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Performance Analysis of Prefix Delegation-Based Route Optimization Schemes: Effects of increasing the Number of Nodes

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Abstract Prefix delegation-based schemes have been proposed to solve the route optimization problem in NEtwork MObility (NEMO) where multiple IP-enabled hosts move together as a mobile network. Differences in the route optimization for hosts at the cost of increased signaling will result in performance difference of the schemes depending on parameters, such as speed of the mobile network, its distance from the home network (the network to which mobile network usually belongs), and the number of hosts in the mobile network. Although the effects of the first two parameters on the performance of the schemes have been studied, effects of increasing the number of hosts have not been studied. Therefore, there is a need to evaluate performance when the number of hosts is increased. We perform the evaluation through ns-2 simulation. Results show that the performance superiority achieved by the hosts' route optimization is only affected by the distance significantly only when the number of hosts is small. The results will help to decide when to use the route optimization for hosts depending on the values of the parameters.

1 Introduction

NEtwork MObility (NEMO) [1] was proposed to efficiently manage the mobility of a group of hosts moving together, such as hosts in a vehicle. In NEMO, hosts are in a subnetwork called mobile network with mobile routers managing the mobility on behalf of the hosts [1]. A mobile router, moved to a new network, obtains a new address from the prefix of the new network to use as

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the location identifier, and ensures reachability by informing the location to a router, called home agent, in the home network where the mobile network usually resides.

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* that incurs the problems of large header overhead and end-to-end delay [2]. The problems intensify when a mobile network attaches to another mobile network to form a nested mobile network. Therefore, route optimization has been the active area of research in NEMO. To solve the problems, route optimization schemes [3–5] proposed in the literature take various approaches to avoid packets going through home agents. A comparison of the approaches shows that the prefix delegation-based approach, where addresses are obtained from new network's prefix, performs better than other approaches [4]. Therefore, we concentrate on further analysis of the performance of the prefix delegation-based schemes.

Prefix delegation-based schemes differ in optimizing routes of some mobile network hosts to result in different Round Trip Time (RTT) when the mobile network is away from the home agent. Since TCP throughput is inversely proportional to the RTT, the throughput of the schemes that optimize routes for hosts is expected to be better than that of those not optimizing routes. The difference also yields variation in the number of signaling depending on the number of hosts in the mobile network and its speed i.e. handoff frequency. Signaling packets compete for bandwidth with data packets. Thus, throughput of the scheme generating a larger amount of signaling is expected to be smaller than that of the others, as the number of hosts and the speed increase. Therefore, throughput characteristics of the schemes need to be evaluated as a function of the parameters, such as the speed of a mobile network, its distance from home agent, and the number of hosts in the mobile network.

In our previous work [6], we compared the throughput of three prefix delegation-based schemes [7–9] in terms of the speed of the mobile network and its distance from the home network. However, the comparison does not consider the potential effects of increasing the number of hosts in a mobile network. In this paper, our *goal* is to compare the throughput of those schemes as a function of the number of hosts in the mobile network at various speed of the mobile network and its distance from the home network. Since the scheme proposed in [9] optimizes route for hosts using the smallest number of signaling, the performance of this scheme sets the upper limit for the performance that can be achieved by optimizing routes for hosts. The two schemes proposed in [7, 8] demonstrate the performance comparison for trading off route optimization for hosts with additional signaling.

Our *contributions* are: (i) comparison of throughput of the schemes in terms of the parameters mentioned above, and (ii) *novel* results demonstrating the effectiveness of route optimization for hosts as a function of the number of hosts in a mobile network. Results show that the mobile network's distance from the home agent determines the performance superiority of the schemes only when the number of hosts is small. Increasing the number of hosts reduces the performance difference achieved by the use of route optimization for hosts. Results demonstrate that at high speed additional signaling used for hosts' route optimization causes the throughput to be lower than what is expected. Results of this research will help network designers to decide when to use the route optimization for hosts based on the given values of the parameters. Results also suggest that route optimization for hosts can be dynamically activated by the mobile router depending on the values of the parameters.

The rest of the paper is organized as follows. Related works on evaluation of route optimization schemes in NEMO are presented in Sec. 2. Sec. 3 summarizes NEMO followed by an overview of the selected prefix delegation-based route optimization schemes and their differences in Sec. 4. Details of simulation and results are presented in Sec. 5. Sec. 6 reveals other advantages and disadvantages of the schemes that are not revealed in the simulation. Finally, Sec. 7 puts forth concluding remarks.

2 Related works

There have been a number of research works on route optimization in NEMO. An overview of the research can be found in [3–5, 10]. Perera et al. [10] survey few route optimization schemes, and present issues related to NEMO research. In [4] Lim et al. present a classification of route optimization schemes and an analytical model-based evaluation of the classes. The models presented in [4] capture the general characteristics of each class, and therefore, cannot compare among the schemes within each class. Ng et al. [3] provide a classification similar to that given in [4]. In [5], we provide an overview and classification of state-of-the-art in NEMO route optimization along with qualitative evaluation among classes as well as among individual schemes within each class.

The qualitative evaluation presented in [5] helps to anticipate the performance of the schemes. But qualitative evaluation does not provide the exact performance required to select a scheme depending on the values of the parameters mentioned earlier. Therefore, it requires a quantitative performance evaluation of the schemes. Since results presented in [4, 5] reveal the performance superiority of the prefix delegation-based schemes, we evaluate those schemes. In [11,12], we evaluated the performance of the prefix delegation-based schemes in terms of the end-to-end delay, memory consumption, and amount of signaling. The simulation-based validation of the evaluations uses only one node in the mobile network and constant bit rate data sources. However, [11, 12] do not evaluate the effects of the end-to-end delay and the signaling on the Transmission Control Protocol (TCP) throughput when the number of nodes in the mobile network increases. In addition, evaluations do not consider the effects of the mobility of the mobile network. Since the majority of the traffic in the Internet is carried by the TCP, it is imperative to compare the TCP throughput of the schemes. Also, the effect of mobility needs to be evaluated.

In [6,13], we evaluated the TCP throughput of three prefix delegation-based schemes as a function of the speed of the mobile network and its distance from the home network. The comparison was performed for fixed hosts in a mobile network because the schemes differ in optimizing the routes for fixed hosts (later referred as LFNs). However, the evaluation performed in [6, 13], and other existing evaluations in the literature do not consider the effects of increasing the number of hosts in the mobile network. As we found in [11, 12], increasing the number of fixed hosts will increase the signaling for schemes like the one proposed in [8] that optimize routes for fixed hosts at the cost of additional signaling. The TCP throughput reduction from the signaling might dominate the throughput reduction from using an unoptimized route depending on the number of hosts, speed of the mobile network, and its distance from the home network. Therefore, this paper evaluates the combined effects of the speed, distance from the home network, and the number of hosts on the TCP throughput that can be achieved using the schemes. The differences of this work from that in [11, 12] are the evaluation of the TCP throughput and the inclusion of the mobility as an evaluation parameter. The difference of this work from those in [6, 13] is the evaluation of the effects of increasing the number of LFNs.

3 NEMO

In this section, we briefly summarize NEMO architecture and NEMO BSP that will help to understand the prefix delegation based route optimization schemes presented in Sec. 4.

3.1 NEMO Architecture

Fig. 1 shows the architecture of a mobile network to manage the mobility of the nodes as a network [1]. One or more routers called Mobile Router (MR) are employed to act as gateways for the nodes in the network. There could be different types of nodes inside the mobile network each called a Mobile Network Node (MNN). Different types of MNNs are - Local Fixed Node (LFN) that does not move with respect to the mobile network, Local Mobile Node (LMN) that usually resides in the mobile network and can move to other networks, Visiting Mobile Node (VMN) that get attached to the mobile network from another network, and MR that can be an MNN to form a nested mobile network. A nested mobile network of multiple levels is formed when an MR attaches to another MR. The MR which is directly attached to the wired network is called Top Level MR (TLMR) while MR1 is an MNN in TLMR's mobile network forming a nested mobile network. MRs attach to the Internet through Access Routers (ARs).

The network to which a mobile network is usually connected is called the home network. In home network, an MR is registered with a router called Home Agent (HA) that performs location tracking and packet re-direction for MNNs. In Fig. 1, HA-TLMR and HA-MR1 are the HAs for the mobile routers

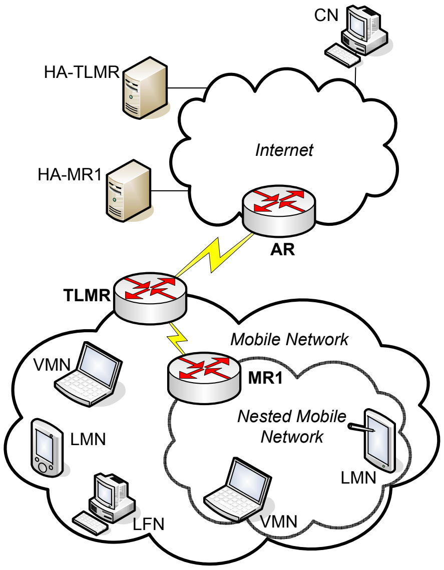

Fig. 1 The architecture of a mobile network.

TLMR and MR1, respectively. Also, a node that communicates with MNNs is termed as a Correspondent Node (CN).

3.2 NEMO BSP

An MR is assigned a prefix, called home prefix, in its home network to advertise inside its mobile network. MNNs obtain addresses called home addresses from this prefix. Packets, sent to the home address, reach the HA that forwards the packets to the mobile network which is attached to the home network. When a mobile network moves to a network (foreign network) other than home 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 creates a binding entry that contains a mapping of the home prefix to the CoA. A binding entry is active for a limited amount of time, and therefore, needs to be refreshed by sending periodic BU.

The HA intercepts packets sent to MNNs' home address and tunnels the packets to the CoA (found in the binding entry) of the MR. Since a visiting mobile network which is nested under another mobile network gets the CoA from the prefix (assigned at home network) of the visited mobile network, packets (sent to the visiting mobile network) will first go through the HA of the visiting mobile network and then through the HA of the visited mobile network. In case of multiple levels of nesting, packets have to go through all

HAs of the mobile networks up the nesting level resulting in suboptimal route and header overhead due to tunneling.

4 Prefix delegation-based route optimization schemes

The basic principle used in prefix delegation-based schemes is to reconfigure CoAs (addresses to identify the location) for MNNs from the prefix of the foreign network whenever the network moves, and to let the CN know the CoAs. MNNs may configure the CoAs and send them to CNs by themselves or alternatively, CoAs can be obtained by MRs on behalf of MNNs. Like the HA, the CN creates binding entries that contains the mapping of the MNNs' home addresses to CoAs. Therefore, the CN can send packets using the CoA to have the packets directly (without going through HAs) reach the foreign network visited by the TLMR. The schemes apply the basic idea in different ways. Based on the differences (see Table 1), we selected three schemes to represent all schemes that follow the basic idea. Selected schemes and their differences are presented in the following subsections.

4.1 Simple Prefix Delegation (SPD)

In SPD, proposed by Lee et al. [7], MRs are delegated prefixes, which can be aggregated at the TLMR's foreign network prefix, to advertise inside their mobile network. MNNs (except LFNs) obtain CoAs from the advertised prefixes and send CoAs to their HAs and CNs. This scheme defines a new neighbor discovery option, called Delegated Prefix Option, which is used by MRs to delegate the prefix to attached MRs. Unlike the other two schemes, presented in Sec. 4, this scheme does not optimize LFNs' routes, and consequently, packets sent to LFNs are tunneled through the HA of the LFNs' MR.

4.2 Optimal Path Registration (OPR)

In this scheme proposed by Park et al. [9], prefix delegation and CoA obtaining procedures are similar to that of SPD, except only MRs obtain CoAs from the foreign network's prefix which is multi-cast to MRs through router advertisements. To optimize route for MNNs, MRs translate destination addresses of packets into new addresses by using the delegated prefix and notify CNs about the new translated address by setting a bit in the packet's header. Like SPD, OPR takes a short time to obtain the CoA, whereas unlike SPD, OPR optimizes routes for LFNs.

4.3 Mobile IPv6-based Route Optimization for NEMO (MIRON)

In MIRON [8], an MR, after obtaining the CoA, notifies (using PANA [14]) attached MNNs (except LFNs) to obtain CoAs. MNNs send DHCPv6 requests

Table 1 Differences related to LFNs' route optimization causing differences in the throughput.

Scheme	**LFNs' route optimization**	**Signaling**
SPD	No	Small
OPR	Yes	Small
MIRON	Yes	Large

that are relayed to the foreign network to which the TLMR is attached. A DHCP server in the foreign network sends DHCPv6 replies (with CoAs configured from foreign network prefix) that are relayed down the nesting level to MNNs. Unlike other two schemes, this CoA obtaining procedure takes longer time due to relay of request/reply upto the foreign network's DHCP server. In MIRON, MR optimizes route for LFNs by sending BUs to CNs on behalf of LFNs resulting in more signaling than that in SPD and OPR.

In Sec. 5, we perform the performance evaluation of the three schemes described in this section.

5 Performance evaluation

MIRON and OPR optimize routes for LFNs resulting in a smaller RTT when compared to SPD that does not optimize routes for LFNs. Differences in RTT increase as the mobile network moves away from the home network. Since the TCP throughput is inversely proportional to the RTT, throughput of SPD will decrease when the mobile network moves away from the home network. Route optimization for LFNs requires more signaling in MIRON than in the other two schemes. The amount of signaling increases with the number of LFNs and the speed of the mobile network. Since signaling packets compete with data packets for bandwidth, throughput of MIRON might decrease when the number of LFNs and the speed of the mobile network increase.

In this section, we quantitatively evaluate the throughput and the RTT of the schemes as a function of the three parameters, such as the speed of the mobile network, its distance from the home network, and the number of LFNs. Other parameters that affects the throughput and the RTT are also evaluated. This evaluation reveals the extent of the anticipated effects on the throughput, obtained using the schemes, for various values of the parameters. To evaluate, we use ns-2 [15] simulations. The simulation environment and the results are presented in the following subsections.

5.1 Simulation Environment

Fig. 2 demonstrates a topology used in the simulation. FTP sources over TCPs are attached to the CN, whereas LFNs (connected to the MR using the Ethernet) are the TCP sinks. The mobile network moves between ARs, placed in a horizontal line. Thus, the frequency of handoff is proportional to the speed

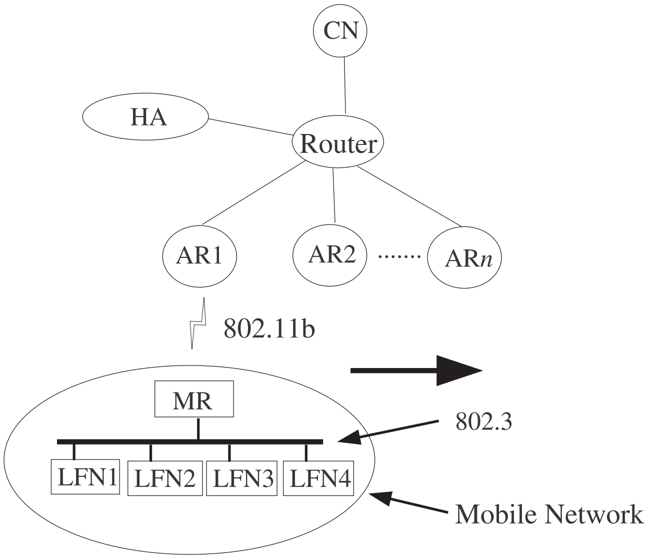

Fig. 2 Topology used for simulation.

Table 2 Values of the parameters used in the simulation.

Parameter	**Value**
Simulation time	200s
Wired link bandwidth	100Mbps
Wired link delay	10.0ms
Wireless (802.11b) link bandwidth	11Mbps
Wireless range	250m
Ethernet (802.3) bandwidth	100Mbps
Queue size	50packets
Interval of sending router advertisements	3s
Interval of sending BUs	10s
Lifetime of HA's binding entry, and CN's binding entry in MIRON	12s
Lifetime of CN's binding entry in OPR	1s

of the mobile network. As we only intend to observe the effects of the frequency of handoffs, we do not use any particular mobility model to generate the movement of the mobile network. Since the schemes differ in the LFNs' route optimization, we use only LFNs in our evaluation. IEEE 802.11b is used for wireless communications. *To simulate the change of distance between the HA and the mobile network managed by the MR, we vary the Router-HA link delay.* Values of parameters, used in the simulation, are presented in Table 2.

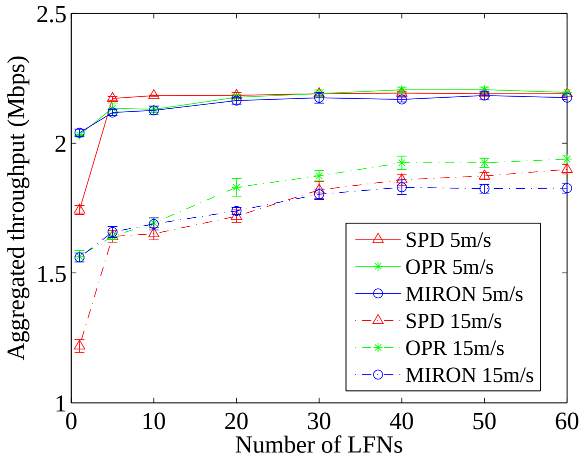

Fig. 3 Aggregated throughput for two different speeds with *Router-HA* link delay at 10ms.

5.2 Results

We measured (at 95% confidence level) the throughput, the RTT, the drop of packets and the handoff latency as a function of the number of LFNs with the speed and the distance between the HA and the mobile network as the parameter. Results are presented in the following subsections.

5.2.1 Aggregated throughput

The aggregated throughput is measured by the total amount of data (TCP packets) received at all LFNs. Fig. 3 shows the aggregated throughput obtained using the schemes for the two different speeds of the mobile network with the *Router-HA* link delay at *10ms*. Although the throughput in SPD is much smaller than that in OPR and MIRON when the number of LFNs is one (1), the throughput obtained using the schemes is similar when the number of LFNs increases. One of the reasons for the similarity is the increase of the RTT (Fig. 5 and Table 3) with the increase of the number of LFNs. Since the TCP throughput is inversely proportional to the RTT, the ratio of RTTs in the schemes determines the ratio of throughput. When the number of LFNs is one (1), the ratio of the RTT in SPD, OPR and MIRON is 70:50:50 (approximate). As the number of LFNs increases, the ratio of the RTT in SPD to the RTT in the other two schemes decreases because the difference in the RTT does not increase much compared to the value of the RTT. For example, when the number of LFNs is 10, the ratio of the RTT becomes 250:225:230 (approximate). Therefore, the ratio of the throughput follows from the ratio of the RTT.

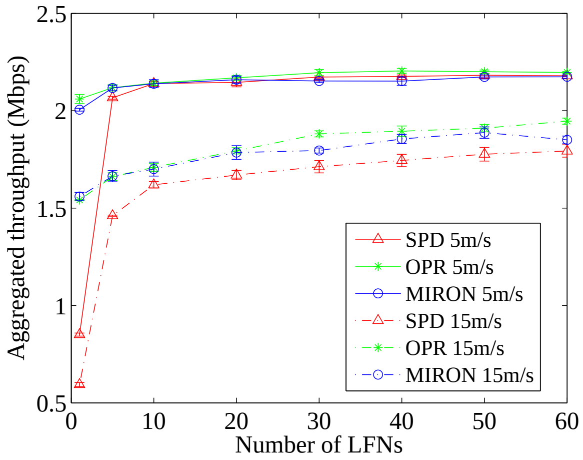

Fig. 4 Aggregated throughput for two different speeds with *Router-HA* link delay at 40ms.

Throughput in MIRON is little lower than that in SPD, particularly at high speed and when the number of LFNs is large despite the RTT in MIRON being lower. The reason for the lower throughput in MIRON is the lower sending rate due to the higher drop of TCP acknowledgement (ACK) packets. Also, the throughput in MIRON becomes lower than that in SPD when the number of LFNs is large due to the higher data packet drop in MIRON. Drop of packets is discussed in Sec. 5.2.3.

Fig. 4 shows the aggregated throughput with the *Router-HA* link delay at *40ms*. When the number of LFNs is increased, the difference of the throughput in SPD with that in OPR and MIRON is reduced like it is when the *Router-HA* link delay is 10ms. However, the throughput loss in SPD caused by the unoptimized route in the 40ms case is more than that in the 10ms case due to the increase of the ratio of the RTT in SPD to that in the other two schemes.

5.2.2 RTT

Heavy solid lines in Fig. 5 show the RTT for the 15m/s case when the *Router-HA* link delay is *10ms*. As expected, the RTT in SPD is higher than that in OPR and MIRON due to the unoptimized route. However, the difference in the RTT among the schemes does not increase much when compared to the increase of the RTT as a function of the number of LFNs. The higher RTT in SPD is due to the *Router-MR* link delay which is a constant. On the otherhand, the increase of RTT in all schemes is mainly due to the increase of the queuing and contention delay at the wireless link between an AR and the MR. Dash-dot patterned lines in Fig. 5 show that the average delay for TCP-packets at the link from an AR to the MR is similar, and increases with the increase of the number of LFNs. Dotted lines in Fig. 5 show the average

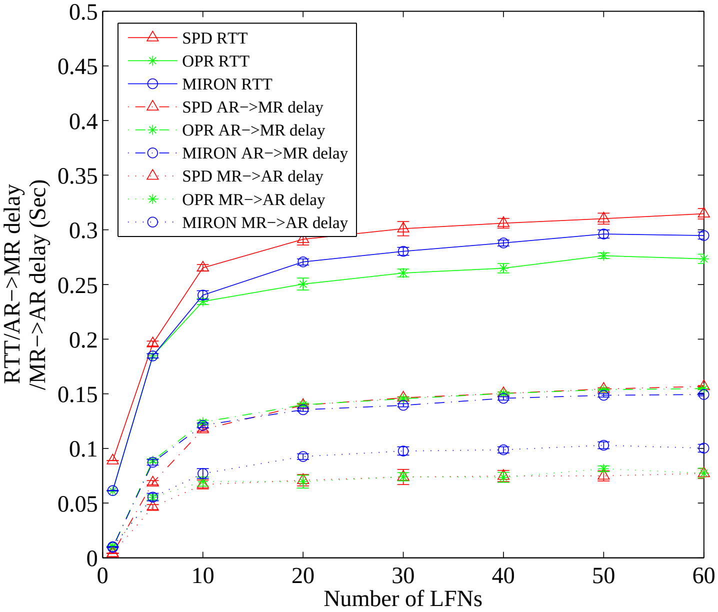

Fig. 5 RTT, AR to MR and MR to AR delays for 15m/s speed of the mobile network when the *Router-HA* link delay is 10ms.

Table 3 Delays at the AR-MR wireless links and the RTT in the three schemes for three different values of the number of LFNs when the speed of the mobile network is 15m/s and *Router-HA* link delay is 10ms.

# of LFNs	**Scheme**	**AR to MR delay (ms)**	**MR to AR delay (ms)**	**RTT (ms)**
1	SPD	3.85	4.14	88.86
	OPR	9.67	10.65	61.04
	MIRON	9.34	10.14	61.47
20	SPD	139.59	70.92	291.39
	OPR	139.92	69.59	250.36
	MIRON	135.48	92.55	270.62
60	SPD	156.72	77.15	314.76
	OPR	154.74	77.46	273.37
	MIRON	149.38	100.25	294.78

delay for ACK-packets at the link from the MR to an AR. Table 3 summarizes the the delays at the wireless links and the RTT for the three different values of the number of LFNs.

The RTT in MIRON is higher than that in OPR, although both the schemes optimize routes for LFNs. One of the reasons for the higher RTT in MIRON is the higher hop delay from the MR to an AR due to the higher number of packets enqueued at the MR. The total number of packets enqueued

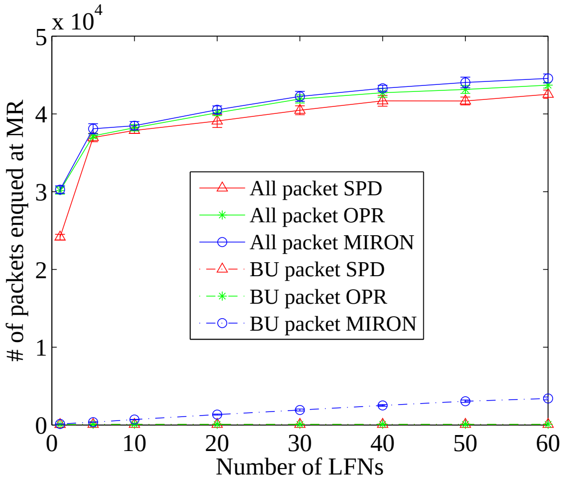

Fig. 6 Number of packets enqueued at the MR for 15m/s speed case when the *Router-HA* link delay is 10ms.

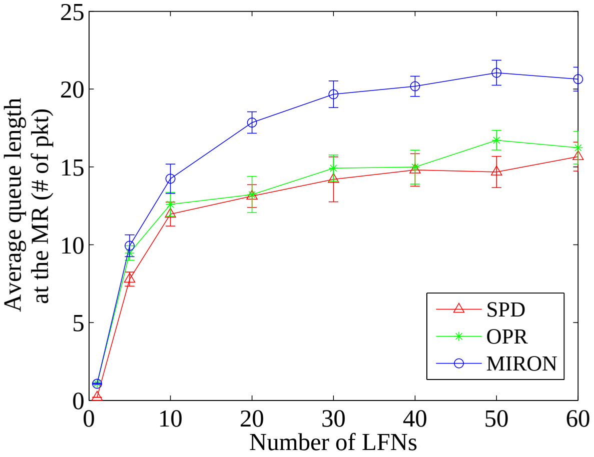

Fig. 7 Average queue length at the MR for 15m/s case when the *Router-HA* link delay is 10ms.

and the average queue size at the MR are shown in Fig. 6 and 7, respectively. The number of packets enqueued and the average queue size at the MR are higher in MIRON than that in SPD and OPR due to the higher number of BUs required for the LFNs' route optimization. And, the number of BUs in MIRON increases with the increase of the number of LFNs (see Fig. 6).

Another reason for the higher RTT in MIRON than that in OPR is the number of packets that travel through the HA i.e. through the unoptimized route is larger in MIRON (see Fig. 8). The RTT for these packets are higher

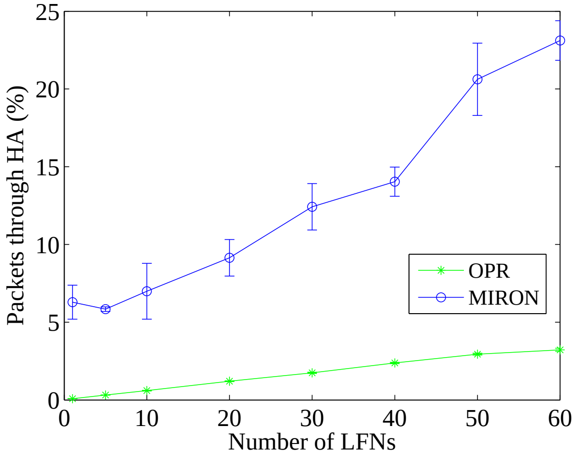

Fig. 8 Percentage of packets that travel through the HA for 15m/s speed case when the *Router-HA* link delay is 10ms. In SPD all (100%) packets travel through the HA

than those traveling through the optimized route. Usually, in MIRON and OPR, packets are expected to bypass the HA to travel through the optimized route. When the binding entry in the CN expires, packets travel through the HA in a similar way they do in SPD. Expiration of binding entries occurs if it is not refreshed within its lifetime. In MIRON, BUs for LFNs' route optimization are sent in bursts for refreshing the binding entries in the CN. Some BUs may get dropped at the queue causing corresponding binding entries to expire. Such drop and expiration events increase with the increase of the number of LFNs resulting in the increase of the number of packets traveling through the HA. Determination of the rate of sending BUs, the lifetime of binding entries for the minimization of the number of expirations and the duration of expirations requires some kind of tradeoff, and is out of the scope of this paper. In OPR, binding entries are refreshed using the information sent in the OPR header of ACK packets which are usually received at the CN at a higher rate than the rate of sending BUs in MIRON. Therefore, the number and the duration of expirations in OPR are smaller than that in MIRON. Hence, in OPR, the number of packets traveling through the HA is small.

Fig. 9 shows the RTT for the case when *Router-HA* link delay is *40ms*. The characteristics of RTT (as a function of the number of LFNs) in this case is similar to that when the *Router-HA* link delay is 10ms. However, the increase of the RTT from the RTT for the *Router-HA* link delay of 10ms case differs among the schemes. As expected, the RTT in SPD has increased more than that in the other two schemes due to the use of unoptimized route. Since more packets in MIRON than in OPR traverse through the HA (explained in the previous paragraph), the RTT in MIRON has increased more than that of OPR. Consequently, the increase of the RTT in OPR is the lowest.

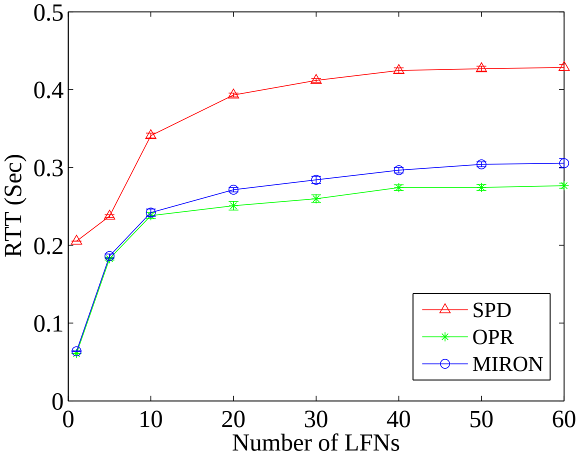

Fig. 9 RTT for 15m/s speed of the mobile network when the *Router-HA* link delay is 40ms.

5.2.3 Drop of TCP packets due to expired or dirty binding entries

For 15m/s speed of the mobile network, and 10ms *Router-HA* link delay case, Fig. 10 shows the drop of TCP packets due to expired or dirty binding entries. The drop is measured as the percentage of packets dropped among the packets received at the AR. An expired binding entry results in drops at the HA. Since the destination MNN for packets is not in home, and no binding entry exists for the destination address, the HA is unable to determine the next hop for packets and drops them. *Dirty binding entries* cause packets to be sent using the old CoA, and therefore, to the old AR that fails to forward the packet because the mobile network has already left this AR's network. Binding entries becomes dirty when the binding entries at HAs and CNs are yet to be updated after the handoff. When the number of LFNs is large (more than 30), the MIRON's drop shown in Fig. 10 is higher when compared to that for the other two schemes because a larger number of packets in MIRON are sent by the CN to the old AR.

Number of packets sent to the old AR is measured as the percentage of the total number of packets sent from the CN, and is shown in Fig. 11. In SPD, packets sent by the CN reach the HA that might tunnel those packets to the old AR if binding entries is dirty. Since the BU to the HA is the one to be sent first after the handoff, and the frequency of sending the first few BUs is high [17], the probability for the HA to receive a BU early after handoff is high. Therefore, the number of packets sent to the old AR is small in SPD.

In MIRON, the CN may send packets to LFNs using old CoAs in the dirty binding entries. However, when the number of LFNs is large, the chance of receiving a BU very late after the handoff is higher than the chances of those at the HA due to two reasons. First, BUs sent to the CN on behalf of LFNs may

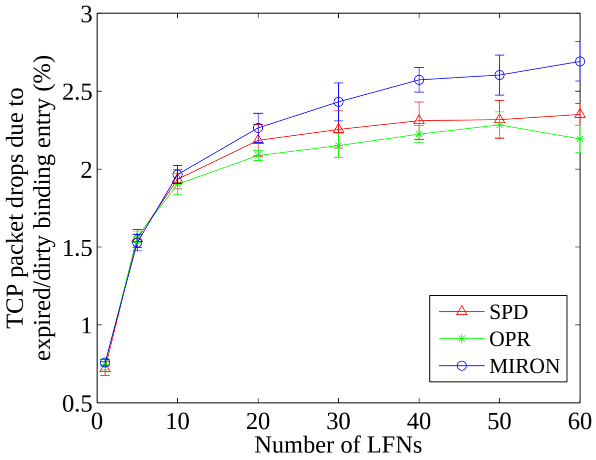

Fig. 10 For 15m/s speed and *Router-HA* link delay of 10ms, TCP-packet drops at the AR due to expired or dirty binding entry.

get dropped at the queue because BUs are sent at a burst. Particularly, those BUs that are sent later in sequence have higher chances of getting dropped at the queue. Second, the list of CNs, to which an MR send BUs, may expire due to no packet reception from CNs during handoff. In this case, the MR cannot not send any BU to the CN after handoff until a packet is received through the HA. Thus, CN's binding entries become dirty, and it continues to send packets to the the old AR as long as binding entries are not expired or BUs are received. Using a small lifetime for binding entries, the chances of sending packets to the old AR, and the duration of the sending can be minimized at the cost of sending BUs at a high rate. In OPR, a small lifetime can be used because binding entries are updated using information carried in ACK packets that are received at the CN at a rate as high as the sending rate of TCP packets. Therefore, in OPR, the number of packets sent to the old AR is small.

Characteristics of the drop of TCP packets at the AR's queue is similar for all schemes. The characteristics of drops at the queue when the number of TCP flows increases can be found in [16].

5.2.4 Drop of ACK packets at MR's queue

Fig. 12 shows the drop of ACK packets at MR's queue for 15m/s case when the *Router-HA* link delay is 10ms. ACK drop was measured as the percentage of incoming packets at the MR. The drop is higher in MIRON than in the other two schemes because of higher signaling in MIRON. Also, the drop in MIRON increases at a higher rate than that in SPD and OPR due to the increase of signaling with the increase of the number of LFNs. At high speed, drops

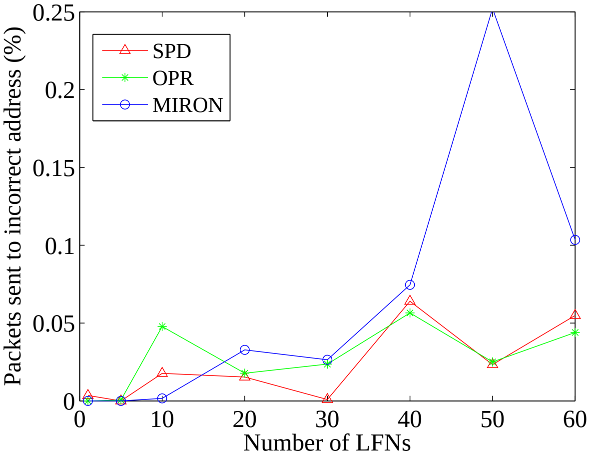

Fig. 11 Packets sent to the old AR for 15m/s case when the *Router-HA* link delay is 10ms.

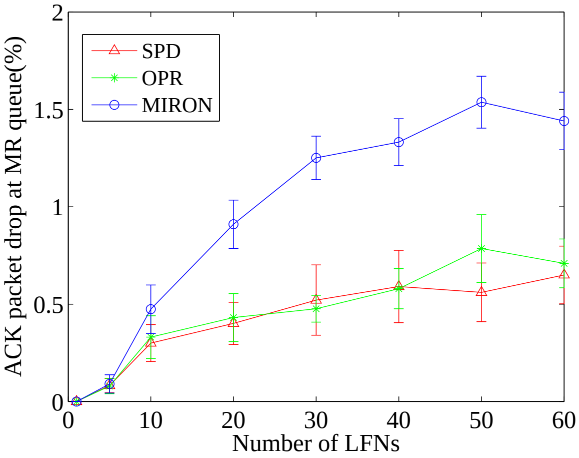

Fig. 12 Drop of ACK packets at MR's queue for 15m/s case when the *Router-HA* link delay is 10ms.

are larger in MIRON than in other two schemes due to increase of signaling resulting from increased handoff frequency.

5.2.5 Handoff latency from MR's viewpoint

Fig. 13 shows the handoff latency from MR's viewpoint for 15m/s and *Router-HA* link delay of 10ms case. Handoff latency is measured as follows:

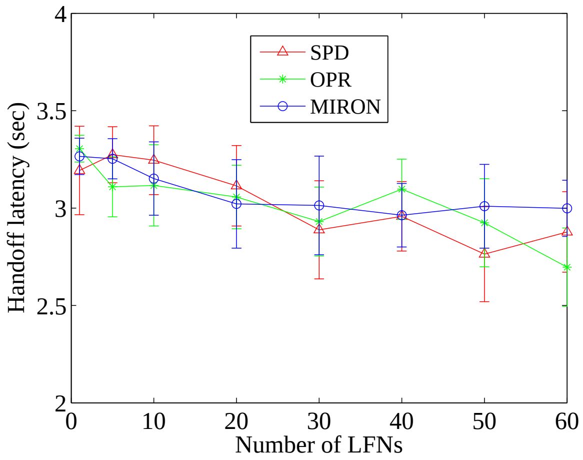

Fig. 13 For 15m/s speed and *Router-HA* limk delay of 10ms, handoff latency from the MR's viewpoint.

Handoff latency = the reception-time of the first router advertisement at the MR from the new AR - the reception-time of the last TCP packet at the MR through the old AR.

Thus, the measured handoff latency can be expressed as the sum of the following components:

1. After reception of the last TCP packet at the MR through the old AR, the time required by the MR to detect that it is out of the coverage of the old AR.
2. After detection of the coverage outage, the time required for the first router advertisement to be received at the MR.

When the mobile network is out of the old AR's coverage area, it does not receive any router advertisement from the old AR. Therefore, the MR becomes aware of the coverage outage at the expiration of the lifetime (3 seconds in our simulation) of the last router advertisement received by the MR from the old AR. Since the router advertisement is sent with an interval which is uniformly distributed between 0 seconds and 3 seconds and the lifetime is always 3 seconds, the time required for the MR to detect the coverage outage is much larger than the half (1.5 seconds) of the lifetime. After detection of the coverage outage, the router solicitations are sent by the MR. MR's reception of the router advertisement sent by the new AR in response to the solicitation completes the router detection process. The time duration between sending the solicitation and receiving the router advertisement is in the order of hundreds of milliseconds. As can be observed from the results, increasing the number of LFNs does not affect the handoff latency of the mobile network.

6 A qualitative comparison of the schemes

In this section, we mention the relative advantages and disadvantages of the three schemes that were not revealed in simulation. The way, CoA is sent to the CN for route optimization in OPR, needs packets to flow from mobile network to CNs at a regular interval. If packets are not flowing from the mobile network to the CN, OPR performs like SPD. Moreover, sending CoA in this way is vulnerable to security breach. Also, the CoA obtaining procedure in OPR and SPD by prefix delegation [18] through router advertisement might not be easily applicable due to accounting and security reasons. On the otherhand, MIRON uses a protocol [14] standardized by IETF to obtain a CoA.

7 Conclusion

In this paper, we evaluate the TCP throughput of three prefix delegation-based schemes, namely MIRON, SPD and OPR, proposed for NEMO route optimization. Evaluation was performed as a function of the number of LFNs (fixed hosts in the mobile network) when the mobile network traveling at two different speeds being at two different distance from its home network.

Results show that route optimization for LFNs improves the aggregated TCP throughput for the entire mobile network significantly only when the number of LFNs is small (not observed in [6]) or when the distance is very large. Results also show that although additional signaling in MIRON does not reduce throughput much, it keeps the throughput in MIRON less than what is expected (like OPR's throughput) when the number of LFNs increases and the speed of the mobile network is high.

Therefore, we can draw two conclusions from the results. First, considering the resource (bandwidth, processing, memory) requirement for LFNs' route optimization, it should be used (may be dynamically) depending on the speed of the mobile network, its distance from the home network, and the number of LFNs. Second, the amount of signaling in MIRON needs to be reduced to achieve the throughput expected to be achieved by using LFNs' route optimization.

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