of this

is a reduction in packet propagation delays, in bandwidth consumption and in congestion at local mobility anchor.

Mobility management signaling is exchanged among network entities in PMIPv6. Furthermore, the MN has home address (HoA) only, so care-of address (CoA) test in the MIPv6 route optimization is not directly applicable to PMIPv6. Route optimization solution for PMIPv6 which is leveraging route optimization procedures in MIPv6 was proposed in [5].

This paper shows the implementation result of route optimization mechanism in PMIPv6 that is proposed in [5]. We implemented the route optimization mechanism in Linux 2.6.10 kernel.

II. PROTOCOL SPECIFICATION OF ROUTE OPTIMIZATION FOR PMIPv6

This section describes implementation details of route optimization mechanism defined in [5]. Since route optimization requires support on the side of a correspondent node, application scenarios for route optimization can be separated into the following three cases. Figure 1 shows the application scenarios in PMIPv6.

- (1) MN and CN are attached to different MAGs, but they are anchored to the same LMA
- (2) MN and CN are anchored to the same LMA
- (3) CN supports Mobile IPv6 and handles route optimization by itself.

In this paper, we describe implementation result of route optimization mechanism that supports Scenario (1) only.

Figure 2 shows the initialization procedures of route optimization in PMIPv6. Route optimization procedures are initiated when MAG1 receives data packet sent from CN. After receiving data packet from CN, MAG1 sends a query to LMA by using CN's MAG Query Option in order to obtain the information about CN's corresponding MAG. Figure 3 depicts Mobility Option so that MAG queries CN's MAG information to LMA. Figure 4 shows query message using CN's address. LMA looks up its binding cache entry and LMA replies with MAG2's information. Figure 5 and Figure 6 show Mobility Option for LMA to reply and reply message format.

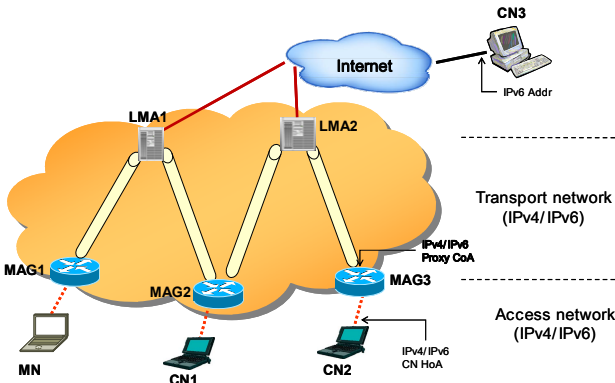


Figure 1. Typical Route Optimization Scenarios in PMIPv6

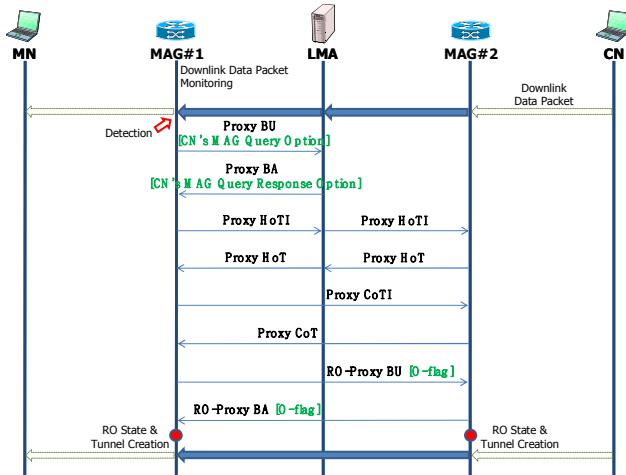


Figure 2. Flows for Route Optimization Signaling Message exchange

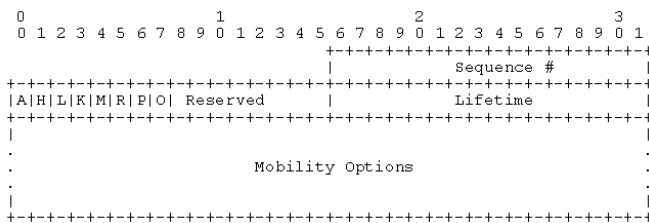


Figure 3. Format of Mobility Option for Querying CN's MAG

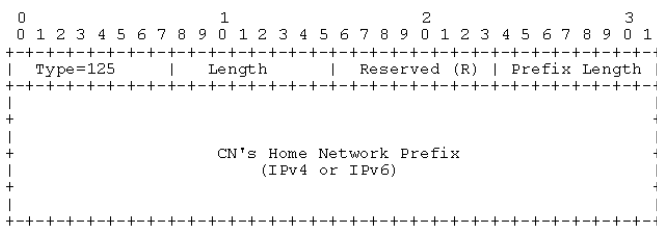


Figure 4. Format of Query Message for CN's MAG

Then, MAG1 starts return routability procedures. When MAG1 initiates return routability test between IPv6 MN and IPv6 CN, MAG1 sends HoTI and CoTI messages to MAG2 as defined in MIPv6 [3]. However, since MN does not have

care-of address in PMIPv6, MAG1 sets the source addresses of CoTI as its IPv6 Proxy CoA. Other parameters for authenticating the MN will be set same as MIPv6. In order to acquire information about which MAG serves the CN, MAG1 queries it to LMA before initiating return routability procedures.

In case of route optimization between IPv4-only MN and CN, they do not have IPv6 address for inner IPv6 header. So, the source and destination address of inner IPv6 header indicate IPv6 Proxy CoA of MAG1 and MAG2, respectively. Then, the IPv4 addresses of the MN and the CN are specified in the outer IPv4 header. Upon creating HoTI and CoTI message, MAG1 tunnels the messages to LMA. Since deciding which tunnel interface to be selected is based on MN's home address, MAG is required to forward packets whose destination address is anchored at LMA to IPv4 tunnel. After the successful return routability procedures, MAG1 and MAG2 create route optimization state and IP tunnel for packet transmission.

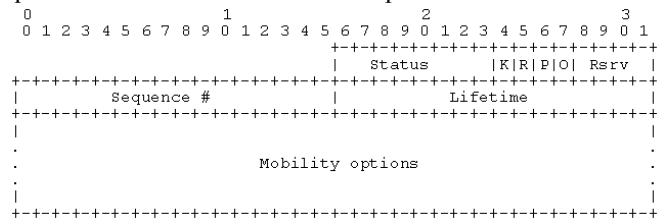


Figure 5. Format of Mobility Option for Replying CN's MAG

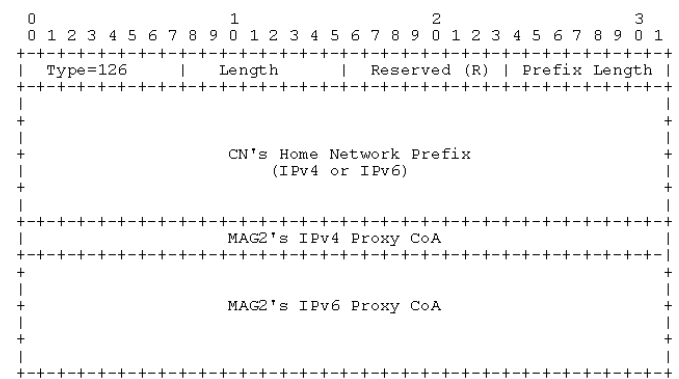


Figure 6. Format of Reply Message for CN's MAG

Figure 7 shows the handover procedures of route optimization in PMIPv6. When MN moves to a new MAG (MAG3), LMA informs the MAG1 of MN's handover by using RO State Cleanup Notify Message depicted in Figure 8. Then, MAG1 sends RO State Cleanup Request Message (Figure 9) to the old MAG (MAG2). MAG2 cleans up the RO state in its binding cache. When MAG3 receives downlink data packet from CN to MN, it initiates route optimization procedures as defined in Figure 2.

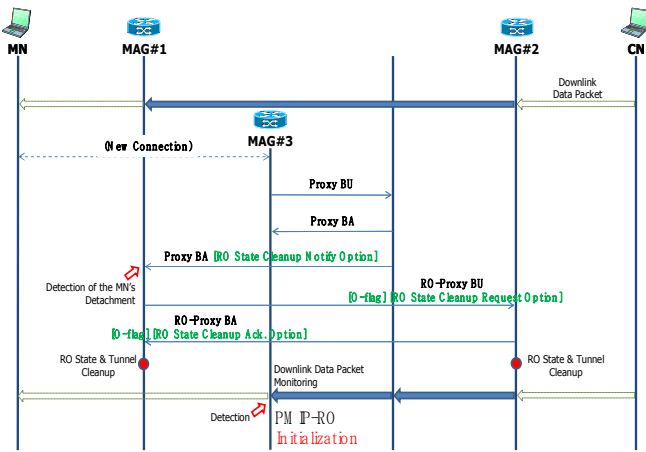


Figure 7. Flows for Route Optimization Handover Signaling Message exchange

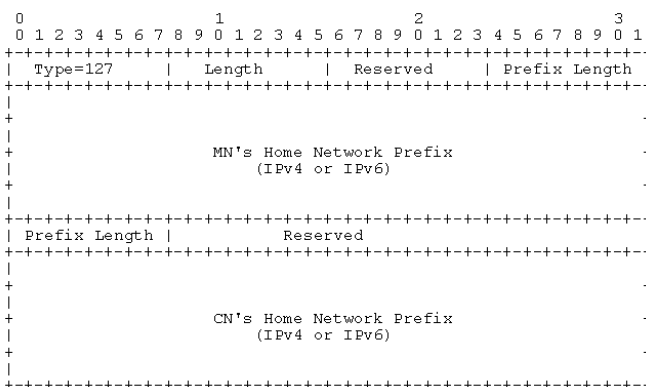


Figure 8. Format of Route Optimization State Cleanup Notify Message

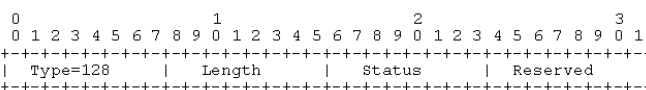


Figure 9. Format of Route Optimization State Cleanup Request Message

III. IMPLEMENTATION OF ROUTE OPTIMIZATION MECHANISM FOR PMIPv6

In this section, we present the implementation details of PMIPv6 route optimization mechanism. We implemented our proposed PMIPv6 route optimization mechanism by extending MIPv6-based PMIPv6 implementation. We ported MIPL MIPv6 code (ver. 2.0.2) to Linux 2.6.10. Then, we modified the MIPL code so as to support PMIPv6 specified in [1][2]. Our PMIPv6 implementation supports full functionality of MAG and LMA including IPv4 support function. Also, we implemented driver update for Link-Up in order to IEEE 802.11 link and network-side Link-Up Trigger in MAG. IEEE 802.11 EAP/MD5 authentication mechanism was used for authenticating MN and MD5/EAPoL and RADIUS are used for encrypt/decrypt algorithm. Hardware specification of MAG and LMA are as follows.

Table 1. Hardware Specification of MAG, LMA and MN

	MAG	LMA	MN
CPU	Intel Pentium 4, 3.00GHz	Intel Pentium 4, 3.00GHz	Intel Pentium 4, 1.80GHz, 1.6 GHz
Network adaptor	802.11 NIC: Linksys Dual-Band Wireless A+G, PCI Adapter WMP-55AG (Atheros Chipset)	PCI Adapter WMP-55AG (Atheros Chipset)	Mobile Intel Express Chipset
OS	Debian 3.1 sarge, kernel 2.6.10	Debian 3.1 sarge, kernel 2.6.10	Windows XP, SP2
Etc.		Free S/W Radius	VoD Streaming Software, VLC media server/client

Figure 10 shows packet filtering architecture for PMIPv6 route optimization mechanism. We extend Linux Netfilter module in order to distinguish route optimized data packets from regular PMIPv6 data packets. When MAG receives a data packet from CN, ro_hook module in the Linux kernel checks whether there exists a route optimization state for the source and destination address of the received packet. If no state exists, MAG initiates route optimization procedures. If there is route optimization state in MAG, the MAG forwards the received packet to MN.

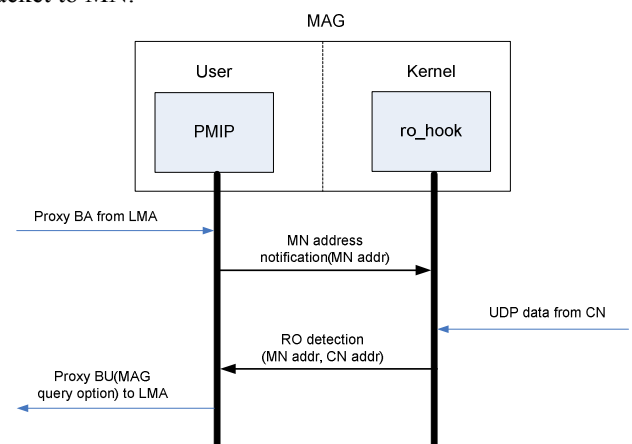


Figure 10. Packet Filtering Architecture for PMIPv6 RO Mechanism

IV. PERFORMANCE EVALUATION

In this section, we provide the performance evaluation result of our proposed route optimization scheme. The key performance parameters are the signaling cost and the packet transmission cost. Each cost can be denoted by SG_{cost} and TR_{cost} , respectively. So, the total cost, C_{total} , can be expressed by the sum of SG_{cost} and TR_{cost} . We use the hexagonal network architecture described in [6]. We assume that the LMD consists of the same number of MAGs. Each cell means an area of MAG and the number of cell in the ring R is $6r(r > 0)$. The innermost cell is called the center cell and it is denoted as 0. The cells labelled R formed around cell $R-1$. Therefore, the

number of cells in the R ring is calculated using the following equation [7]:

$$N(R) = \sum_{r=1}^R 6r + 1 = 3R(R + 1) + 1 \quad (1)$$

The location update cost consists of binding update cost occurred by exchanging proxy binding updates messages and route optimization signaling messages. We adopted the fluid-flow model that is generally used to evaluate the performance of mobility support protocol. The model is suitable for mobile nodes characterized by high mobility and static velocity [7]. Let R_c and R_L be the cell crossing rate and the LMD crossing rate, respectively. Then, the cell and the LMD crossing rate is calculated as following equations [7], [8]:

$$R_c = \frac{\rho v l}{\pi} \quad (2)$$

$$R_L = \frac{\rho v L}{\pi} = R_c(2R + 1) \quad (3)$$

where ρ represents the density of mobile nodes in a domain and v denote average velocity of mobile node. l and L denote perimeter of a cell and a LMD domain consisting of R rings, respectively. L is calculated as $(2R+1)l$ [8]. The signaling cost is proportional to the distance between two network elements. We assume that the distance can be derived from the number of hops and let $D_{x,y}$ be the distance between network element x and y . τ and κ is the unit of transmission cost for a wired link and wireless link, respectively [7]. Since the MAG sends the proxy binding update message on behalf of the mobile node, the transmission cost for a wireless link is not included in the signaling cost. Hence, the signaling cost for a mobile node can be expressed as follows:

$$SG_{\text{cost}}(\text{PMIPv6}) = \frac{2\tau D_{\text{MAG,LMA}} R_c n}{\text{Avg}_{\text{MN}}(R)} \quad (4)$$

And the signaling cost of our proposed scheme can be derived as follows.

$$SG_{\text{cost}}(\text{RO}) = \frac{(6\tau D_{\text{MAG,LMA}} R_c n) + (4\tau D_{\text{MAG,MAG}})(R_c n - R_L)}{\text{Avg}_{\text{MN}}(R)} \quad (5)$$

Therefore, the total cost can be calculated as follows.

$$T_{\text{cost}}(\text{PMIPv6}) = SG_{\text{cost}}(\text{PMIPv6}) * D_{\text{MAG,LMA}} \quad (6)$$

$$T_{\text{cost}}(\text{RO}) = SG_{\text{cost}}(\text{RO}) * D_{\text{MAG,MAG}} \quad (7)$$

To analyze the signaling costs in the PMIPv6 without and with proposed RO procedure, we set the system parameters used in diverse publications, listed in Table 1 [7], [8], [9]. Figure 11 shows the comparison of total cost between PMIPv6 and our proposed PMIPv6 route optimization scheme. As depicted in the figure, our proposed route optimization scheme shows better performance than PMIPv6 protocol from the total cost perspective.

Table 2. Performance analysis parameters

Parameters	Value
ρ	0.0002 MNs/m^2
v	28.9 m/s
l	120 m
τ/κ	1 / 2
$\lambda/\alpha/\beta$	0.1 / 0.3 / 0.7
$D_{\text{MAG,LMA}} / D_{\text{MAG,MAG}}$	16 / $\sqrt{n}$

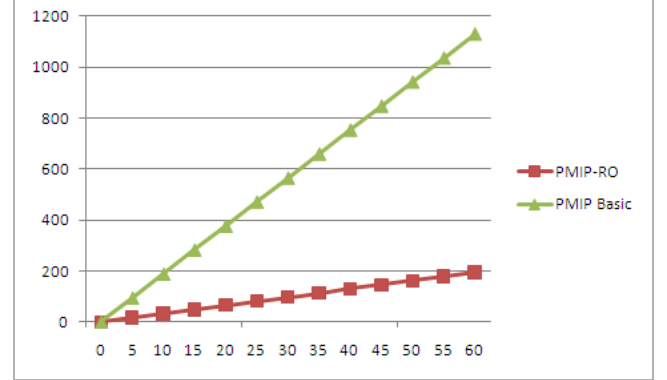


Figure 11. Total cost comparison between PMIPv6 and PMIPv6 RO

V. CONCLUSIONS

In this paper, we presented the implementation details of route optimization mechanism in PMIPv6, which is based on Linux platform. We have compared total cost between basic PMIPv6 with our route optimization mechanism and our route optimization scheme. Our performance comparison results are based on the analytical performance analysis of our proposed route optimization scheme for PMIPv6. We showed that our proposed scheme achieved better performance than the basic PMIPv6 that does not support route optimization mechanism.

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