PERFORMANCE OF PREFIX DELEGATION BASED ROUTE OPTIMIZATION SCHEMES FOR NEMO

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***Abstract*—A number of prefix delegation-based schemes have been proposed in the literature to solve the route optimization problem in mobile networks. The route optimization solutions generate overheads and affect the performance of mobile networks. However, currently there is no tool available to aid in the selection of an appropriate scheme for a given mobility scenario. The objective of this paper is to develop analytical models for prefix delegation based schemes and compare the performance of the schemes for different mobility scenarios. Results show that the performance of a scheme depends on the characteristics of the mobile network, and there is no single scheme which suits all mobility scenarios.**

I. INTRODUCTION

The increasing demand for Internet on-the-go has increased the necessity of mobile networks. Mobile networks are envisioned to provide seamless Internet access to nodes inside the network, handle mobility for them wherever needed and relieve them from using power hungry communication interfaces. Mobile networks can typically find their application for public and military purposes. Public transport systems like buses, aeroplanes etc. are examples of mobile networks where a wide variety of devices with different level of capabilities are moving together. As far as military application is concerned, mobile network can be an integral part of global intelligence, surveillance and reconnaissance systems. Examples of such mobile network include aircrafts or spacecrafts with an on-board Local Area Network of multiple data collection devices.

To standardize the support for mobile networks, Internet Engineering Task Force (IETF) proposed the Network Mobility (NEMO) Basic Support Protocol [1] as an extension to MIPv6 [2]. Like MIPv6, a mobile router in NEMO configures a care-of-address when it moves into a foreign network and establishes a bidirectional tunnel with its home agent. In NEMO, data communication between a node inside a mobile network and a corespondent node takes place via the home agent, using the tunnel, creating a suboptimal (indirect) path for the communication. In MIPv6, this problem of suboptimal routing was addressed with Route Optimization (RO) which is not available in NEMO Basic Support Protocol (BSP). The suboptimal path results in additional delays and packet overheads. These issues are more critical for NEMO than for MIPv6 [3] specially with the possibility of multiple mobile networks joining in a nested fashion.

In order to solve the problem of suboptimal route in NEMO BSP, several route optimization solutions have been proposed in literature. Some solutions introduce new entities in the infrastructure, some propose changes only within a mobile network while others propose new protocols or extend existing ones. An overview of the route optimization solutions can be found in [4] and [5]. Lim et al. [6] have categorized route optimization solutions according to approach used i.e. Recursive approach, Hierarchical approach and Aggregate & Surrogate approach. *The comparison of these approaches show that the aggregate and surrogate approach outperforms others in various metrics*. In this article, we further *analyze* the individual schemes that use the aggregate and surrogate approach.

All the schemes following aggregate and surrogate approach use prefix delegation to provide topologically correct IP addresses inside a visiting mobile network, however they employ different methods of doing so and their impact is different on various performance metrics. The performance evaluation provided in [6] is based on the general characteristics of the schemes following a particular approach and does not consider the individual features of each scheme. It is, therefore, necessary to evaluate influence of different

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prefix delegation based schemes on overall performance of a mobile network under different conditions. We *perform* the evaluation by developing analytical models to measure certain performance metrics. To the best of our knowledge, not all the performance metrics considered in this paper were measured using analytical models in any other article.

Our *goal* is to provide a comparative analysis of representative prefix delegation based schemes. The schemes selected in this article are representative because performance of other schemes are similar to the selected schemes as far as performance metrics used in this paper are considered. This analysis will help network designers to select an appropriate route optimization solution for a particular mobile network. For this purpose, we *develop* and *evaluate* analytical models of the schemes. The analysis demonstrates the impact of the schemes on the performance of a mobile network under different network configurations. Results show that the performance of a scheme depends on the characteristics of the mobile network, and there is no single scheme which suits all mobility scenarios.

The rest of the paper is organized as follows. Sec. II gives an overview of the route optimization schemes being considered here. Sec. III describes the notations and assumptions used for models. Sec. IV presents the mathematical models created to evaluate the schemes. This is followed by a discussion of the results in Sec. V and comparative analysis in Sec. VI. Finally, Sec. VII concludes the paper.

II. PREFIX DELEGATION BASED ROUTE OPTIMIZATION

The basic idea behind prefix delegation based route optimization is to enable nodes inside a mobile network to configure a Care-of-Address (CoA) from the prefix of the network the mobile network is visiting. With this CoA, a node inside the mobile network can communicate directly with a Correspondent Node (CN) without going through the Home Agent (HA).

This basic idea of prefix delegation has been applied in different ways in the literature. In this section, we will present a brief overview of the representative prefix delegation based route optimization schemes. For this purpose, we consider a mobile network consisting of Mobile Routers (MR) connected to an Access Routers (AR) in a foreign network and manage mobility of a number of Mobile Network Node (MNN)s namely Local Fixed Node (LFN), Local Mobile Node (LMN) and Visiting Mobile Node (VMN) as shown in Fig. 1. An MR such as MR1 can also join another mobile network to form nested mobile networks. We call the MR in a nested mobile network that has direct access to the AR a Top Level MR (TLMR). *We assume that LFNs have only IPv6 capability whereas all other nodes (mobile nodes) are MIPv6 capable.*

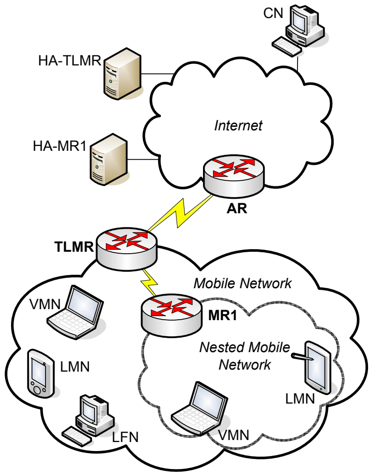

Fig. 1. Topology of a mobile network.

A. Simple Prefix Delegation

In this approach, proposed by Lee et al. [7], the MR obtains a CoA from the AR in the foreign network and also gets a prefix to advertise. Mobile nodes obtain a CoA from the advertised prefix and registers the CoA with their respective HAs. This scheme defines a new neighbor discovery option, called Delegated Prefix Option, which is used by MRs to advertise prefix. This scheme requires a specialized prefix delegator in every mobile network that has the overhead of performing extra functionality related to prefix delegation. Moreover, packets sent to the LFNs have to be tunneled through the HA of the LFNs' MR.

B. Mobile IPv6 based Route Optimization (MIRON)

Mobile nodes in MIRON [8] configure CoA from the AR-delegated prefix using DHCPv6 and thus can perform RO. RO for LFNs is done by MR sending Binding Update (BU)s, requiring additional memory to track LFN-CN pairs, to CNs on behalf of the LFNs. This method of MR-assisted RO for LFNs also results in increased processing cost at the MR.

C. Optimal Path Registration (OPR)

In this scheme proposed by Park et al. [9], only MRs obtain CoA from AR-delegated prefix which is multi-cast to them. MRs translate prefix of source and destination address of outbound and inbound packets (from attached nodes) respectively. Therefore, address changes are transparent to MNNs except MRs. RO is made possible by the OPR procedure that performs new address registration at CN and HA. This is similar to BU procedure but requires table look up for each packet (in MR, CN and HA) and new options in IP headers.

D. Adhoc protocol based

Su et al. [10] proposes a RO solution for NEMO that uses an adhoc protocol to find the AR in the foreign network. A mobile node gets the prefix of the foreign access network from other MRs upon joining a mobile network and obtains a CoA. Then a path to the AR in foreign network is discovered using an adhoc protocol to use the AR directly as gateway. Therefore, no encapsulation is required for communication with the CN. But path discovery introduce an additional delay at the start of packet delivery and after each handoff.

III. NOTATIONS AND ASSUMPTIONS

In this section, we introduce the parameters that are used in models (in Sec. IV) of the schemes (see II) and assert the assumptions under which the models are developed.

A. Assumptions

We make the following assumptions for developing the models:

1) BUs to refresh a binding are not considered.
2) Number of CNs per MNN is same for all MNNs.
3) Propagation speed in wired and wireless links is equal.
4) Processing capacity of all the nodes are equal.
5) Time required for all types of processing such as encapsulation, address swapping, table searching etc. is same.
6) We only consider the movement of the TLMR for number of BUs and handoff delay calculations as this is more likely in the real world.
7) Handoff delay can be expressed as the sum of layer 2 and 3 handoff times, address configuration time and location update time. Layer 2 and 3 handoff times and the location update delay for the schemes are equal in all the schemes. So, differences in handoff delay among the schemes is determined by the differences in the time required for *address configuration*.

B. Parameters for performance analysis

l = Nesting Level of a MNN (hops to TLMR)
s_p = Size of data packet
s_a = Size of router advertisement packet
τ_r = Packet processing time by router
τ_e = Tunnel processing time
b_w = Bandwidth at a wireless node
b_d = Bandwidth at a wired node
n_b, n_c = No. of BUs, CNs respectively
n_r, n_f, n_m, n_v = Total no. of MRs, LFNs, LMNs, VMNs respectively in the entire mobile network
$h_a^h, h_a^c, h_h^c, h_h^h$ = Avg. no. of hops from AR to HA, AR to CN, HA to CN, HA to HA respectively
n'_r, n'_f, n'_m, n'_v = No. of MRs, LFNs, LMNs, VMNs respectively attached to a particular MR
p_d, p_w = Propagation delay for wired link and wireless link respectively

IV. ANALYTICAL MODELS FOR SCHEMES

In this section, we develop analytical models for four prefix delegation based RO schemes (Sec. II) using the following metrics to evaluate and compare the schemes:

- *Number of binding updates* is measured by the number of binding updates generated from a mobile network during handoff, and reflects the load on the TLMR during handoff.
- *End-to-End delay* measures the time taken by a packet sent from an MNN to reach a CN. It is a very crucial performance metric for real time applications.
- *Memory overhead* reflects additional memory required by an MR to provide RO for MNNs. It is measured by the number of IPv6 addresses stored in the MR, and measures storage capability of an MR to manage nested mobile network.
- *Address configuration delay* measures the delay experienced by an MR at a particular level to get the new address prefix during handoff. The performance of real time applications can be affected by this delay.

A. Simple Prefix Delegation

1) No of Binding Updates: Simple Prefix Delegation provides RO for all MNNs except LFNs. Therefore total number of BUs sent to HAs and CNs depends only on the number of LMNs, VMNs and MRs in the mobile network.

$$n_b = (n_c + 1)(n_r + n_m + n_v) \tag{1}$$

2) End-to-End Delay: Since no RO is provided for LFNs, each packet generated by a LFN must go to its MR's HA before going to the CN. This is same as NEMO BSP MR-HA tunnel solution, however, since MRs have optimized routes, there is a single tunnel. End-to-end delay between LFN and CN (ignoring the increased packet size due to tunneling) is given by Eqn. 2 whereas delay between mobile node and its CN is given by Eqn 3.

$$T_f^c = (l+1)\left(\frac{s_p}{b_w} + p_w + \tau_r\right) + (h_a^h + h_h^c)\left(\frac{s_p}{b_d} + p_d + \tau_r\right) + 2\tau_e \tag{2}$$

$$T_m^c = (l+1)\left(\frac{s_p}{b_w} + p_w + \tau_r\right) + h_a^c\left(\frac{s_p}{b_d} + p_d + \tau_r\right) \tag{3}$$

3) Memory Overhead in MR: MRs in Simple Prefix Delegation use hierarchical prefix delegation and use the same routing table as the conventional routers. Therefore, no additional memory is required.

$$m_r = 0 \tag{4}$$

4) Address Configuration Delay: When an MR receives a prefix advertised by an AR, it obtains a CoA and relays the prefix inside the mobile network. All mobile nodes receiving this advertisement obtains CoAs from this prefix whereas nested MRs also relay the prefix on their ingress interface. The address configuration delay is thus given by the following.

$$T_a = l\left(\frac{s_a}{b_w} + p_w + \tau_r\right) \tag{5}$$

B. MIRON

1) Number of BUs: MRs, VMNs and LMNs send BU to their HAs and CNs. Thus the number of BUs sent by each of those MNNs is (n_c+1). Moreover, MRs also send BUs to the CNs that are communicating with the LFNs attached to the MRs.

$$n_b = (n_c+1)(n_v+n_m+n_r) + n_c n_f \tag{6}$$

2) End-to-End Delay: End-to-end delay encountered by mobile nodes is similar to that in Simple Prefix Delegation (Eqn. (3). Packets from LFNs are subject to an additional delay (τ_{ad}), as an MR intercepts packets from its LFNs, replace the source address by its CoA, and places the LFN's source address in the extension header. End-to-end delay from LFN to CN is given below.

$$\begin{aligned} T_f^c = {} & \tau_r(l+h_a^c+1) + \left(\frac{s_p}{b_w}+p_w\right)(l+1) \\ & + \left(\frac{s_p}{b_d}+p_d\right)h_a^c + \tau_{ad} \end{aligned} \tag{7}$$

3) Memory overhead in MR: An MR in MIRON creates a host route entry for all mobile nodes to route packet inside the mobile network. To route packets for LFNs, the host route entries of MRs are used. An MR also keeps track of the CN-LFN pairs to send BU for those LFNs that are attached to the MR. Thus the memory overhead for MR in MIRON is computed as follows:

$$m_r = 2 \times (n_v + n_m + n_r + n_c n'_f) \tag{8}$$

4) Address configuration delay: After configuring a CoA, an MR starts PANA re-authentication phase (requires four messages) [11] to tell a mobile node attached to the MR to obtain a CoA. A mobile node then sends a DHCPv6 request to obtain a CoA from the AR of the foreign access network. The request is relayed by MRs on the path to the TLMR. The DHCPv6 response with a CoA follows the same path back to the node. An MR can start PANA re-authentication only when it completes its own address configuration. So, CoA obtaining time for a node at any level is the sum of time required to obtain new address by all the MRs on the path to the TLMR. Let,

s_n = Size of PANA message
s_h^q = Size of DHCPv6 request message
s_h^r = Size of DHCPv6 reply message

Then address configuration time is given by

$$T_a = 4\left(\frac{s_n}{b_w} + p_w + \tau_r\right)l + \left(\frac{s_h^q + s_h^r}{b_w} + 2p_w + 2\tau_r\right)\sum_{i=1}^{i=l}(i+1) \tag{9}$$

C. OPR

1) Number of BUs: In OPR, only MRs obtain CoA and send BU to HA. No BU is sent to the CN for RO. Thus the number of BUs is equal to the number of MRs in the mobile network.

$$n_b = n_r \tag{10}$$

2) End-to-End delay: Optimized Path Registration process of new translated address with the CN requires table searching at MR and binding cache searching at CN for every packet. Also, the address of a packet is changed by MR before forwarding it. We combine these three processing times as OPR processing time (τ_{OPR}) in our model. Therefore, end-to-end delay in OPR is sum of OPR processing time and the end-to-end delay in MIRON (Eqn. (7) and (8)) as given below.

$$\begin{aligned} T_f^c = {} & \tau_r(l+h_a^c+1) + \left(\frac{s_p}{b_w}+p_w\right)(l+1) \\ & + \left(\frac{s_p}{b_d}+p_d\right)h_a^c + \tau_{ad} + \tau_{OPR} \end{aligned} \tag{11}$$

$$T_m^c = \tau_r(l+h_a^c+1) + \left(\frac{s_p}{b_w}+p_w\right)(l+1) + \left(\frac{s_p}{b_d}+p_d\right)h_a^c + \tau_{OPR} \tag{12}$$

3) Memory overhead in MR: OPR scheme stores a table at the MR for OPR procedure. This table requires an entry (consisting of three slots) for each pair of communicating CN and MNN that are attached to the MR. Hence, memory overhead for MR in OPR scheme is given by (13).

$$m_r = 3n_c(n'_v + n'_m + n'_f + n'_r) \tag{13}$$

4) Address configuration delay: The address configuration delay is same as Simple Prefix Delegation (see Eqn. (5).

D. Adhoc protocol based

1) No of Binding Updates: Adhoc protocol based scheme optimize route for all MNNs except LFNs. Therefore number of BUs can be found from Eqn. 1 which also gives the number of BUs for Simple Prefix Delegation scheme.

2) End to End Delay: End-to-end delay for this scheme is similar to that of Simple Prefix Delegation. Only difference might be some additional delay incurred at the start of packet delivery to find a route to AR using AODV (RFC 3561). This additional delay will not be there for subsequent packets, and ignoring the additional delay, we can use Eqns. 2 and 3 to find end-to-end delay for this scheme.

3) Memory Overhead in MR: During communication of an MNN with a CN, an MR has to have an entry to forward packets for that MNN. Assuming on the average half of the MNNs are communicating at a time, memory overhead of this scheme is given by Eqn. 14.

$$m_r = \frac{1}{2} \times 2(n_v + n_m + n_r) = n_v + n_m + n_r \qquad (14)$$

4) Address Configuration Delay: After receiving a prefix advertised by an AR, an MR obtains a CoA from the advertised prefix followed by path discovery to AR using AODV and relays the prefix inside the mobile network. Therefore, the delay will be the sum of propagation delay of prefix and the path discovery delay. To calculate path discovery delay, we use the number of hops between the AR and an MR which is essentially the level of that MR.

$$T_a = l(\frac{s_a}{b_w} + \frac{s_r^q}{b_w} + \frac{s_r^r}{b_w} + 3(p_w + \tau_r)) \qquad (15)$$

Where,
s_r^q = Size of AODV request message
s_r^r = Size of AODV reply message

V. RESULTS

In this section, we compare the schemes based on results obtained from the models developed in Sec. IV. Table I shows the values of parameters that are used to evaluate the schemes. Values for processing delays, bandwidth and propagation delays are the same as those used in [9]. Since Delegated Prefix Translation (DPT) in OPR includes table searching, address changing and copying new address, we set the value for DPT processing time three times the other processing times. Values for packet size of different protocols are taken from respective protocols' specifications.

Values for number of MNNs were taken considering a mobile network in a train or ship or aircraft where the number of MNNs can approach a thousand. MNNs can be LFNs connected to LAN or can be VMNs/ LMNs whose relative velocity is very low compared to the velocity of the vehicles with respect to the base stations. Alternatively, a fleet of aircrafts or a convoy of tanks whose relative velocity with respect to each other is insignificant can also form a mobile network of this kind.

TABLE I
VALUES OF DIFFERENT PARAMETERS USED IN THE MODELS

$s_p = 1500$ bytes	$s_a = 72$ bytes
$\tau_r = 10\mu$s	$s_n = 56$ bytes
$\tau_e = 10\mu$s	$s_h^q = 96$ bytes
$b_w = 10^7$ Mbps	$s_h^r = 184$ bytes
$s_r^q = 80$ bytes	$s_r^r = 76$ bytes
$\tau_{dpt} = 30\mu$s	$\tau_{ad} = 10\mu$s
$p_w = 30/(3 \times 10^8)$ s	$p_d = 1000/(3 \times 10^8)4$ s

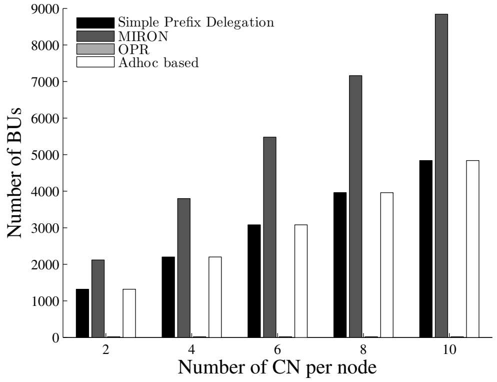

Fig. 2. Number of BUs generated when the top level MR moves with $n_r = 20$, $n_m = 20$, $n_v = 400$ and $n_f = 400$ (number of BU for OPR scheme is very low compared to that of others and hence difficult to find in the figure).

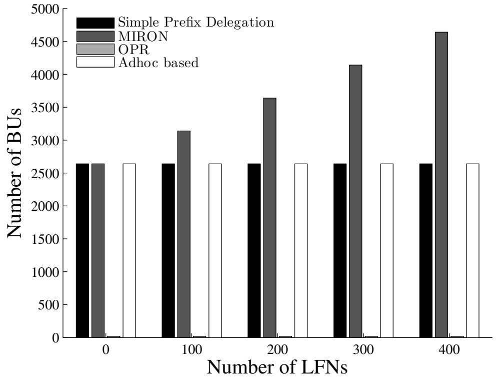

Fig. 3. Number of BUs generated when the top level MR moves with $n_r = 20$, $n_m = 20$, $n_v = 400$ and $n_c = 5$ (number of BU for OPR scheme is very low compared to that of others and hence difficult to find in the figure).

A. Number of BUs

Figs. 2 and 3 show the number of BUs generated for the four PD-based schemes. In OPR, only MRs perform location update with their HAs. In MIRON, location update is required for all types of nodes, whereas Simple Prefix Delegation and Adhoc based protocol does not require any location update for LFNs. As the number of MRs in a nested mobile network is much lower than the number of MNNs, OPR generates the lowest amount (equal to the number of MRs) of BUs. Also, the number of BUs in OPR is constant for a fixed of number MRs. Number of BUs generated by Simple Prefix Delegation and Adhoc based protocol is lower than that of MIRON due to no location updating for LFNs. Generating less BU costs OPR higher end-to-end delay for each packet due to table searching.

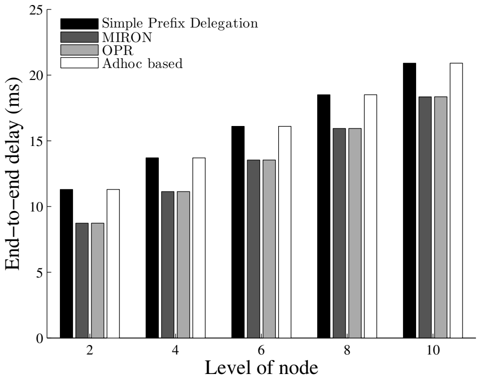

Fig. 4. End-to-End delay for LFNs for the four RO schemes.

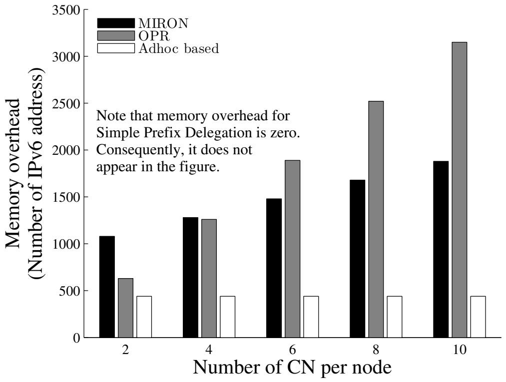

Fig. 5. Memory overhead with increasing number of CN.

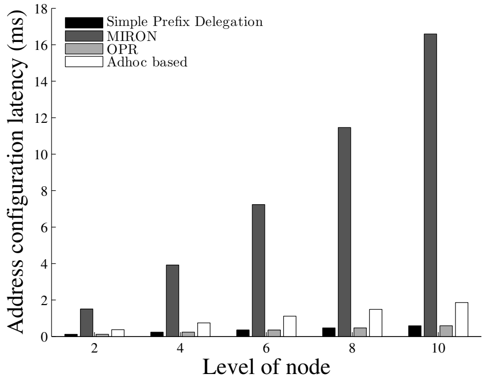

Fig. 6. Address configuration time for different schemes with increasing the number of level.

B. *End-to-end delay*

Route optimization is done for mobile nodes in all the schemes. Simple Prefix Delegation and Adhoc based protocol do not completely optimize route for LFNs causing higher end-to-end delay for LFNs as shown in Fig. 4. End-to-end delay for mobile nodes does not vary much across the schemes. Although OPR has longer processing time for each packet due to the DPT processing, it is very small compared to the total delay on the entire path of the packet. But, throughput over a long period of time for OPR will be lower due to this DPT processing time. Thus, if the residency time of the mobile network is high compared to handoff frequency, the performance of OPR will suffer (see Sec. VI).

C. *Memory overhead in MR*

Figs. 5 shows the impact of the number of CNs communicating to each MNN on the memory overhead of the MR. Memory overhead is higher for OPR for higher number of CNs because an MR has to track all CN-MNN (attached to MR) pairs for OPR registration procedure. Memory overhead for MIRON increases in a lower rate with increase in number of CNs due to tracking the communicating LFN-CN pairs only to optimize route for LFNs. Keeping host route entry for all mobile nodes in the entire mobile network causes higher memory overhead in MIRON when the number of CNs is small. Memory overhead for Adhoc based protocol is low because route entry only for communicating mobile nodes and communicating LFNs' MRs are kept.

D. *Address configuration delay*

Fig. 6 presents the delay for address configuration in different schemes. Delay for MIRON is higher than that of other schemes and increases quadratically with respect to the number of nesting levels. This is expected because MIRON requires more time to configure address due to PANA handshaking and DHCPv6 messages. Obtaining new address for each MR requires PANA re-authentication messages (1 level) and DHCPv6 request/ reply messages (relayed to TLMR). Time required to obtain a new address for a node is sum of address obtaining time for all MRs on the path from the node to the TLMR and address obtaining time of its own. This accounts for the quadratic address configuration time when the level of a node is changed. Address configuration time for Simple Prefix Delegation and OPR is the time to relay the RA message down to the level of node (Adhoc based protocol has some more due to route discovery procedure); this time is linear in terms of the level of the node. Although the address configuration time for MIRON is longer than other RO schemes, MIRON's authentication procedure will be standardized by IETF making it more suitable for future wireless network access.

VI. COMPARATIVE ANALYSIS OF THE SCHEMES

Mobile networks may have different mobility scenarios (in terms of residency time and handoff frequency) depending on velocity and pause time. Values of all the performance metrics modeled in Sec. IV, except memory overhead, are influenced by the mobility scenario of the mobile network. Hence, the results presented in Sec. V can be analyzed for comparison among the schemes based on the residency time and frequency of handoff.

- Scenario 1: A mobile network in a high-speed train or aircraft has low residence time and high handoff frequency. OPR is the most preferable schemes when handoff frequency is larger compared to the residency time of the mobile network because OPR generates the lowest number of BUs and thus incur additional processing on each packet. On the other hand, when the number of LFNs is high, number of BU generated by MIRON will be high in this scenario.
- Scenario 2: A mobile network in a bus or a ship or consisting of a convoy of tanks moving with low velocity has high residency time and low handoff frequency. MIRON will provide better throughput than the other schemes because of lower round trip time due to combination of lower processing delay and optimal route for LFNs that costs more BUs. Higher address configuration delay of MIRON will have lower impact due to less frequent handoff in this scenario.

Packets for LFNs undergo one tunneling in Simple Prefix Delegation and Adhoc based protocol that eliminates sending BUs to CNs (that are communicating with LFNs). So, both these schemes will produce a combination of high overall throughput and less BUs in both the scenarios if the number of LFNs is small.

In memory constrained environment (such as mobile phones, PDAs etc. are acting as routers) and with small number of LFNs, Adhoc based protocol is the best choice due to less memory overhead despite one tunneling for LFNs. OPR is the worst as far as memory overhead is concerned when number of CNs is large. Although, Simple Prefix Delegation has no memory overhead, it requires delegation of prefix through router advertisement that might not be feasible because of security, authenticity and accounting issues. Thus Simple Prefix Delegation scheme is not suitable for MRs with limited processing power and memory because of prefix delegator functionality.

VII. CONCLUSION

In this paper, we have presented analytical model-based comparative analysis and evaluation tool for four prefix delegation based schemes (shown to be better performing among other class of schemes) for route optimization in NEMO. Evaluation criteria include number of binding update messages, end-to-end delay, memory overhead, and time required to obtain a new CoA. Parameters for models have been chosen to match real world mobility scenarios. Results show that the performance of a scheme depends on the characteristics of the mobile network, and there is no single scheme which suits all mobility scenarios. Analytical models developed in this paper can be used to select an appropriate prefix delegation based route optimization scheme for a real-world mobile network scenario. Based on the characteristics, different schemes can be used for different mobile networks, and convergence of the schemes might be required for co-operative operation. However, realization of these schemes for classified applications (i.e. military intelligence, surveillance and reconnaissance) requires security measures to be incorporated. MIRON provides security along with RO using PANA where as the other schemes do not consider security aspects. Since MNNs are unaware of mobility, security check points needs to be enforced at MRs, HAs and CNs. Research work on NEMO security is in its incipient stage and needs to be investigated further before it can be useful for classified applications.

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