Route Optimization for Large Scale Network Mobility Assisted by BGP

Feriel Mimoune ±, Farid Naït-Abdesselam ∓, Tarik Taleb † and Kazuo Hashimoto †

± Computer Science Department, University of Béjaïa, Algeria. mimoune@univ-bejaia.dz.
∓ IRCICA/LIFL - CNRS UMR 8022 - INRIA, University of Sciences and Technologies of Lille, France. nait@lifl.fr.
† Graduate School of Information Sciences, Tohoku University, Japan. {taleb,kh}@aiet.ecei.tohoku.ac.jp

***Abstract*—This paper presents a novel scheme that enables IPv6 mobile networks to perform optimal route optimization. The proposed scheme exploits features of the widely deployed border gateway protocol (BGP). When a mobile network is about to change its point of attachment to the Internet, its mobile router (MR) gets a new care-of-address (CoA) from the visited location and sends a binding update to its home agent (HA). Additionally, MR gets a new temporary network prefix (TNP) at the new location using the prefix delegation protocol. MR then advertises this TNP to its subnet via a router advertisement (RA) message and enables the mobile network nodes (MNNs) to build their own respective CoAs. Simultaneously, this TNP is also sent to the border router (BR) of the home network to enable BR update its BGP routing table. This operation is performed to build an association between the TNP and the mobile network prefix (MNP). BR then notifies its peers of this new update. This procedure will enable any correspondent node (CN) to directly communicate with MNNs, avoiding therefore ingress filtering and reducing both signaling and processing overhead on MR and the home agent (HA). A comparison of the proposed scheme against the NEMO Basic Support scheme, in terms of communication delay, is made via a simple performance analysis.**

I. Introduction

Along with the constant pervasion of the Internet in our daily life, there is a strong desire of the users community in having a seamless access to the Internet anywhere, anytime, and with no disruption in services [7], [20]. In the near future, airplanes, cars, and even people will be able to carry an entire network of IP-based devices connected to the Internet. However, as they move, these networks may change their points of attachment to the Internet seamlessly.

Nowadays, it is possible to handover a single IP-based mobile device from one access point in the Internet to another access point without loosing higher level connections. This is made possible by using Mobile IP (MIP) [6], [13]. If we consider mobility of an entire network, it is possible in fact to use Mobile IP to enable mobility for all the devices within the mobile network. However, this would require all the devices to be Mobile IP capable and will incur significant overhead, i.e, a storm of control packets as every device has to perform Mobile IP functions.

These deficiencies are actually considered by the NEMO working group with the Internet Engineer Task Force (IETF), which is in charge of extending the existing protocols or developing new ones to support IPv6 based network mobility. The actual proposed solution to maintain the continuity of sessions of Mobile Network Nodes (MNNs) within mobile networks is dubbed NEMO basic support protocol [16]. It extends Mobile IPv6 (MIPv6) to support network mobility by suggesting a bi-directional tunnel between the home agent (HA) and the mobile router (MR). In this case, MR's HA intercepts all packets directed to MNNs and tunnels them toward the MR. In the opposite side, MNNs outbound packets are also tunneled to the HA in order to bypass ingress filtering [16]. This mechanism is simple and provides complete and transparent mobility to nodes within the mobile network. However, it raises some issues that should to be solved in order to provide a more reliable, smoother, and more scalable network mobility. In fact, when a bidirectional tunnel is established between a MR and its correspondent HA, with NEMO basic support protocol, a triangular suboptimal routing (known also as dog-leg routing) arises since packets are always encapsulated and forwarded through HA. This results in an increase in the network load across the Internet and adds latency to communication. Moreover, all the packets destined for a mobile network are tunneled through the bidirectional tunnel between MR and HA, so HA becomes the bottleneck of the entire system [21].

In this paper, we discuss the design of a new scheme to enable IPv6 mobile networks to perform simple route optimization by invoking the widely deployed border gateway protocol (BGP). In this scheme, when a mobile network is about to leave its home network and to change its point of attachment to the Internet, its MR gets a new Care-of-Address (CoA) from the visited location and sends a binding update to its HA. Along with this CoA allocated to its egress interface, the MR gets a new temporary network prefix (TNP) at this new location using prefix delegation protocol. The MR then advertises this TNP to its subnet by sending a router advertisement (RA) message and let the MNNs build their own CoAs. This temporary network prefix (TNP) is also sent to the home network's border router (BR) to let it update its BGP routing table by adding this temporary network prefix to the mobile network prefix (MNP) for association. Thereafter, BR advertises its peers with the new update. This operation enables direct communication between MNNs and their correspondent nodes (CNs). It also avoids ingress filtering and reduces signaling and processing overhead at both MR and

HA.

The remainder of this paper is organized as follows. In Section II, we give a brief overview on previous research work related to route optimization in NEMO. Section III portrays our proposed route optimization scheme. Performance analysis is given in Section IV. Section V concludes this paper and shows some further research perspectives to enhance the performance of route optimization.

II. Related Work

Currently, there is a major interest in network mobility. Discussions on related issues are still undergoing at IETF NEMO working group. We present here some of proposed NEMO support protocols [7], [16], [17] with route optimization capability.

The Optimized Route Cache (ORC) scheme [7] performs two main operations. One is performed by proxy routers. In ORC, proxy routers intercept packets, destined to the target network prefixes, using the Interior Gateway Protocol (IGP) in the Autonomous System (AS). They then encapsulate the packets and tunnel them to the corresponding MRs. This operation efficiently reduces the number of binding updates when the mobile network moves. The other operation consists in the fact that the upper routers, in the nested mobile network, are aware of the network prefix information of lower routers and are designed to send them to their ORC routers. For this purpose, it modifies the route advertisement (RA) message by adding a mobility flag to inform MR that the upper network is a mobile network and the information about its ORC routers may be delivered to the upper MRs. However, since modified RAs (with the mobility flag) can not traverse fixed router in the mobile network, fixed routers should be also modified.

The NEMO basic support [16] provides a basic routing scheme to support network mobility. Since Mobile IPv6 does not consider network mobility, packets can not be forwarded to nodes in the MRs network using Mobile IPv6. Hence, NEMO basic support considers a bidirectional tunnel between MR and its correspondent HA. However, when the mobile networks are nested, data packets experience pin-ball routing and multiple encapsulations.

In [17], a Reverse Routing Header (RRH) is proposed to record addresses of intermediate MRs into the packet header and to avoid packet delivery through all HAs of the intermediate MRs. Therefore, in this scheme, there is only one bidirectional tunnel between the first MR and its HA. Although the authors claim that this scheme performs route optimization between a CN and a MR, there is no detailed description on the route optimization operation. Moreover, their scheme suffers from lack of a secured binding update mechanism using RRH and has to modify the router advertisement (RA) messages to count the number of intermediate MRs.

In the next section, we describe our proposed route optimization scheme for network mobility. The proposed scheme is backward compatible with both Mobile IPv6 and NEMO basic support, and solves the intra-mobile network communication problem.

III. ROB: Route Optimization Assisted by BGP

A. Basic Concept

Various approaches have been proposed to cope with route optimization (RO) in NEMO. A vast majority of these protocols require additional network entities or functionalities to be implemented outside the mobile network domain. This obviously may hinder their deployment in the existing Internet. In this paper, our goal is to enable mobile networks to seamlessly change their point of attachment to the Internet while maintaining an efficient routing optimization between any pair of MNN and CN. Our aim is also to reduce the number of signaling messages that could be generated, to improve the quality of service in term of delays, to preserve established sessions without deploying other additional entities, and to solve the triangle or dog-leg routing problem. To achieve these goals, we propose a new scheme to route optimization for network mobility assisted by the border gateway protocol (BGP). This scheme requires only one modification in the routing table maintained by BGP on border routers (BRs) of the Internet. This modification consists in the addition of TNP to the MNP obtained by the mobile network upon visiting a new network. Our purpose is to enable data packets to travel along an optimal path from the source to the destination without invoking the mobile network's home agent as in standard Mobile IPv6. Each MNN will directly communicate with its correspondent nodes using the Care-of-Address (CoA) obtained from the temporary network prefix (TNP) delegated to its mobile router in the visited network. The mobile router advertises this temporary prefix to its home network's border router, which will update its BGP routing table and send the updates to its border router peers. Any corresponding node, willing to communicate with any MNN, will use the corresponding CoA. This yields direct routing and therefore prevents the dog-leg routing.

In our scheme, route optimization is based on BGP. BGP is used in the Internet as exterior routing protocol to allow autonomous systems exchange their routing informations [1]. Core routers in an autonomous system (AS) usually employ an Interior Gateway Protocol (IGP) [2], [3] to exchange routing information within AS. BGP is used between the interconnected autonomous systems to exchange their routes. BGP is a highly robust and scalable routing protocol, as evidenced by its wide use in the Internet. BGP neighbors exchange full routing information when a TCP connection is first established between two neighbors. When changes to the routing table are detected, the BGP routers send information on only changed routed to their neighbors. BGP routers do not send periodic routing updates, and BGP routing updates advertise only the optimal path to a destination network.

For the sake of simplicity, we consider only one single border router per AS. Border routers run BGP as exterior border routing protocol. We represent each entry in the BGP routing table as (*Network*, *Next Hop*, *Path*). The *Network* field represents the network destination address. *Next Hop* field defines the BR's IP address that should be used as the next hop to the network destination listed in *Network* field. The *Path* field is composed of a sequence of autonomous system path segments. In order to know the location of a mobile network in a visited network, we upgrade the entry of the routing table by one more field related to the temporary network prefix (TNP) as (*Network*, *Next Hop*, *Path*, *TNP*). This TNP is advertised by MR upon visiting a new location, to each node setting behind it by sending a router advertisement (RA) message.

B. Location Registration Process

When a mobile network changes its point of attachment to the Internet, it first gets a topologically correct Care-of-Address (CoA) for its egress interface, as well as a new temporary prefix from the visited Access Router (AR). The MR of the mobile network then advertises the delegated prefix to its subnet by sending a router advertisement (RA) [6] message and enables each mobile network node to build its CoA from the delegated TNP. This CoA will be then used when the mobile network node has to communicate with a correspondent node in the Internet. Intuitively, this prevents the ingress filtering and helps reduce the overhead on the mobile router (MR).

Fig. 1 shows an illustrative example of network mobility. First, when MR reaches the visited network, it gets the temporary network prefix (3:1::) from the visited access router. MR advertises the delegated prefix to its subnet by sending router advertisement message with delegated prefix option. When the mobile network nodes receive the router advertisement message with the delegated prefix option, they build individually their respective CoA using this temporary network prefix. At the same time, the MR sends an update message to its home network's BR sitting in its home AS. The BR will then update its routing table entries with this temporary network prefix associated to the mobile network prefix (MNP) (BR1 in Fig. 1). Thereafter, this BR (BR1) advertises its peers with this update (i.e., with the temporary network prefix) according to the standard BGP's behavior.

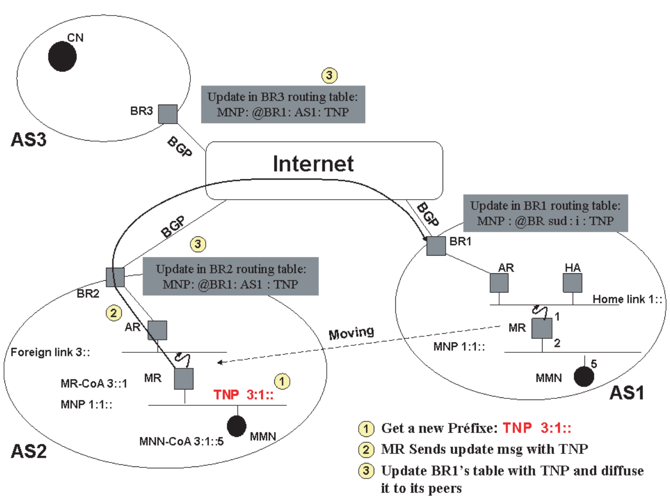

Fig. 1. Location registration procedure.

C. Communication Procedure

When the communication stats from a mobile network node (MNN) to any correspondent node (CN) in the Internet, it sends packets using its CoA as source address to avoid the extra header process and possible ingress filtering mechanism. In contrast, if the communication process is initiated by any correspondent node (CN). At the beginning, the correspondent node receives the home address of the mobile network node by means of DNS request. Thereafter, it sends its first packets toward the nearest border router (BR) within its AS (BR3 in Fig. 2), which will be routed to the home AS (AS1 in Fig. 2) using the home mobile network prefix (MNP) as packet destination address (home address of MNN). We can assume that these first packets are tunneled by the home agent (HA) to the current location of mobile network, using NEMO basic support protocol. Meanwhile, the BR3 advertise the correspondent node with the new location of the MNN, by sending him the new temporary network prefix (TNP) related to MNN's new location. After receiving this TNP, CN forms the corresponding couple (MNN address-CoA) and sends the following packets using the CoA as destination address. By doing so, we avoid the harness of triangle routing implied in the home network.

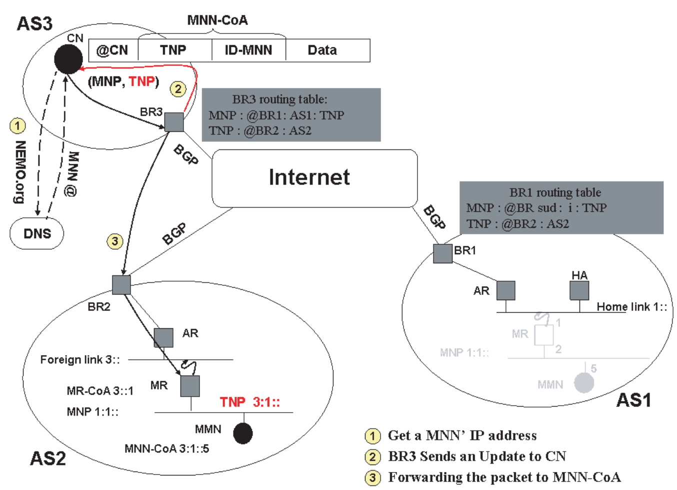

Fig. 2. Communication procedure with ROB scheme

D. Packet Delivery Procedure

In our scheme, generally the first n packets $(P_1 ... P_n)$, sent by any CN toward a given MNN in the mobile network, are generally directed to the home agent of the mobile network. These packets are then encapsulated toward the MNN using the NEMO basic support protocol. When the temporary network prefix (TNP), related to the new location of the mobile network, is known by the border router (BR) of the correspondent node (CN), BR sends the new prefix to CN in order to be used as the new network prefix of the MNN in question. Thereafter, the following packets $(P_{n+1}, P_{n+2}, ...)$ sent by this CN to its BR will be henceforth directly sent to the mobile network node at its new location (Fig. 3).

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Fig. 3. Packets flow.

When the mobile network moves to a new network, the mobile router sends an update message to the border router of its home AS notifying it of its new location. Fig. 4 shows a typical format of the update message used to advertise both BR and CN of the new location of the mobile network. The *Mobile Network Prefix* (MNP) field represents the prefix of the mobile network and the *Temporary Network Prefix* field represents the temporary prefix delegated by the access router and announced by the mobile router to its mobile network nodes.

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |     Code      |          Checksum             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Reserved                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                 Mobile Network Prefix (MNP)                   |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                Temporary Network Prefix (TNP)                 |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Options ...
+-+-+-+-+-+-+-+-+-+-+-+-+-
```

Fig. 4. Update message format.

IV. Performance Analysis

This section compares the performance of the proposed (ROB) scheme against that of the NEMO basic support (BS) scheme. The comparison is made in terms of communication delay, both analytically and with simulations.

A. Analytical Analysis

Let CD_{ROB} and CD_{BS} denote the Communication Delay between CN and MNN in case of the proposed ROB scheme and the NEMO Basic Support (BS) protocol, respectively. The following notations are also used:

- d: the communication delay on a link of one hop,
- i: hop count from MNN to MR,
- j: hop count from CN to HA,
- k: hop count from HA to MR, and
- l: hop count from CN to MR.

The communication delays, CD_{ROB} and CD_{BS}, in case of the two approaches can be formulated as follows:

$$CD_{ROB} = (i + l) \times d \quad (1)$$

$$CD_{BS} = (i + j + k) \times d \quad (2)$$

Subtracting (1) from (2), the delay difference, $diff$, between the two mechanisms is as follows:

$$diff = (j + k - l) \times d \quad (3)$$

Since j and l are bounded and k contributes most to the delay difference, the $diff$ value increases in proportion to the distance of the bi-directional tunnel.

In the performance analysis, we randomly choose the delay values on the one hop link d from the interval $[3ms, 5ms]$. With no specific purpose in mind, we set the hop counts i, j, and l to 3, 10, and 11, respectively.

Fig. 5 shows the global stabilized routing packet delays according to the length of the bi-directional tunnel in terms of hops k. It shows that our ROB scheme can significantly reduce the routing packet delay, especially when the mobile network is far away from its home network, i.e., for large values of k.

Fig. 7 shows the end to end delay experienced by each packet sent by CN toward a particular MNN in the mobile network, considering a scenario where the bi-directional tunnel length is set equal to five. We can notice that the first packets (until packet 10) are experiencing almost the same end to end delay in both BS and ROB schemes. However, as soon as the ROB scheme becomes aware of the new location of the mobile network, the routing optimization takes place and the ROB scheme shows a better performance compared to the NEMO basic support scheme.

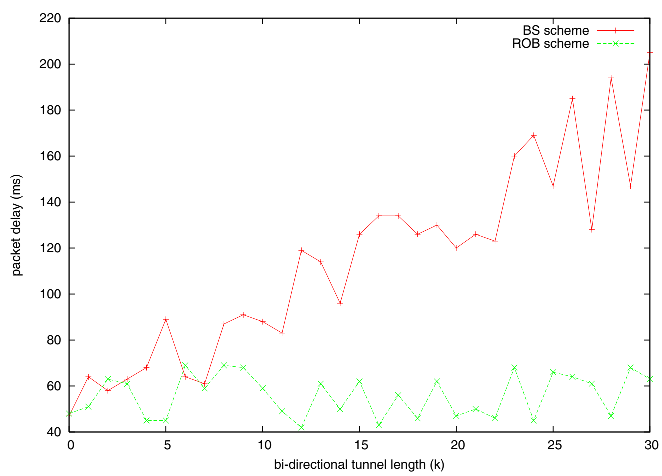

Fig. 5. Global stabilized packet delay as function of tunnel length.

B. Simulation Analysis

In our experiments, we used *OPNET Modeler* simulations [22] to study the performance of our ROB scheme. For our simulations, we used the topology shown in Fig. 1 and generated a constant bit rate traffic between the CN and MNN nodes at 200kbps. A background traffic is also injected within the network in order to simulate other possible communications.

Fig. 7 shows the end to end delay experienced by each packet exchanged by the CN and the MNN in the mobile network. We can notice, as in the analytical analysis, that the

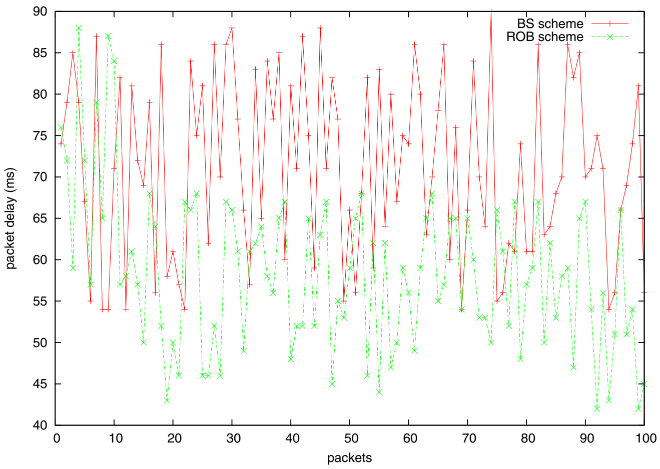

Fig. 6. Individual packet delay ($k = 5$).

first packets (until packet 10) are experiencing almost the same end to end delay in both BS and ROB schemes. However, as soon as the ROB scheme becomes aware of the new location of the mobile network, the routing optimization takes place and the ROB scheme shows a better performance compared to the NEMO basic support scheme.

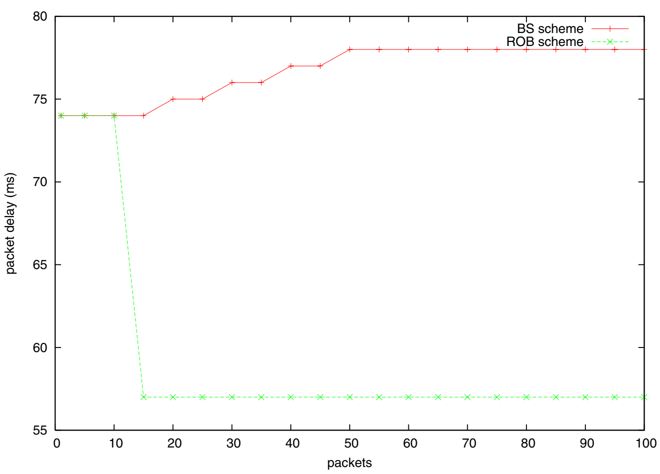

Fig. 7. Experienced packet delays.

V. Conclusion

In this paper, a route optimization scheme assisted by BGP is proposed for large scale network mobility. This scheme requires only few modifications in the BGP routing tables. No changes are required at neither the correspondent nodes nor any of the other network components located outside the mobile network. Our approach enables a correspondent node to transmit packets directly to mobile network nodes without any tunneling. Therefore, it reduces possible encapsulation overheads in both HA and MR, and improves quality of service in terms of bandwidth usage and end to end delays. We have evaluated analytically and by means of simulations the performance of the proposed scheme in terms of packet communication delay between correspondent nodes and mobile network nodes. Results show that our ROB scheme outperforms the NEMO Basic Support scheme in terms of communication delays. However, it may incur a small control message overhead within the core network when advertising the temporary network prefix between the border routers of the area of network mobility. As a future work, we will further investigate the impact of this control packet overhead and see how it can trade off the obtained gain in terms of the end-to-end delay. Nested mobility will be also considered in our scheme to better tune the ROB mechanisms to offer a complete solution for route optimization in network mobility.

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