Performance of Prefix Delegation-Based Route Optimization Schemes: Intra Mobile Network case

Abu Zafar M. Shahriar and Mohammed Atiquzzaman
School of Computer Science
University of Oklahoma, OK 73019, USA
Email: {shahriar, atiq}@ou.edu

William Ivancic
Satellite Networks and Architectures Branch
NASA Glenn Research Center, Cleveland, OH 44135, USA
Email: wivancic@grc.nasa.gov

***Abstract*—Among the route optimization schemes in NEtwork MObility (NEMO), the prefix delegation-based schemes perform better than other schemes. Since the prefix delegation-based schemes are designed for communication between a mobile network and a wired network, they lack evaluation for the case of intra mobile network communication involving MIPv6 incapable hosts in a mobile network. We evaluate prefix delegation-based schemes to reveal their inefficiencies for the case where both the communicating hosts are mobile and MIPv6 incapable, propose extensions, and compare them. Since both the communicating hosts are mobile, handoff latency in extended schemes are large resulting in significant performance loss when the speed of the mobile network is high. Results reveal that the effect of speed of the mobile network dominates the performance in such cases. We conclude that for slow moving mobile networks, extended schemes are preferable.**

I. Introduction

To efficiently manage mobility of multiple hosts, moving together, Internet Engineering Task Force proposed NEtwork MObility (NEMO) where mobile routers manage the mobility of hosts in a subnetwork called mobile network [1]. A mobile router, moved to a new network, obtains an address from the new network, and ensures reachability by sending the address to a router, called home agent, in the home network. NEMO Basic Support Protocol (BSP) [1] enables communication with the mobile network through a bidirectional tunnel between the mobile router and its home agent resulting in a *suboptimal route* incurring the problems of high header overhead and end-to-end delay [2]. The problems intensify in a nested mobile network, a mobile network attached to another mobile network. Route optimization schemes [3], [4] take various approaches to avoid tunnels, and the Prefix Delegation (PD)-based approaches perform better than the other approaches [4].

PD-based schemes obtain new addresses for Mobile IPv6 (MIPv6) [5] capable hosts in a mobile network while differing in optimizing route for MIPv6 incapable hosts (called Local Fixed Node (LFN)), and in the way addresses are obtained. Effects of the differences on throughput were evaluated for the case when an LFN communicates with a MIPv6 capable wired-network-host [6]. However, PD-based schemes lack evaluation for a case of intra mobile network communication [2] involving two LFNs. Evaluation of some non-PD-based schemes for the latter case is found in [2], [7]. Since peer hosts are MIPv6 incapable and mobile, effects of the differences are expected to be different than that were found in [6]. Therefore, our *aim* is to evaluate PD-based schemes for the intra mobile network case.

The work has been supported by NASA Grant NNX06AE44G.

To evaluate, we select three schemes - Simple Prefix Delegation (SPD) [8], MIPv6-based Route Optimization (MIRON) [9] and Optimal Path Registration (OPR) [10] that are representatives of PD-based schemes. LFNs' route is unoptimized in SPD causing high end-to-end delay due to packets going through home agents. This reduces throughput when mobile networks are away from the home. In MIRON and OPR, LFNs' route optimization fails for LFN-LFN communication because both are MIPv6 incapable. We *extend* MIRON and OPR to optimize route for LFN-LFN case by using mobile routers' MIPv6 capability. In extended schemes, handoff latency is high because communication after handoff cannot resume until the new address is received, and consequent reduction of throughput is significant at high speed of the mobile network. Thus, throughput is not obvious for various speeds of the mobile network and its distances from home agent, and so, we perform a quantitative performance *comparison*.

Our *contributions* are: (i) extension of MIRON and OPR, and (ii) comparison of the schemes. We find that extended schemes perform better at low speeds and nesting levels. Unlike that in [6], performance of extended schemes degrades at a faster with increasing speed, and SPD performs better than MIRON at high speeds at any distance. Results of this research and those presented in [6] will help to select a suitable route optimization scheme for NEMO.

The rest of the paper is organized as follows. Sec. II summarizes NEMO followed by an overview of three PD-based schemes in Sec. III. Inefficiencies and the extensions of the schemes, and their analysis is presented in Sec. IV. Simulation results are discussed in Sec. V followed by concluding remarks in Sec. VI.

II. NEMO

In this section, we summarize NEMO architecture and BSP.

A. NEMO Architecture

Fig. 1 shows the architecture of a mobile network [1]. Mobile Routers (MRs) are gateways for the nodes in the mobile network each called a Mobile Network Node (MNN).

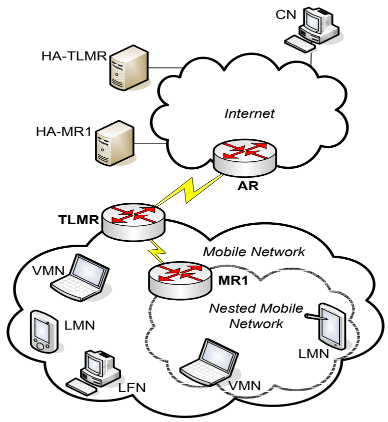

Fig. 1. Architecture of a mobile network.

Different types of MNNs are - a Local Fixed Node (LFN) that does not move with respect to the mobile network, a Local Mobile Node (LMN) that usually resides in the mobile network and can move to other networks, and a Visiting Mobile Node (VMN) that gets attached to the mobile network from another network. An MR attaches to another MR to form a nested mobile network. The MR, directly attached to the wired network through an Access Router (AR), is called Top Level MR (TLMR) while MR1 is nested under TLMR.

A mobile network is usually connected to the home network where an MR is registered with a router called Home Agent (HA). In Fig. 1, HA-TLMR and HA-MR1 are the HAs for TLMR and MR1, respectively. A Correspondent Node (CN) communicates with MNNs through HAs.

B. NEMO BSP

An MR gets a prefix in its home network to advertise to MNNs that obtain addresses, called Home Addresses (HoA), from the prefix. Packets sent using the HoA reach the HA that forwards the packets to the mobile network in home. When a mobile network moves to a foreign network, the MR obtains a new address called Care-of-Address (CoA) from the prefix of the foreign network, and sends a Binding Update (BU) to the HA informing the CoA. The HA intercepts packets sent to MNN's, and tunnels them to MR. Since a mobile network, nested under another mobile network, obtains the CoA from the prefix of the mobile network above, packets first go to the HA of the nested mobile network and then to the HA of the mobile network above. Thus, packets are tunneled through multiple HAs resulting in suboptimal route and header overhead. Therefore, route optimization schemes, based on various approaches, have been proposed.

III. PD-based Route Optimization Schemes

In PD-based schemes, MNNs obtain CoAs from the prefix of the foreign network, and notifies the CN that creates Binding Entries (BEs) mapping HoAs to CoAs. Like MIPv6 route optimization [5], CN uses the CoA to send packets that reach the foreign network without going through HAs. Based on variations of PD-based schemes in CoA obtention process and LFNs' route optimization, we selected three schemes as follows.

A. Simple Prefix Delegation (SPD)

In SPD [8], MRs are delegated a prefix, aggregated at foreign network's prefix, to advertise to MNNs for obtention of CoAs to perform MIPv6 like route optimization [5]. Being MIPv6 incapable, LFNs cannot perform route optimization resulting in packets to be tunneled through their HAs.

B. Optimal Path Registration (OPR)

In OPR [10], only MRs obtain CoAs from the delegated prefix. To optimize route for MNNs, MRs translate addresses of packets into new addresses using the delegated prefix, put the original address in OPR header [10], and use the OPR header to notify the translated address to CN. CN uses the translated address to send packets to an MNN through optimized route. Unlike SPD, OPR optimizes route for LFNs.

C. Mobile IPv6-based Route Optimization (MIRON)

In MIRON [9], an MR, after obtaining a CoA, notifies attached MNNs (except LFNs) to obtain a CoA. An MNN sends a request which is relayed to the foreign network. A reply with a CoA configured from foreign network prefix is sent to the MNN. For LFNs' route optimization, MRs' CoAs are used to communicate with CNs.

IV. PD-based Schemes for Intra Mobile Network Communication

This section presents inefficiencies, proposed extensions, and a qualitative performance analysis of the schemes.

A. Inefficiencies of PD-based schemes

We consider LFN-LFN communication because that for VMNs/LMNs are efficient. In SPD, packets travel through HAs of both LFNs resulting in higher end-to-end delay than that in LFN-CN communication. In OPR, LFNs, being transparent to mobility, will not recognize the OPR header whereas in MIRON, BU sent to an LFN will not be recognized resulting in failure of the notification of the CoA. Moreover, in OPR, failure to get the original address of the LFN will result in communication to cease. However, communication can continue in MIRON like in SPD. Thus, none of the schemes can optimize route for LFN-LFN communication.

B. Extension of the PD-based schemes

SPD does not optimize LFNs' route while MIRON and OPR does. We extend the route optimization procedure of OPR and MIRON for LFN-LFN communication, and explain below for LFN1-LFN2 (see Fig. 2) communication.

1) Extension for OPR (xOPR): In OPR, the first packet, sent by LFN1 to LFN2, will reach MR4 through the HA_MR4. In extended OPR, MR4 will process (like CN) the OPR header in the packet to create BE that maps address (address of LFN1) in OPR header to the source address (translated address of LFN1) of the packet. When an outgoing packet (from LFN2 to LFN1) is received, MR4 search the BE to find the translated address of LFN1, puts the destination address of the packet into Routing Header Type 2 (RH2) header, and replaces the destination address with the translated address. Since the translated address is obtained from the foreign network's prefix, the packet reach LFN1 without traversing HAs.

2) Extension for MIRON (xMIRON): When a packet (from LFN1 to LFN2) is received, MR2 puts its CoA in the source address field whose content is put into Home Address destination Option (HAO), and forwards the packet that will reach MR4 through HA_MR4. At reception of the packet, MR4 (LFN2's MR) adds the source address of the packet in the BU list, replaces the source address with address in HAO which is removed from the packet, and forwards the packet to LFN2. BU, sent from MR4 on behalf of LFN2, will reach MR2 that will create a BE that maps LFN2's address to CoA of MR4. MR2 will forward subsequent packets, from LFN1 to LFN2, by replacing destination address with the CoA from the BE along with putting the destination address into RH2. Since the destination of packets is the CoA of MR4, packets will be routed by the MRs (without going outside the mobile network) to MR4 which will forward the packets to LFN2 after replacing the destination address with the address in RH2 which is removed.

C. Performance analysis of the schemes

Since packets in SPD are routed through HAs, end-to-end delay increases with increasing distance between the mobile network and its HA. In xMIRON and xOPR, end-to-end delay is independent of the distance because packets are routed within the mobile network. Thus, TCP throughput, being inversely proportional to end-to-end delay, is different for the schemes when the mobile network is away from its HA.

Route optimization for LFNs affects handoff latency that affects throughput. In SPD, MR tunnels packets using its CoA and the address of HA. Since the address of HA is always available, packets, tunneled after MR obtains a new CoA, can reach the destination. Packets tunneled using old CoA are discarded due to ingress filtering. In xMIRON and xOPR, an MR searches a BE for the CoA which is, if found, put as the destination address. Otherwise, the packet is forwarded with its original destination address. Therefore, as long as the BE containing the old CoA is not updated or deleted after the handoff, packets are sent using the old CoA as destination address. These packets are dropped because the CoA is no longer in use. Thus, handoff latency of the extended schemes can be different than that of SPD. The difference can result significant variation in the throughput when frequency of handoff (i.e. speed of mobile network) increases.

A quantitative evaluation of the effects of the differences is performed in Sec. V.

V. Performance Evaluation

To evaluate, we simulated SPD, xOPR and xMIRON in ns-2 (http://www.isi.edu/nsnam/ns/). Simulation environment, analysis of the results and a comparative discussion are presented in the following subsections.

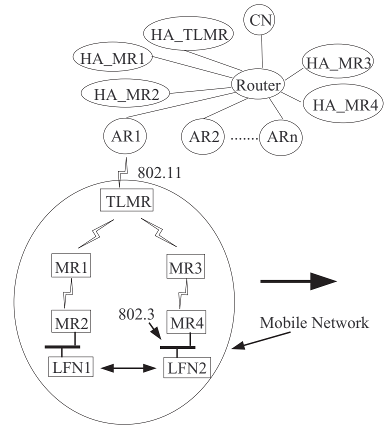

Fig. 2. Topology used for simulation.

TABLE I
Values of parameters used in the simulation.

Parameter	Value
Simulation time	360s
Wired link BW	10Mbps
BE lifetime for SPD and xMIRON	10s
BE lifetime for xOPR	5s

A. Simulation Environment

Fig. 2 shows the topology used in simulation. LFN1 is an FTP source over TCP whereas LFN2 is a TCP sink. The mobile network moved between ARs, placed in a horizontal line. Wireless links use IEEE 802.11b (11Mbps) whereas Ethernet (10Mbps) was used for mobile networks. Other values of parameters used in the simulation are presented in Table I.

B. Results

We measured (at 95% confidence level) end-to-end delay, handoff latency, and throughput at different speeds and delays between the HA and the mobile network. Throughput was measured by the amount of data received at LFN2. Since LFN-LFN communication is not possible in OPR, and MIRON's performance is similar to SPD for LFN-LFN communication, we show results for SPD, xMIRON and xOPR.

1) End-to-end delay and throughput without handoff: End-to-end delay between LFN1 and LFN2 is shown in Fig. 3. With the increase of delay between Router and HA, end-to-end delay for SPD increases while that of the other schemes is unaffected. Since SPD does not optimize route, packets reach LFN2 through HAs causing the end-to-end delay to be dependent on the Router-HA link delay. Other schemes optimize route enabling packets to be routed to LFN2 without going through the HAs, and consequently, end-to-end delay is unaffected by the delay. End-to-end delay in SPD is higher because of the same reason. Since the TCP throughput is inversely proportional to end-to-end delay, the characteristics of the throughput, shown in Fig. 4, follows from that of end-to-end delay.

2) Handoff latency: Events constituting the handoff latency are presented in Fig. 5, and explained below.

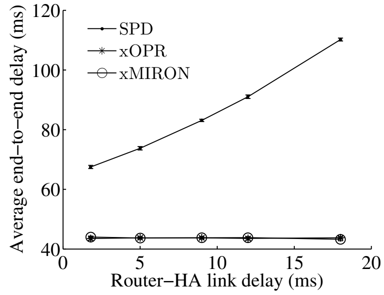

Fig. 3. End-to-end delay between LFN1 and LFN2.

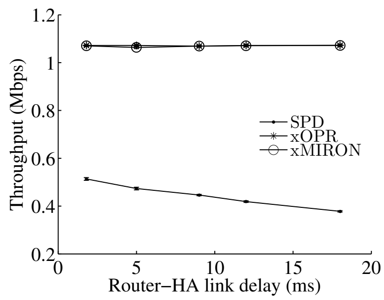

Fig. 4. Throughput of different schemes without handoff.

a) SPD: Due to suspension of flow of packets during the handoff, the first packet after obtention of the CoA is sent when TCP reaches the next timeout. Therefore, handoff latency, $(t_e - t_s)$ = time to detect AR by TLMR since the last packet received at MR4 + time to propagate AR's prefix to MR4 + delay for TCP to reach the next timeout + delay for the packet to reach MR4 = $(t_d - t_s)$ + $(t_c - t_d)$ + $(t_o - t_c)$ + $(t_e - t_o)$.

On the average, $(t_d - t_s)$ is constant with respect to nesting level with a maximum value of just over 2.3 seconds which is the expiration time for an AR's liveliness. $(t_c - t_d)$ and $(t_e - t_o)$ are proportional to the nesting level, and is in the order of milliseconds. The rest of the handoff latency is due to $(t_o - t_c)$ which is small if $(t_c - t_s)$ is small, and can be exponentially large, otherwise. For SPD, small $(t_c - t_s)$ incurs a small handoff latency (Fig. 6).

b) xOPR: Packets sent during handoff cannot reach destination until BE is updated or deleted (see Sec. IV-C). BE at MR2 is updated when a packet arrives from MR4 which is also awaiting a BE update resulting in a deadlock. When the BE-lifetime (5 seconds) expires, MR2 forwards packets without modifying the destination address (HoA of LFN2), and packets reach MR4 via HA_MR4 to break the deadlock.

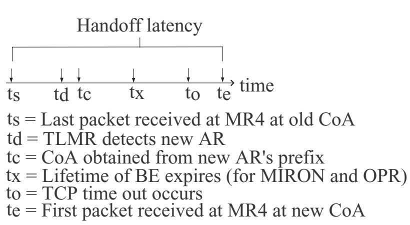

Fig. 5. Events that occur during handoff.

Since BE-lifetime is updated whenever a packet is received, $(t_x - t_s)$ is always 5 seconds, which is much greater than $(t_c - t_s)$. Therefore, handoff latency, $(t_e - t_s)$ = time to expire BE-lifetime + delay of TCP to reach the next timeout + delay for the packet to reach MR4 = $(t_x - t_s)$ + $(t_o - t_x)$ + $(t_e - t_o)$ = 5 + $(t_o - t_x)$ + $(t_e - t_o)$. Hence, handoff latency is more than 5 seconds (Fig. 6) which is larger than that of SPD.

c) xMIRON: Like xOPR, deadlock occurs because BU, sent to old CoA, cannot reach MR2 whereas MR4 cannot send a BU to new CoA of MR2 until it receives a packet from MR2 at the new CoA. Like xOPR, deadlock is broken when MR4 receives a packet via HA_MR4.

BE-lifetime is refreshed at reception of BU, received at or before t_s; therefore, $(t_x - t_s)$ can be between 0 to 10 seconds which is the BE-lifetime. Thus, when $(t_c - t_s) > (t_x - t_s)$, handoff latency, $(t_e - t_s)$ = Time to detect AR by TLMR since the last packet received at MR4 + time to propagate AR's prefix to MR4 + delay for TCP reaches the next timeout + delay for packets to reach MR4 = $(t_d - t_s)$ + $(t_c - t_d)$ + $(t_o - t_c)$ + $(t_e - t_o)$. Otherwise, handoff latency, $(t_e - t_s)$ = Time to expire BE since reception of last packet + delay of TCP reaches the next timeout + delay for the packet to reach MR4 = $(t_x - t_s)$ + $(t_o - t_x)$ + $(t_e - t_o)$.

Since $(t_x - t_s)$ is uniformly distributed between zero and ten, average $(t_e - t_s)$ is expected to be around five. This is not true because large values of $(t_x - t_s)$ make $(t_o - t_x)$ exponentially large, and hence, the average handoff latency (Fig. 6) is much larger than five.

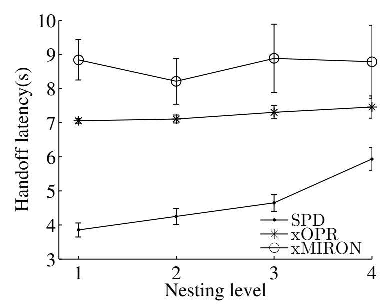

Fig. 6. Handoff latency of the schemes.

3) Throughput vs speed: Fig. 7 shows the throughput for different nesting levels. Throughput of SPD is low because of high end-to-end delay. At high nesting levels, throughput of xOPR and xMIRON is close to that of SPD due to increase in the number of wireless hops that start to dominate the effect of unoptimized route.

Throughput decreases with increasing speed due to increasing number of handoffs causing packet loss. For SPD and xMIRON, the rate of decrease is the smallest and the largest, respectively because of the smallest and the largest handoff latency. At high speeds, throughput loss due to handoffs dominates the loss due to high end-to-end delay resulting in throughput of xMIRON to fall below that of SPD. Throughput of xOPR is close to that of SPD due to high handoff latency which is not high enough to bring the throughput below that of SPD even at high speeds.

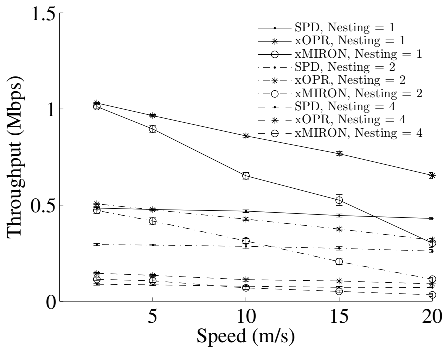

Fig. 7. Throughput for various nesting level.

4) Throughput vs mobile network's distance from HA: Fig. 8 presents the throughput as a function of Router-HA link delay. Throughput of SPD decreases with increasing Router-HA link delay while that of xMIRON and xOPR are unaffected (Fig. 4). At low speeds, throughput of SPD is the smallest because of the high end-to-end delay. At high speeds, loss of throughput due to handoff latency dominates even at high Router-HA link delay resulting in the lowest throughput for xMIRON. xOPR has the highest throughput because of small end-to-end delay and handoff latency which is not much larger than that of SPD. At low speeds, xMIRON's throughput is a little less than that of xOPR because of the reason explained below. In xOPR, packets can be sent through the optimized route after the first packet is received after handoff. In xMIRON, after reception of the first packet following a handoff, packets cannot be sent through the optimized route until the BU is sent to the peer when the next event for sending BUs triggers.

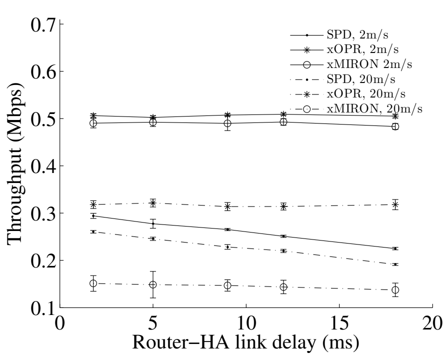

Fig. 8. Throughput for two extreme speeds.

C. Comparative discussion

From the results presented in Sec. V-B, xOPR appears to be the best; xOPR, however, needs packets to flow in both direction for route optimization. xMIRON performs better than SPD when nesting level is low except at very high speed. At high nesting levels, performance of the schemes are similar, and xMIRON performs the worst at speeds above 7.5 m/s.

Performance of xOPR and xMIRON degrades faster (unlike [6]) than that of SPD due to high handoff latency which can be lowered using small BE-lifetime. However, small lifetime increases signaling and processing at MRs. In xOPR, lifetime has to be set considering the interval of packet reception to avoid unnecessary expiration. If interval of unidirectional packet flow is high, lifetime has to be high resulting in high handoff latency. BE-lifetimes can be set through BU.

xMIRON uses a feasible CoA obtention process whereas CoA obtention by prefix delegation through router advertisement in xOPR and SPD might not be easily applicable due to accounting, authentication and security requirements [11]. Moreover, xMIRON and xOPR requires additional processing and memory.

VI. Conclusion

In this paper, we evaluated the performance of PD-based schemes for intra mobile network communication. We simulated three schemes, namely SPD, xMIRON and xOPR, and measured end-to-end delay, handoff latency and throughput under various speeds at different delays from the HA. Results show that xOPR performs the best, limited due to its inability to optimize route when packets do not flow in both directions. xMIRON, having a feasible solution for CoA obtention, performs better at low speeds. SPD, with the advantage of requiring less resources, is a good choice at high speeds. In addition, the performance loss in xMIRON due to speed dominates over performance loss in SPD due to distance from HA. Overall, xOPR and xMIRON are preferable to SPD at low speed, and vice versa.

References

[1] V. Devarapalli, R. Wakikawa, A. Petrescu, and P. Thubert, "NEtwork MObility (NEMO) basic support protocol," RFC 3963, Jan. 2005.

[2] M. Watari, T. Ernst, and J. Murai, "Routing optimization for nested mobile networks," *IEICE Transaction on Communication*, vol. E89-B, no. 10, pp. 2786–2793, Oct. 2006.

[3] C. Ng, F. Zhao, M. Watari, and P. Thubert, "Network mobility route optimization solution space analysis," RFC 4889, Jul. 2007.

[4] H. Lim, D. Lee, T. Kim, and T. Chung, "A model and evaluation of route optimization in nested NEMO environment," *IEICE Transaction on Communication*, vol. E88-B, no. 7, pp. 2765–2776, Jul. 2005.

[5] D. B. Johnson, C. E. Parkins, and J. Arkko, "Mobility support in IPv6," RFC 3775, Jun. 2004.

[6] A. Z. M. Shahriar and M. Atiquzzaman, "Evaluation of prefix delegation-based route optimization schemes for NEMO," in *IEEE International Conference on Communication*, Dresden, Germany, Jun. 14-18, 2009.

[7] S. Baek, J. Yoo, H. Cho, Y. Choi, T. Kwon, and E. K. Paik, "Route optimization for intra communication of a nested mobile network," in *Workshop on Networking in Public Transport*, Waterloo, Ontario, Canada, Aug. 10, 2006.

[8] K. Lee, J. Park, and H. Kim, "Route optimization for mobile nodes in mobile network based on prefix delegation," in *IEEE 58th Vehicular Technology Conference*, Orlando, Florida, USA, Oct. 6-9, 2003, pp. 2035–2038.

[9] M. Calderon, C. J. Bernardos, M. Bagnulo, I. Soto, and A. de la Oliva, "Design and experimental evaluation of a route optimization solution for NEMO," *IEEE Journal on Selected Areas in Communications*, vol. 24, no. 9, pp. 1702–1716, Sep. 2006.

[10] H. Park, T. Lee, and H. Choo, "Optimized path registration with prefix delegation in nested mobile networks," in *International Conference on Mobile Ad-hoc and Sensor Networks*, Wuhan, China, Dec. 13-15, 2005.

[11] S. Miyakawa and R. Droms, "Requirements for IPv6 prefix delegation," RFC 3769, Jun. 2004.