Evaluation of the Route Optimization for NEMO in Satellite Networks

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Abstract

Network Mobility (NEMO) has been proposed to efficiently manage the mobility of the group of hosts that are moving together as a mobile network. NEMO Basic Support Protocol (BSP) suffers from the problem of inefficient route. A number of route optimization schemes have been proposed in the literature to solve the problem. The schemes are mainly based on four approaches – Delegation-based, Hierarchical, Source routing and BGP-assisted. The approaches have been evaluated in the literature in terms of various performance metrics. The selection of a route optimization approach for NEMO in terrestrial networks is straight forward from the evaluations that implicitly assume NEMO in such networks. However, the selection of a route optimization approach requires additional evaluations for NEMO architecture that has been proposed for satellite networks to manage the mobility of Internet Protocol-enabled devices onboard satellites. The requirement for the additional evaluations results from the satellite network characteristics, such as long delay links, the link asymmetry, and power constraints. In addition, the availability of multiple connections for mobile networks in satellite networks requires the use of multihoming, a feature to support multiple connections in NEMO, with the route optimization. There are only a few route optimization schemes that consider multihoming. In this work, we discuss the desired characteristics of a route optimization scheme for satellite networks, and the requirements for incorporating multihoming into each of the approaches for the route optimization. Based on the characteristics, previous evaluations and the requirements for multihoming, we analyze the approaches to find suitable route optimization approaches for NEMO in satellite networks. Results show that delegation-based and hierarchical approaches are more suitable for NEMO in satellite networks compared to the other two approaches. In addition, the relative advantages and disadvantages among the approaches are also shown in terms of the desired characteristics. Thus, our analysis lays the basis for the future research to select a suitable scheme for the route optimization in NEMO for satellite networks.

1 Introduction

A satellite network is interconnections of satellites that are also connected to ground stations [1,2]. Satellite networks are characterized by long-delay links, frequent switching of satellite-satellite and satellite-ground station connections, the availability of multiple connections, and the asymmetry of links. One of

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the most important use of satellites is to collect Earth-observing data that are used to monitor flood, wildfire, volcanoes and cryosphere events [3]. To transfer such data to the end users through the Internet [4] or to the Internet Protocol (IP)-enabled end-users, future satellites will contain multiple IP-enabled devices. At present, IP is being used to transfer imaging data, collected by satellites in the Disaster Monitoring Constellation, to the ground to aid in disaster area relief operations [5].

The switching of connections in satellite networks results in the mobility of onboard devices that are connected to the Internet. To ensure the reachability and session continuity for those IP-enabled devices onboard satellites, a mobility management scheme is required. There have been efforts on the use of IP and IP-based mobility protocols in satellite networks. National Aeronautics and Space Administration (NASA) has been experimenting with the use of IP in the satellite networks [6]. Application of the Mobile IP (MIP) [7] to satellite networks has been proposed by Israel et al. [8] where an onboard device is considered as a mobile host with mobility management agents residing in terrestrial networks. However, MIP and Mobile IPv6 [9], the IPv6 version of MIP, are not efficient for managing the mobility multiple IP-enabled devices when they move together.

To efficiently manage the mobility of multiple IP-enabled devices, Internet Engineering Task Force has standardized Network Mobility (NEMO) [10]. In NEMO, devices that move together, and a mobile router which manages the mobility of the devices are connected as a network called the mobile network. A mobile network can connect to another one to form a nested mobile network. Leung et al. [11] presented the application of the IPv4-based mobile network onboard a single satellite. In the IPv4-based mobile network, a router is used inside a satellite to route packets sent from multiple devices onboard the satellite. Based on concepts similar to NEMO, Shi et al. [12] proposed a satellite constellation network architecture where satellite-hosts forms mobile networks to communicate with hosts in the Internet through satellite mobile routers. In [13,14], we have also presented architecture and protocols for NEMO in satellite networks.

To enable communications with the mobile network, IETF standardized NEMO Basic Support Protocol (BSP). In NEMO BSP, all communications are performed through a bidirectional tunnel between the mobile router and a home agent which is a router in the mobile network's home network [10]. However, NEMO BSP suffers from the problem of inefficient route [15]. The problem increases when a mobile network is nested. A number of route optimization schemes have been proposed to solve the problem in NEMO [16,17]. The schemes are mainly based on four approaches – Delegation-based, Hierarchical, Source routing and BGP-assisted [17–19]. The approaches have been evaluated in terms of various performance metrics, such as delay, handoff latency, signaling and memory requirement [16–19]. Using the results of the evaluations is straight forward to select suitable route optimization schemes for NEMO in terrestrial networks.

The selection of route optimization schemes for NEMO in satellite networks is not obvious due to the previous evaluations' not considering the distinct characteristics of satellite networks and NEMO in satellite networks. The characteristics, such as the asymmetry of links, long delay, and the changes induced in the mobile network because of the movements of satellites need to be considered for evaluations of the route optimization for NEMO in satellite networks. Moreover, the availability of multiple connections in satellite networks requires the use of multihoming that has not been considered in majority of the schemes and, therefore, in the evaluations. Our *objective* is to evaluate the schemes considering the characteristics of satellite networks, and make recommendations on the suitability of the schemes. We first determine the desired characteristics of a route optimization scheme for NEMO in satellite networks along with requirements for the incorporation of multihoming into the approaches used for the route optimization. Based the characteristics, previous evaluations and the requirements for multihoming, we analyze the approaches to show their advantages and disadvantages.

Our *contributions* are:

- Identification of the desired characteristics for the route optimization in NEMO for satellite networks.
- Presentation of the requirements to incorporate multihoming into each of the route optimization approaches.
- Analysis of the approaches based on the previous evaluations, the desired characteristics and the presented requirements.

Our analysis will help in future research to select a route optimization scheme for NEMO in satellite networks.

The rest of the paper is organized as follows. In Sec. 2, we present a brief review of satellite constellation networks. In Sec. 3, the architecture for NEMO, NEMO BSP and the route optimization approaches for NEMO are revisited followed by the review of architecture of NEMO in satellite networks in Sec. 4. Sec. 5 presents the desired characteristics of route optimization schemes for NEMO in satellite networks, the requirements for incorporation of multihoming into the approaches, and the analysis of the approaches to show the advantages and the disadvantages of the approaches for NEMO in satellite networks. In Sec. 6, we put forth conclusive remarks.

2 Satellite networks

A satellite network is a network of satellites and stations on the ground. Satellites connect to each other through Inter Satellite Links (ISLs), and to ground stations through Ground to Satellite Links (GSLs). Depending on the relative movement with respect to the Earth, and on the orbital distance, satellites can be of several types – Geo Stationary Satellites (GEO), Low Earth Orbit Satellite (LEO) and Medium Earth Orbit Satellites (MEO). A network of satellites can involve all types of satellites. Examples of networks involving LEO satellites are constellations of LEO satellites, such as Iridium [1], Globalstar [2] etc. Satellites in a constellation are uniformly placed in several hypothetical orbital planes that are dispersed at equal distance and concentric with the surface of the Earth. A satellite is connected to neighboring satellites through ISLs to form a grid like connectivity. Usually satellites on neighboring planes orbit in the same direction except at the seam position of the constellation where satellites in two neighboring planes (first and last planes) orbit in opposite directions.

Satellite networks are characterized by long-delay links, asymmetric capacity of GSLs, multiple links to neighboring satellites, and frequent but predictable movements. Satellites handoff with respect to ground stations and neighboring satellites in different planes because of the movement around the Earth and the limitation of ISLs' connectivity over polar regions, respectively. These characteristics and efforts to integrate satellite networks with the Internet demand the use of IP-based mobility management and routing protocols for satellite networks.

3 NEMO

In this section, we present NEMO architecture and the BSP [10]. This will help the reader to understand the adaptation of NEMO to satellite networks presented in Sec. 4.

3.1 NEMO Architecture

Fig. 1 shows architecture of NEMO. To manage the mobility of nodes in a network collectively, one or more Mobile Routers (MRs) act as gateways for the nodes called Mobile Network Nodes (MNNs) which could be of different types. A Local fixed Node (LFN) does not move with respect to the mobile network. A Local Mobile Node (LMN) can move to another mobile network whereas a Visiting Mobile Node (VMN), which belongs to another network, can get attached to the mobile network. A node in the mobile network can even be an MR itself with a mobile network under it to form a nested NEMO i.e. a mobile network connected to another mobile network. Top Level MRs (TLMRs) are directly connected to the Internet through Access Routers (ARs). During the movement of a mobile network, MRs perform handoff and keep the movement transparent to nodes in the mobile network. The network to which a mobile network is usually connected is called the home network of the mobile network. A Home Agent (HA) in the home network keeps track of the location of the mobile network.

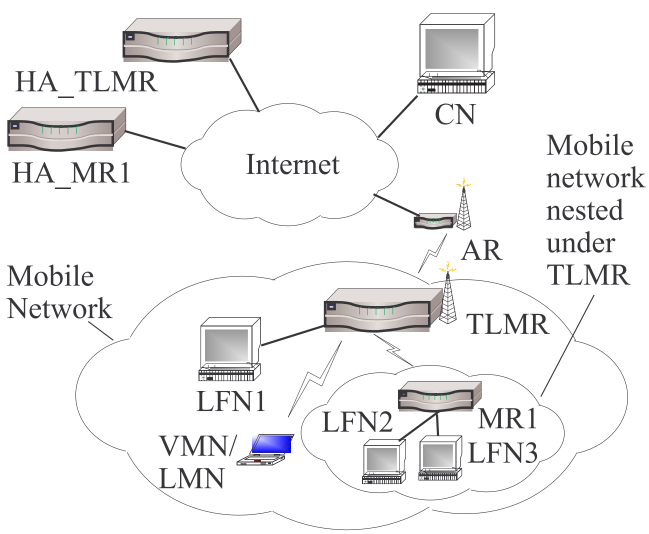

Figure 1: Architecture of NEMO [10].

3.2 NEMO Basic Support Protocol

An MR registers with its HA and acquires a Home Address (HoA) through which the MR is reachable in the home network. MRs are also delegated one or more address prefixes to use inside their network. Prefixes delegated to an MR are aggregated in the prefix advertised by the HA in the home network of the MR. When the mobile network moves out of its home network to a foreign network, the MR obtains a new address, called the Care-of-Address (CoA), from the foreign network and sends a Binding Update (BU) to its HA informing the CoA. The HA creates a binding cache entry that maps the HoA and prefixes of the MR to the CoA of the MR and sends a binding acknowledgement to indicate that the forwarding to the MR is set. Once the binding process is completed, a bidirectional tunnel [20] is established between the HA and the MR, and the HA tunnels all subsequent packets for the mobile network to the MR.

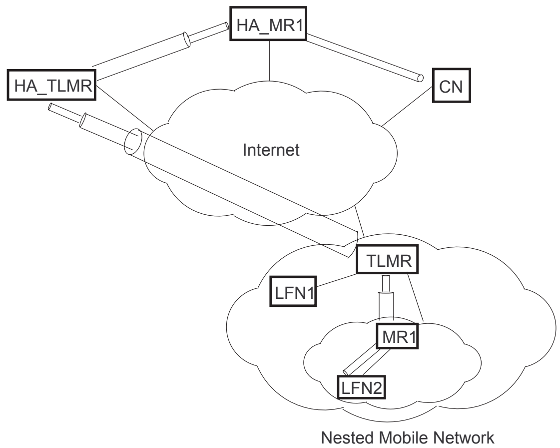

Figure 2: Multiple tunneling in nested mobile network.

Fig. 2 shows packets going from the CN to LFN2 through multiple tunnels in a nested mobile network. Since LFN2 obtains its address from the MR1's prefix (which is obtained from the MR1's home network), the packets are intercepted by HA_MR1 which encapsulates and tunnels the packets to MR1. Since MR1's CoA is obtained from the TLMR's prefix, the packets are intercepted by HA_TLMR which again encapsulates and tunnels them to the TLMR, resulting in multiple encapsulations. Encapsulated packets on reaching the TLMR are decapsulated and forwarded to MR1, which again decapsulates the packets and forwards them to LFN2. Thus, two encapsulations are required for a single level of nesting; in general, the number of encapsulations increases with the nesting level and is one more than the nesting level.

The route to the mobile network is inefficient due to the requirement of traversing through the HAs resulting in a route longer than the direct route between the end hosts. Moreover, the HA has the load of forwarding all packets for mobile networks and nodes. Therefore, several route optimization schemes, based on various approaches, have been proposed.

3.3 Route optimization in NEMO

Based on approach used, the various route optimization schemes that have been proposed can be generally classified [17, 18] as:

- Delegation-based
- Hierarchical
- Source routing
- BGP-assisted

A brief introduction to the approaches are presented in the following subsections.

3.3.1 Delegation-based

In this approach, a prefix of the foreign network is delegated inside the mobile network. The prefix can be delegated using any of the existing prefix delegation techniques, such as DHCPv6 prefix delegation

[21]. VMNs, LMNs and MRs obtain CoAs from the prefix and send BUs to respective HAs and CNs. Therefore, any packet from a CN, addressed to the CoA, reaches the foreign network without going through HAs. For example, as shown in Fig. 3, prefix 2001:afce:1ff3:: is relayed by TLMR inside its mobile network. VMN1 and MR1 obtains CoA 2001:afce:1ff3:110 and 2001:afce:1ff3:11a, respectively; and MR1, in turn, relays the prefix inside its network.

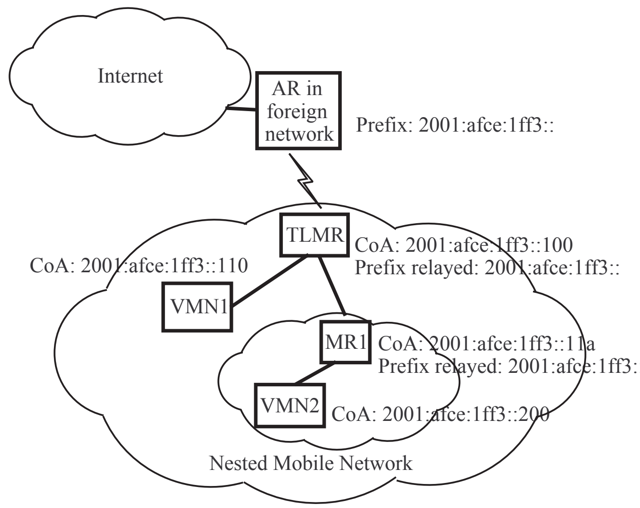

Figure 3: The delegation-based approach for the route optimization.

3.3.2 Hierarchical

In the hierarchial approach, a packet, rather than traveling through all HAs, reaches the foreign network either from MNN's HA (the first HA) or by traveling only through the HAs of an MNN and the TLMR. Unlike the delegation-based approach, an MR does not send its CoA to CNs. Rather, an MR sends the TLMR's CoA or HoA to the HA. CNs use the MNN's HoA to send packets to an MNN. Packets, sent by the CN to an MNN, reach the MNN's HA that tunnels the packets to the TLMR's CoA or the HoA. Packets, tunneled to the CoA, directly reach the foreign network, where as packets, tunneled to the HoA, reach the TLMR's HA that tunnels packets to the TLMR. On reaching the TLMR, packets are routed to the MNN by MRs that maintain a routing table containing the mappings of the MNNs' prefixes to the nexthop MRs.

Fig. 4 shows an abstract view of the hierarchical approach. TLMR_CoA is passed to HA_MR1 and HA_VMN by MR1 and VMN, respectively. Also, MR1 and the VMN send their CoAs to the TLMR to enable the forwarding inside the mobile network. Therefore, a packet sent to the VMN will first reach HA_VMN that tunnels the packet to the TLMR for forwarding towards the VMN. Thus, the communication route is divided into two parts: the route between the TLMR and HA_VMN, and the route from the TLMR to the VMN. This division of the route resembles the hierarchical MIPv6 [22], and hence, the name hierarchical. At least one tunnel always exists between the TLMR and HA_VMN. The route between the CN and MR1 is similar to that between the CN and the VMN.

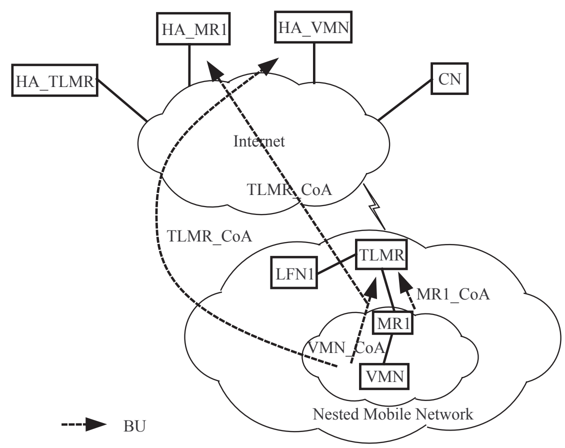

Figure 4: The hierarchical approach for the route optimization.

3.3.3 Source routing

In this approach, the route optimization is achieved by sending the CoAs of MRs to the CN which, like in source routing [23, 24], inserts the CoAs in the packet header to reflect the nesting structure of the MRs. This however, results in increased header overhead. Packets from the CN reach the TLMR in an optimal route (without going through HAs); routing within the mobile network is done using the CoAs in the packet header. Fig. 5 shows the basic principle of the source routing approach where CoAs of the TLMR, MR1 and the VMN are inserted in packets. Packets, on reaching the TLMR, are source routed (using the CoAs) inside the mobile network by the TLMR and MR1.

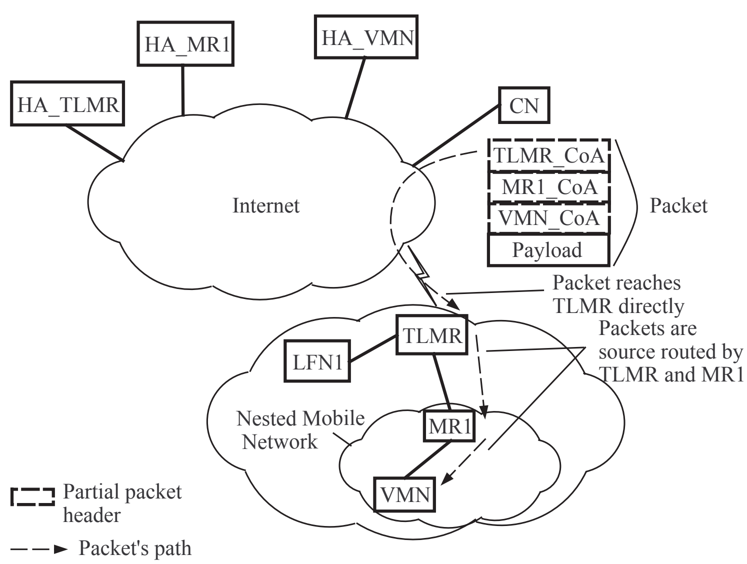

Figure 5: The source routing approach for the route optimization.

3.3.4 BGP-assisted

This approach relies on Border Gate Way Protocol (BGP) [25] or similar protocols for the mobility management. When the mobile network moves, core routers in the Internet are updated to make necessary changes in the routing tables by creating forwarding entries for the prefix of the mobile network. Information regarding the change of the route of the mobile network is signaled to few core routers that exchange the information with peers using the existing routing protocols in the Internet. Therefore, routers contain routing entries to route packets to the mobile network irrespective of its location, and are responsible for the location management. To route packets inside the nested mobile networks, routing entries at MRs are also created from the updates.

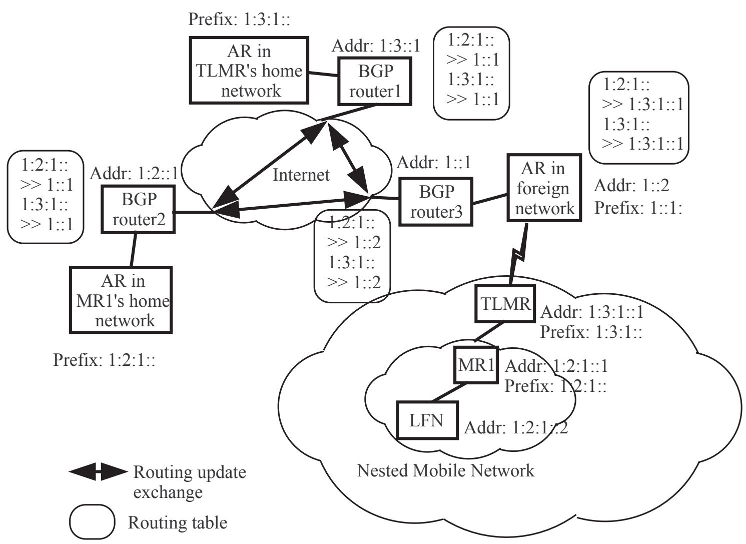

Figure 6: The BGP-assisted approach for the route optimization.

An abstract view of the approach has been shown in Fig. 6. When the TLMR joins the AR in the foreign network, the AR injects an update that maps the TLMR's prefix (1:3:1::) to the AR's address (1::2). BGP router3 in the AR's network updates its peers (BGP router1 and BGP router2), accordingly. Therefore, packets sent by the CN will reach a BGP router in its network, and will be forwarded to the appropriate BGP router's network where the mobile network resides.

4 NEMO in satellite networks

Architecture of NEMO in satellite networks, and its characteristics are reviewed in this section.

4.1 Architecture of NEMO in satellite networks

Fig. 7 shows the architecture for NEMO in satellite networks [13, 14]. Each satellite contains a mobile network connecting the onboard IP-enabled devices, such as LFN1 and LFN2, to an MR onboard.

An MR may form a nested mobile network by connecting to another MR through the ISL. TLMRs are directly connected to ARs through GSLs. In any particular instance of time, a TLMR is connected to a single AR which is co-located with a ground station. For example, AR1 is connected to one TLMR whereas AR2 is connected to another. Thus, multiple isolated nested mobile networks under multiple TLMRs overlay the physical network of satellites. The HAs for the mobile networks reside in the Internet. This architecture can be extended to connect the remote hosts on the ground as VMNs or nested mobile networks.

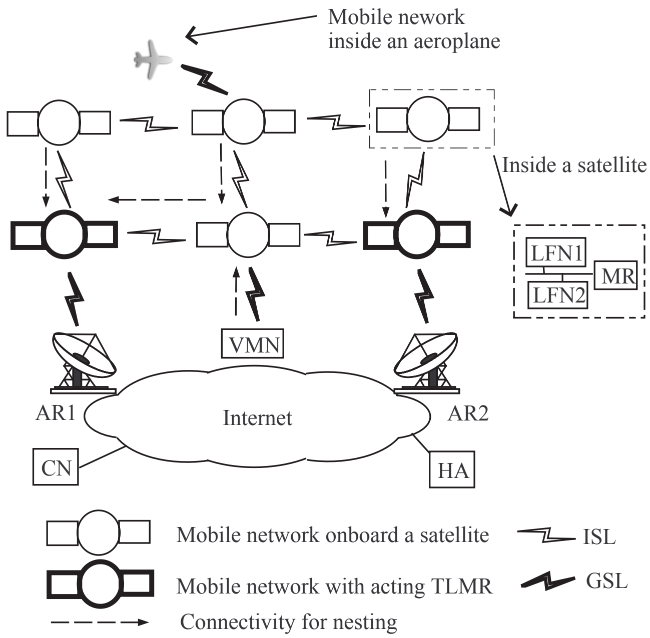

Figure 7: Architecture for NEMO in satellite networks.

4.2 Characteristics of NEMO in satellite networks

Following are the characteristics of NEMO in satellite networks:

- Architectural characteristics: There will be multiple upper-level MRs available to an MR for the nesting.
- Movement characteristics: There will be following two types of movements in satellite networks:
  1. Movements of TLMRs with respect to the ground stations: Such movements will bring either of the following two changes to the mobile network:
     - The change of the AR: In this case, the entire mobile network will move under a new AR.
     - The change of the TLMR of the mobile network: In this case, a TLMR may become an MR whereas an MR either from the same mobile network that was under the TLMR or from another mobile network may become a TLMR.

2. Movement of MRs with respect to other MRs: This type of movements may result in a handoff of an MR either within the same mobile network or to a different mobile network.

- MNNs types and numbers: It is expected that majority of the MNNs will be LFNs.
- Data transfer characteristics: Most of the data transfers will be directed from the MNNs to CNs that reside in the Internet. As TCP is not suitable for the use in satellite networks, UDP-based constant rate protocols, such as Saratoga [26], or other rate-based protocols with minimum rate control are used for transferring data [14].

The characteristics of satellite networks and that of NEMO in satellite networks require determination of the desired characteristics for the route optimization for NEMO in satellite networks.

5 Route optimization for NEMO in satellite networks

In this section, we present the desired characteristics for the route optimization schemes to be used in satellite networks, the requirements for multihoming with the route optimization, and the analysis of the approaches presented in Sec. 3.3.

5.1 Desired characteristics for a route optimization scheme in satellite networks

Desired characteristics for the route optimization schemes to be used for NEMO in satellite networks are also desired for those to be used for NEMO in terrestrial networks. However, it may not be possible to have all desired characteristics, which are sound for the route optimization in NEMO for both types of networks, in a single route optimization scheme. Therefore, by saying desired, we refer to high priority. Based on the characteristics mentioned in Secs. 2 and 4, the following are the desired characteristics for the route optimization schemes:

- Able to take advantage of multiple available MRs for the nesting: Because of the availability of multiple upper-level MRs, an MR either have to rationally choose an upper-level MR for the nesting or have to support multihoming [27], a feature that enables an MR to simultaneously use multiple upper-level MRs. The rational choice of an upper level MR or multihoming is useful to minimize the nesting level, allow load-balancing and avoid overloaded-TLMRs.
- Effects of the movement or change of TLMRs are localized : As has been said in Sec. 4, there will be frequent changes of TLMRs for a mobile network. Given that, and the long-delay links, it is desired that the effects of the movements or the change of TLMRs are localized. By saying localized we mean that information regarding the change is not required to be conveyed to the other MRs or MNNs down the nesting level. Without localizing the effects, information regarding the changes of networks because of TLMRs' movements has to be conveyed down the nesting levels. Conveying information to MNNs takes time due to the long-delay links resulting in large handoff delay for MNNs that are deep in the nesting level.
- Effects of the movements of the MRs are localized: When the MRs move from one network to another, they have to obtain CoAs from the new network, and let CNs and HAs know the CoAs. However, it is desired that the effects of the change are local to keep the handoff latency small. By local it is meant that MRs will obtain new CoAs from the next level MRs, and the MRs up and down the level are not required to be updated. Obtaining CoAs from MRs at levels higher than the next level or conveying the CoA to MRs up/down the level will result in a large handoff latency (because of the long-delay links in satellite networks), and a large amount of signaling.

- Small header overhead: In satellite networks, the links are highly asymmetric with downlinks' capacity being very large and uplinks' capacity being very small. The down links are expected to carry data whereas the uplinks are expected to carry feedback. The header overhead induced by the route optimization should be small to avoid congestion and long delay for feedback. The congestion and delay for feedback may affect the efficiency of the data transfer. Moreover, small header overhead requires small amount of transmission power.

- Small per packet processing: The processing of data at MRs consumes power which is limited in satellite networks. Increased power consumption decreases the life-time of the satellites. It is, therefore, desired that the route optimization schemes require small amount of processing per packet.

Among the desired characteristics, the ability to maintain connections through multiple available MRs is the most desirable of all. The reason behind such desirability is the large delay incurred during the handoff for a mobile network in satellite networks. If multiple connections are available, one of the connections can be used for communications while another one is being handed off. Small header overhead is the second desirable characteristics considering the very low uplink in satellite networks. In addition, small header overhead will also reduce the processing to some extent. The third desirable characteristic is the small per packet processing, as the processing consumes power which is limited in satellite networks. The next desirable characteristics is to localize the effects of the movement of the TLMR to minimize the handoff delay. We suggest prioritizing the localization of the movement of the TLMR over the movement of other MRs based on two reasons. First, the movement of the TLMR will be more frequent than that of other MRs. A TLMR hands off around every eight minutes whereas the handoff of an MR occurs only at polar regions due to physical limitations of antennas. Second, the movement of the TLMR is likely to affect more number of MRs down the level than that affected by the movement of other MRs.

5.2 Multihoming for route optimization schemes

Sec. 4.2 suggests that multihoming [27] is desired to take advantage of the multiple available MRs for the nesting. Multihoming enables a mobile network to have MRs with multiple CoAs, multiple HAs and multiple MRs. Thus, multihoming increases the fault-tolerance capability and options for routing packets. However, there have been very few efforts [28, 29] to consider multihoming with the route optimization. These multihoming techniques can be used to select a suitable upper-level MR for the nesting. However, these multihoming techniques are not suitable for all approaches used for the route optimization. In this section, we present the requirements to implement multihoming for the approaches presented in Sec. 3.3.

5.2.1 Multihoming for the delegation-based approach

In the delegation-based approach, there may be two way to delegate prefixes. In the first way, the prefix of the AR is relayed inside the mobile network. The second way is to hierarchically delegate prefix to each MR.

For the first way, an MR might get the prefixes of the ARs from multiple neighboring MRs. The MR can obtain a single CoA from each of the prefixes, and choose which neighboring MR to use to forward packets. However, if one prefix is advertised by all neighboring MRs, an MR can have only one CoA. However, multiple routes for the CoA can be set up using some routing algorithms inside the mobile network.

To implement multihoming in the second way, an MR has to obtain and delegate more than one prefix from and to the neighboring MRs, respectively. To prevent routing loops, there must be a mechanism in the MR to identify the advertised prefixes that are obtained from any of its prefixes. For example, an MR may avoid obtaining prefixes from an advertised-prefix whose leading part matches any of its prefixes. The number of prefixes obtained and advertised by an MR can be as large as the number of possible routes towards the ARs. Therefore, some control is required to limit the number of prefixes maintained by an MR. For example, the nesting level associated with each prefix can be advertised with the prefix, and MRs can choose to use only a few prefixes that have lower levels than others. However, state information for all available prefixes have to be maintained to enjoy the flexibility of choosing a route from multiple available routes.

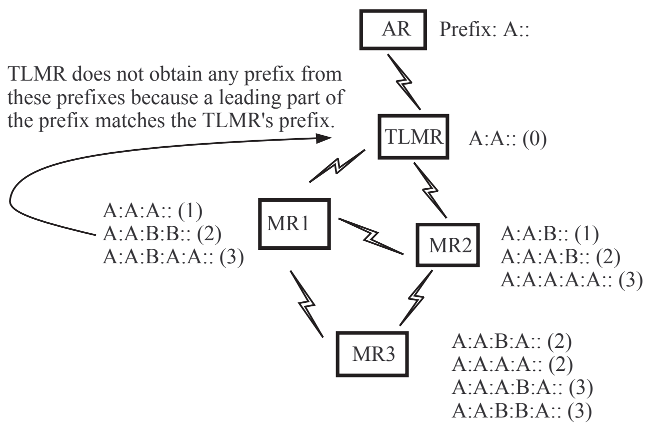

Figure 8: Hierarchical prefix delegation for the delegation-based approach with multihoming. For MRs' prefixes, the number of hops to reach the TLMR is indicated in parentheses.

Fig. 8 shows hierarchical prefix delegation for the delegation-based approach with multihoming. Each of MR1 and MR2 obtains three prefixes from their neighboring MRs. The number of prefixes maintained at each MR is equal to the number of possible routes to the ARs. The number of hops required to reach the TLMR using a prefix is indicated within parentheses. Based on the hopcount, MR1 can decide not to use the prefix $A:A:B:A:A::$, if it is allowed to use two prefixes only. Moreover, to prevent routing loops, the TLMR will not attempt to obtain a prefix from the prefix $A:A:B:A:A::$ advertised by MR1 because the TLMR already has a prefix that matches the leading part of the advertised-prefix. Like the TLMR, MR1, MR2 and MR3 can also prevent the routing loop.

The CoAs obtained from the chosen prefixes have to be sent to the HA and the CNs for the route optimization. The schemes that uses BUs to send the CoAs, can do it by sending a separate BU for each CoA. The schemes that send the CoAs using packet headers have to include a list of CoAs in the header. The level and other route-related information associated with a prefix, from which a CoA has been obtained, can be sent with the CoA. Those information will enable CNs or the HA to decide how to use CoAs to send packets to improve the performance.

5.2.2 Multihoming for the hierarchical approach

Multihoming for the hierarchical approach is less complicated than it is for schemes using the delegation approach. Since each MR only advertises its home prefix only, the number of prefixes will be equal to the number of neighboring MRs assuming one home prefix per MR. Therefore, no mechanism is required to control the number of the advertised prefix. Also, the level and other route-related information can be advertised with the prefix to allow MRs to be able to choose a CoA for communications to improve the performance.

The CoAs obtained from neighboring MRs have to be sent to the TLMR to set up the routes inside the mobile network for the CoAs. An MR can forward a message containing a CoA to the upper-level MR from which the CoA has been obtained. The upper-level MR may forward the message to multiple upper-level MRs. A hopcount can be maintained for the message carrying the CoA. An MR can maintain multiple forwarding entries for a particular CoA along with the number of hopcount to reach the MR to which the CoA belongs. Also, to prevent flooding of the messages, an MR can only forward the message for a CoA for which no message has been forwarded yet. The hopcount and optionally, other information related to a particular entry can be used by an MR to dynamically choose a suitable route for packets.

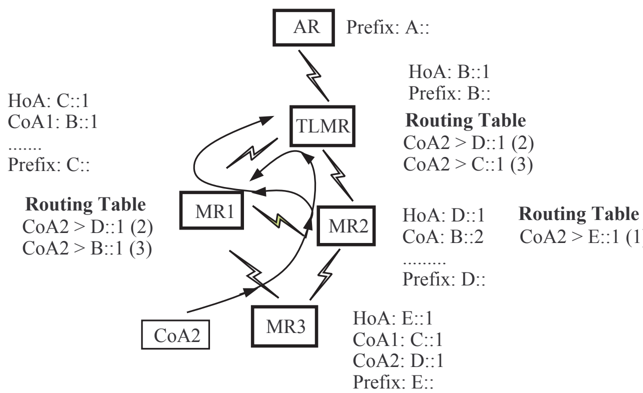

Figure 9: Routing tables in MRs and setting up the routing for CoA2 in the hierarchical approach in a multihomed mobile network.

Fig. 9 shows how the route towards an MR can be set up. A message containing CoA2, obtained by MR3 from the MR2's prefix, is sent to MR2 by MR3. MR2 creates a forwarding entry (CoA2 > E::1 (1)) in the routing table for CoA2 along with storing the number of hops to reach MR3 using CoA2. MR2 also forwards the message to MR1 and the TLMR. The TLMR and MR1 create entries similar to the one created by MR2 in their respective routing tables, and forward the message to MR1 and the TLMR, respectively. The second entries in the TLMR and MR1 are created using the latest forwarded messages. However, MR1 and the TLMR will not forward the latest messages because they have already forwarded a message for CoA2.

An additional requirement for the hierarchical approach in multihomed mobile network is to setup the nexthop towards the TLMRs. In a mobile network without multihoming, the route towards the TLMR is by default the upper-level MR. However, because of the existence of multiple upper-level MRs in the multihomed mobile network, some mechanism is required to identify the upper-level MR to be used to reach the TLMR. An MR can choose the upper-level with the smallest number of hops to the TLMR. Therefore, each MR will need to advertise the smallest number of hops to reach the TLMR.

5.2.3 Multihoming for the source routing approach

Multihoming in source routing approach is similar to that in hierarchical approach from the viewpoint of the number of CoAs obtained by an MR from the neighboring MRs. Unlike the hierarchical approach, each MR has to maintain a list of CoAs of the MRs upto a TLMR for each route towards a TLMR. An MR obtaines the lists of CoAs from neighboring MRs to build its own lists of CoAs. To avoid loops, an MR have to discard the lists, which contain its own CoA, from the lists obtained from neighboring MRs.

In addition, lists of CoAs have to be sent to the CN so that it can include the list in the header to source route the packet. The requirement for maintaining lists of CoAs at MRs and CNs, and sending the lists to CNs might limit the use of multiple routes. To limit the use of multiple routes to a certain number, the number of hops from an MR to the TLMR can be obtained from the list of CoAs. Other information, such as the link quality, congestion etc. can also be used to selectively choose routes to the TLMR.

Fig. 10 demonstrate how multihoming could be used with the source routing approach. As can be seen, MR3 has to maintain four lists of CoAs for the four possible routes toward the TLMR. MR1 and MR2 get the lists of CoAs from MR3; but discards the lists that contain their own CoAs.

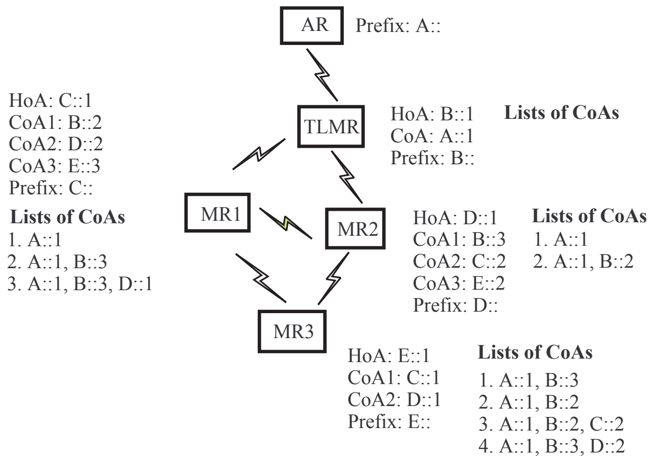

Figure 10: The lists of CoAs each MR need to maintain in the source routing approach for multihomed mobile networks.

In some schemes [30], MRs send one CoA at a time to the to the source of the decapsulated-packet instead of sending the list of CoAs. Thus, the CN eventually receives the lists of CoAs of MRs which are on the route from an MR to the TLMR. To incorporate multihoming in these schemes, an MR will retain the same functionalities from the single-homed versions except the maintenance of multiple CoAs. However, the CN must build the list of CoAs by assigning a CoA to an appropriate list depending on the sender of the CoA, if multiple CoAs for an MR are received.

5.2.4 Multihoming for the BGP-assited approach

Multihoming is simpler in the BGP-assisted approach than in other approaches because the MRs are only required to maintain multiple forwarding entries for the prefix of a mobile network. When an MR joins a mobile network, it has to inject an update containing its prefix towards all neighboring MRs which have to do the same. To limit the number of updates and the number of forwarding-entries per mobile network, the hopcount to the destination can be used. Based on the hopcount, an MR can also dynamically select a route to a mobile network. In addition, a mechanism will be required so that MRs know the route towards TLMRs to route packets to the Internet.

Fig. 11 shows the possible routing tables in MR for multihomed mobile networks. For example, MR1 has two entries in the routing table corresponding to the prefix D :: which is MR2's prefix. One entry can be used to directly reach MR2 whereas the other can be used to reach MR2 through the TLMR. The number of hops to reach MR2 using an entry is indicated inside parentheses. Although the routers in the core network have not been shown in Fig. 11, they have to maintain multiple forwarding entries per mobile network if multiple ARs are available.

Fig. 11 also shows the forwarding of the routing update injected by MR3. MR1 updates the routing table, and forwards the update towards the TLMR and MR2 which insert appropriate entries in their respective routing tables, and forward the update towards each other. However, none of the TLMR or MR2 forwards the latest update to MR1 because, from the routing table, they know about MR1's ability to reach MR3 using a number of hops lower than the number of hops that could be obtained from the update to be forwarded.

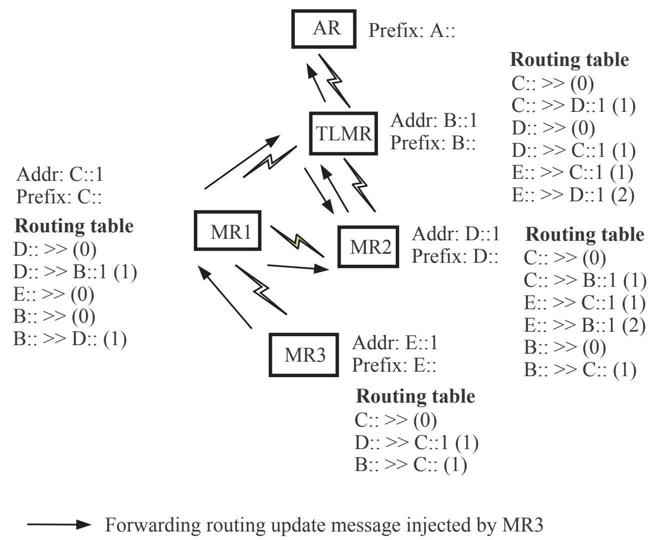

Figure 11: Routing tables for MRs in the BGP-assisted approach with multihoming.

5.3 Analysis of the approaches in terms of the desired characteristics

Based on the desired characteristics and the requirements for multihoming for the approaches presented in Secs. 5.1 and 5.2, we analyze the approaches for the route optimization in the following subsections. Based on the analysis performed in the sections below, acomparison of the approaches is shown in Table 1.

5.3.1 Analysis of the delegation-based approach

The advantages of the delegation-based schemes are the smallest end-to-end delay, header overhead and per packet processing, and the ability to obtain the CoA locally when the MRs move. However, the amount by which the end-to-end delay is smaller than that in the other approaches is very insignificant compared to the value of the end-to-end delay that results from the satellite links.

The disadvantages of the delegation-based schemes are the failure to localize the effects of the TLMRs' movements. For any of the two changes, mentioned in Sec. 4, brought due to the TLMR's movement, the effects are not localized. Due to the change of the AR, the delegated-prefix currently being used in the mobile network will be no longer available. Therefore, new prefixes have to be delegated to MRs. Due to the change of the TLMR, the new TLMR will see a new prefix despite there is no change of the prefix as far as the foreign network is concerned. Therefore, the new TLMR have to re-delegate the prefix to lower level MRs that will also do the same.

In the delgation-based approach, choosing a suitable upper-level MR for the nesting is the easier option than multihoming. An MR can choose an upper-level MR considering the level and/or the TLMRs'

Table 1: Comparison of the approaches used in the route optimization for NEMO in satellite networks.

Approach	**Taking advantage of multiple MRs**		**Effects localized on TLMR's movement**		**Effects localized on MR's movement**	**Header overhead**	**Per packet processing**	**Effects on the core Internet**
	Single MR selection	Multihoming	AR change	TLMR change				
Delegation-based	Possible but inefficient	Feasible by limiting the number of prefixes to be used	No	No	Yes	Small	Low	Small
Hierarchical	Possible but inefficient	Feasible by limiting the number of routes towards the AR	Yes	No	No	Medium	Low	Small
Source routing	Possible but inefficient	Feasible but more resource consuming	No	No	No	Large	High	Small
BGP-assisted	Possible but very inefficient	Feasible but scalability will be an issue	No	No	No	Smallest	Lowest	Large

load. However, if an MR changes its upper-level MR, all MNNs (except LFNs) down the level have to be delegated new prefix or have to obtain new CoAs. Therefore, the flexibility for changing the upper-level MR is costly. Multihoming is difficult for the delegation-based approach because of the hierarchical delegation of the prefix. Because of the large number of possible routes towards the ARs for NEMO in satellite networks, the number of prefixes to be maintained in each MR will be large. Advertising and maintaining a large number of prefixes is a virtually infeasible option because of the resource and processing requirements. However, multihoming could be used with the delegation-based approach by restricting the number of prefixes.

5.3.2 Analysis of the hierarchical approach

The major advantage of the hierarchical approach is the localization of the effects of the change of AR. After moving under a new AR, the TLMR has to obtain a new CoA and perform registration with its HA. The MRs under the TLMR uses the TLMR's HoA which does not change on movements. Therefore, MRs are transparent to the change of the AR. However, in the proposed architecture for NEMO in satellite networks change of ARs may not frequent enough, as it requires placing ground stations fairly close to each other to have a TLMR handing off from one AR to another without incurring a large handoff delay. Also, small per packet processing is another advantage for the schemes using this approach.

Effects of the movements of MRs are not localized in the hierarchical approach because of the conveying of CoAs to the MRs up/down the level. The end-to-end delay and the header overhead are larger in hierarchical approach than in the delegation-based approach due to packets going through two tunnels. However, the difference between the end-to-end delays in the delegation-based and the hierarchical approaches is very insignificant compared to the large values of the end-to-end delays that result from the delay in satellite links. Also, the effects of the change of TLMR of a mobile network are not localized in the hierarchical approach because all MRs have to be updated by conveying the HoA of the new TLMR.

Like the delegation-based schemes, choosing a single upper-level MR for nesting is easy in hierarchical schemes. However, the movement of an MR requires that all MRs up/down the level have to be updated about the change to update the routing entries. Therefore, like the delegation-based schemes, the flexibility of changing the upper-level MR is not there. Multihoming is a feasible option for the hierarchical schemes. Unlike the delegation-based schemes, the number of prefixes and CoAs to be maintained and advertised is equal to the number of neighboring MRs. However, the new CoAs, which are obtained because of the movement of the MR, have to be sent to the TLMR through multiple routes to set up the routes inside the mobile network.

5.3.3 Analysis of the source routing approach

The source routing approach is not suitable for the route optimization in satellite networks for multiple reasons. The basic principle to put all CoAs in the packet header will increase the packet size resulting in the congestion and increased transmission delay at the uplinks due to the small available bandwidth. The congestion and the delay will result in large end-to-end delays despite the complete optimization of the route. Per packet processing overhead is also high because every MR has to process the packet header to replace the source address of the packet with an address taken from the extended header, and remove the address from the extended header.

The source routing approach is also disadvantageous as far as the movement of a TLMR or an MR is concerned. When the TLMR moves, the new CoA obtained by the TLMR have to be conveyed to the MRs below so that they can send the list of CoAs to their HAs or CNs. Thus, the effect of the movement of the TLMR is not localized. The effects of the movement of MRs are not localized either for the same reason.

In terms choosing a single MR from multiple available MRs for nesting, the source routing approach is the same as the hierarchical approach. Multihoming is more resource consuming in this approach than it is in the hierarchical approach. Because of the large number of routes to ARs in the proposed architecture for NEMO in satellite networks, the number of lists of CoAs to be maintained by an MR will be large in the source routing approach. And, a large amount of resource consumption results from the maintenance of the lists, and sending the lists to the HAs and CNs.

5.3.4 Analysis of the BGP-assisted approach

The advantage of the BGP-assisted approach is the small end-to-end delay, per packet processing and the small header overhead. Particularly, the header overhead and the amount of processing is the smallest in this approach, and thus very suitable for the satellite networks as far as the the small uplink and the limited power-availability are considered.

The disadvantage of this approach is the updating of the routers in the core network resulting from movements of MRs with respect to ARs. Any movement of an MR with respect to the AR will trigger updates in the core network. Also, the movement of the MRs will generate a large number of updates in the nested mobile networks. Considering the frequent movements of mobile networks onboard a large number of satellites in a constellation, the number of such updates will be large to raise the scalability issue.

Choosing a single upper-level MR for the nesting from multiple available MRs for nesting is possible in this approach. Multihoming is also possible in this approach. An MR can be connected to more than one mobile network by sending multiple routing updates. However, routers in the core networks have to maintain multiple forwarding entries for the prefixes of a mobile network because of the availability of multiple ARs. MRs also have to maintain a large number of forwarding entries due to the large number of possible routes towards the ARs in the proposed architecture for NEMO in satellite networks. Given those, and the movements of satellites, the scalability issue is aggravated when multihoming is used.

6 Conclusion

In this paper, we evaluate the route optimization approaches for Network Mobility (NEMO) in satellite networks. We start by reviewing the proposed NEMO architecture for satellite networks, and the basic route optimization approaches – Delegation-based, Hierarchical, Source routing and BGP-assisted. Depending on the architecture and the characteristics of satellite networks, we come up with the desired characteristics for the route optimization for NEMO in satellite networks. Since one of the desired characteristics is the multihoming capability, we present the requirements for incorporating multihoming into the basic approaches use for the route optimization. Based on the characteristics and the requirements, we analyze the route optimization approaches to determine the suitability for NEMO in satellite networks. Our analysis shows that delegation-based and hierarchical approaches are more suitable for the route optimization for NEMO in satellite networks than the other two approaches. Analysis also shows the advantages and disadvantages of those two approaches for consideration when selecting an approach. Thus, our analysis lays the base for further analysis to select a route optimization scheme for NEMO in satellite network.

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