

Seamless Handoff Solution For Nested Mobile Networks

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Abstract—Ensuring seamless mobility for users is becoming one of the main objectives of ongoing research activities in the field of data telecommunications. More over, if some proposals are efficient in reducing handoff latency for single mobile hosts, adequate solutions are still required for moving networks. The NETwork MObility protocol (NEMO), designed to provide network mobility, is not efficient to offer low latency handoff in the case of nested mobile networks because it uses fairly sub-optimal routing. In this paper, an optimized solution to reduce handoff latency for Nested Mobile Networks is proposed. This solution minimizes the registration delay component of the overall handoff latency. The paper describes the new architecture and mechanisms and provides simulation results indicating performance compared to the basic NEMO solution.

Index Terms—low latency handoff, MIPv6, NEMO, Nested mobile network

I. INTRODUCTION

With the growing number of wireless enabled devices such as laptops, PDAs and smart phones, new user behaviors, services and network architectures are emerging. Nowadays, nomadic and mobile users can carry different terminal devices that can connect to different and heterogeneous wireless access networks such as WiFi, WiMax, GSM and UMTS. These terminal devices have different capabilities and limitations in term of networking capabilities, battery and processing power. To perform some functions (computing, Internet access, data storage...), some of the devices may need assistance from other devices that have more capabilities. In this context, Mobile networks such as Personal Area Networks (PANs) can be formed. Within a Mobile Network, some of the devices can be configured to route flows, and to provide connectivity to the other devices. These are Mobile Routers (MR).

Different applications and scenarios are imagined and proposed for mobile networks. Moving networks can be formed within cars, buses, airplanes or ships to offer network access to the moving set of professional and/or personal users on board. In some cases, one mobile network can behaves as a gateway and provide the Internet access to another mobile network. This results in more complex and multi-level hierarchical architectures known as nested mobile networks. Different scenarios can illustrate these nested architectures. A simple example can be formed when a mobile user accesses the Internet through a mobile gateway. More complex architectures can be formed, for instance, when a PAN of a given user evolving within a bus (or a boat), uses a mobile gateway available onboard.

In this context, the networking community is facing new challenges to manage and ensure seamless mobility within mobile networks. The complexity of the challenge is also raised by the heterogeneity of the used technologies, by the high number of intervening parties (network/service providers and users), and by the architectures of the mobile network it self. Most of the existing mobility management solutions such as Mobile IP (MIP)[1] are only conceived for host mobility (i.e. single devices) management. Applying them in the mobile network context (and mainly in nested architectures) results in poor performance with very high delays and overhead.

Recently, the IETF (Internet Engineering Task Force) mobile working group has proposed the NETwork MObility (NEMO) basic support [2] solution for mobility management of mobile network.

A. NEMO protocol

For managing network mobility, The IETF mobile working group has proposed the NEMO basic support [2] solution by extending the Mobile IP [1] protocol. Instead of registering all the home addresses of the Mobile Network Nodes (MNNs) within its network, the Mobile

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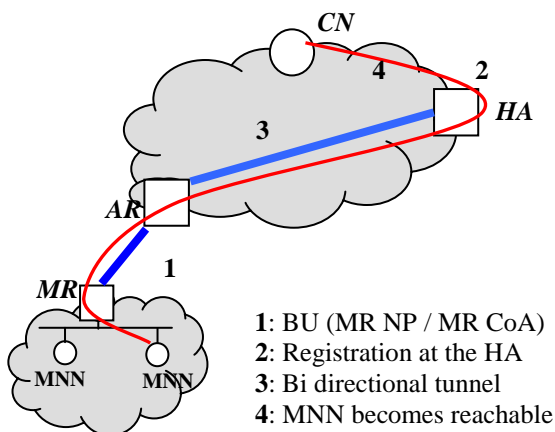


Figure 1: NEMO overview

Router (MR) only sends one Binding Update (BU) message to its HA (Home Agent) in order to update the location of its mobile network as shown in figure 1.

Each time the MR enters a foreign network, it configures a new temporary address named Care of address (CoA). This address can be acquired in stateless or statefull auto-configuration manner [1]. After that, the MR will send a BU message to register its new location with its HA (step 1). At the difference with the Mobile IP protocol, the BU message sent by the MR will contain also the prefix of the Mobile network. By informing its Home Agent (HA) about its Network Prefix (NP) and its new CoA, the MR can provide connectivity to all nodes within its network (step 2). Indeed, when a Correspondent Node (CN) establishes a communication with a MNN inside the mobile network, the HA will intercepts the packets forwarded by the CN to the MNN. Then it looks up for an entry in its binding cache corresponding to the packet destination address or its prefix and encapsulates packets to the CoA of the MR. For outbound packets sent by the MNN, they are encapsulated by the MR to its HA and then redirected to the CN (step 3 and 4). As we can see, all communications from/to the Mobile network must go through the MR-HA tunnel. This results in extra overhead and high delay. Moreover, with nested mobile networks, the problem is amplified with each nested level. In fact, exchanged packets must go through the HAs of all MRs of higher levels before reaching their destination. This problem is well known and called the "pinball problem"[4]. In addition to the drawbacks cited above, these IP-in-IP encapsulations lead also to high handoff latency that may imply packet losses and disconnections.

B. Handoff Latency

The handoff latency is an important issue for the quality of service in mobile networks. Most of time sensitive applications, like audio/video streaming can not tolerate high handoff delays. TCP like protocols can also suffer from these delay variations since they can be interpreted as network congestion and can force the protocol to reduce the throughput.

A handoff with MIP (NEMO) occurs when a VMN (Visitor Mobile node) (MR) switches from an AR

(Access Router)/MR to another across adjacent wireless IP subnets. This results on a delay or latency equal to the time between the last packet received before the handoff and the first one received after it. This delay is divided into two components:

- The Movement Detection Delay (MDD) and
- The registration delay

The MDD is defined as the time required by a VMN:

- To discover that it has been disconnected from the old AR (oAR) and
- To receive the router advertisements (RA) from the new AR (nAR).

Two algorithms [1] are proposed for movement detection in Mobile IP. The first one is based on the expiration of a lifetime period defined as three times the router advertisement interval. This gives a mean MDD of 2.5 s. The second algorithm is based on the reception of a new RA with different prefix and has a mean delay of 0.5 s. Different solutions have been proposed in order to reduce the MDD component. The Fast handoff [3] concept is the most popular and promising solution. It reduces the MDD by allowing the MN to configure a new CoA before it moves towards a new sub-network.

The second component is the time needed by the VMN to become reachable and able again to receive packets sent by the CN. It is the time for the BU to reach the HA and to redirect the traffic to the new VMN' location. However, with the pinball problem described above, this time is very great when dealing with nested network. The BU message will go through different HAs before reaching the VMN HA.

In this paper, we propose a solution to reduce the handoff latency for nested mobile networks by minimizing the registration delay (i.e. phase 2) when a handoff occurs. The following section elaborates on the inefficiency of NEMO to provide seamless handoff when dealing with nested mobile networks. Section II presents an overview of related work and describes major solutions available in the literature. Section III describes the proposed solution and provides details on the added functionalities. A detailed Handoff latency analysis when dealing with our proposal is described in section IV. Finally, simulation and performance results are presented and discussed in section V.

II. PROBLEM DESCRIPTION

In order to illustrate the weaknesses and the low performances of the NEMO protocol when dealing with nested mobile networks, let's consider, in the following sections, the example illustrated in Figure 2.

In this example, three Mobile Networks: MN1, MN2 and MN3 are considered. These mobile networks are managed respectively by MR, oMR (old MR) and nMR (new MR). MN1 is directly connected to the Internet through the Access Router AR. MN2 and MN3 can access the Internet through MN1. MN1, MN2 and MN3 form a two levels nested mobile network.

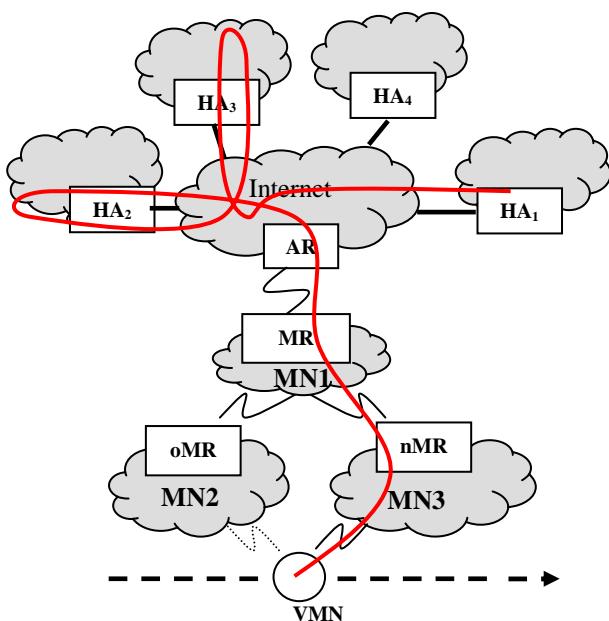


Figure 2. Pinball Problem with NEMO

A. Pinball Problem

When NEMO is used to manage this kind of nested architecture, sent and received packets go through multiple MR-HA tunnels. Indeed, each MR encapsulates generated and received packets on its ingress interfaces to its HA. This results in sub-optimal end-to-end delay and overhead performance. Let us consider the case of a VMN performing a handoff between the nMR and the oMR as shown in Figure 2. As described in [1], once the movement detection phase is completed, the VMN starts the registration phase by sending a BU message to its HA (here HA1). According to [2], both the nMR and the MR encapsulate the packet to their respective HAs (i.e. HA3 and HA2) instead of routing it directly towards the VMN HA. The resulting path for the BU message is the following:

$$\text{VMN} \rightarrow \text{nMR} \rightarrow \text{MR} \rightarrow \text{HA2} \rightarrow \text{HA3} \rightarrow \text{HA1}$$

If in the example of Figure 2, only two nested levels are considered, in practice, the path length is proportional to the number of nested levels. The higher is the number of nested levels, the higher are delays and packet losses and the higher are the ratios of connections and sessions dropping.

B. Communications within the nested mobile network

The reliance on the MR-HA tunnel has also negative effects on the communications between mobile nodes within the nested architecture. Indeed, the IP-in-IP encapsulations have the effect to hide the inner destinations' addresses in the packets' headers. Hence, even if the source and destination nodes are physically located inside the same nested mobile network, all packets are forced to go through the long sequence of HAs. Let's consider again the example of Figure 2. With

NEMO solution, a packet sent from oMR to nMR for example will pursue the following path:

$$\text{oMR} \rightarrow \text{MR} \rightarrow \text{HA2} \rightarrow \text{HA4} \rightarrow \text{HA3} \rightarrow \text{HA2} \rightarrow \text{MR} \rightarrow \text{nMR}$$

whereas they are within the same nested mobile network. Consequently any communications established between nodes inside the same nested network are subject to lack of route optimization due to the pinball problem. One of major drawbacks of this observation is related to the fast handover mechanism proposed to decrease MDD component. As we said before, with the Fast Handover solution [3], a MN asks its AR for a new CoA before the handoff occurs. The oAR and the nAR exchange signaling messages (*Handoff Initiation* (HI) and *Handoff Acknowledgment* (HACK)) to check the validity of the new CoA and to establish a tunnel between them to forward packets received by the oAR while the MN performs its handoff. With the lack of optimization problem described above, these signaling messages are subject to a high end-to-end delay in nested architecture. Consequently, the MN can be disconnected from the oMR before the end of the handoff initiation operation which results in high packet loss ratios. Moreover, even if the tunnel is established successfully before that the MN disconnects from the oMR, all packets forwarded by the oMR are subject to the pinball problem resulting in sudden increase of the end-to-end delay. This typically causes protocols such as TCP to reduce their advertising window sizes and hence induce an unacceptable reduction in connection throughputs.

As we can see, all these drawbacks are due to the IP-in-IP encapsulation introduced by MIP, continued with NEMO and amplified with nested network. In order to reduce the handoff latency, a route optimization solution must be provided. In the following, we present some proposals described in the literature.

III. RELATED WORK

Numerous methods have been proposed to reduce the registration phase delay. Decreasing this delay will minimize the handoff latency impact for nested mobile network. A taxonomy of the different solutions is presented in [4]. The most of them consists of reducing the number of MR-HA tunnels to just one bi-directional tunnel between a MR (in general the TLMR: Top Level Mobile Router) and the Home Agent of the visiting mobile node VMN.

In [5], a new routing header called the RRH (Reverse Routing Header) is proposed. This new RRH header is used to record the route out of the nested mobile networks. Each MR on the egress path places its CoA in the RRH. Receiving this header, the HA can construct the chain of Mobile Routers the first MR is attached to. The major inconvenient of this solution is the additional overhead, introduced by RRH on each packet, which increases with the number of levels of the nested mobile

TABLE I.
ROUTE TABLE (RT) OF TLMR AND IMR

TLMR RT	H@ VMN	oMR' CoA
oMR RT	H@VMN	VMN' CoA

network.

In [6], authors extend partially HMIPv6 (Hierarchical MIPv6) to support nested mobile networks. The main idea is that the TLMR acts as a Mobile Anchor Point (MAP). In addition to its LCoA (Local CoA) configured as described in [2], each MR configures a RCoA (Regional CoA) based on the TLMR prefix. Outbound packets will be encapsulated using the RCoA to avoid encapsulation by the others MRs. For inbound packets, reference [5] proposes a new header, denoted RH2, to indicate the next hop for each MR in the egress path. In addition to the overhead introduced by the RH2 header, this solution presents limitations in solving the communications problems within the nested mobile networks.

Some proposals ([7], [8], and [9]) provide prefix delegation based-solutions to optimize the route in mobile networks. The access router of a nested structure is both, a NEMO home agent and a DHCP-PD (Dynamics Host Configuration Protocol- Prefix Delegator) server which gives nodes in the mobile network a topologically meaningful address and the ability to communicate with external CNs.

IV. PROPOSED ARCHITECTURE

As seen in the previous section, reducing the handoff latency in nested mobile networks environment would be achieved by eliminating the pinball problem. In [10], we proposed a solution that optimizes the routing mechanisms in nested mobile networks for NEMO basic support. In this paper, we extend the performance analysis of this solution in order to show that the same proposal reduces significantly the handoff latency, and hence enhances mobility management for mobile networks, users and nodes. Moreover, proposal described in [10] focalizes only on the case of a MIPv6 node visiting a mobile network. In the following, we extend this solution to be more general and include the case of all a mobile network getting connection from another mobile network. Security considerations are also discussed.

A. Overview of the proposed solution

The proposed solution in [10] reduces the number of IP-in-IP encapsulations, resulting in one unique tunnel between the VMN HA and the MR that provides access to the entire nested mobile network. This is achieved by introducing the following functionalities to MNs, MRs and HAs:

1) A new bit, R, is added to RA (Router Advertisement) messages of MRs. It is set to "1" by a

MR if it is away from its home network or if it receives a RA message with R set to "1".

2) When a VMN receives a RA with R set "1", it does not encapsulate packets (generated or received on its ingress interfaces) as described in [1] and [2].

3) A new CoA option is added to the BU (Binding Update) messages and used to store the CoAs of VMNs.

4) When receiving a BU with the CoA option, a MR inserts a new entry in its route table for the BU home address option value. The source address of the BU will be the next hop. This entry will be used to route packets sent to/by the VMN. Then, the MR swaps the source address to its CoA

5) The only tunnel in this architecture is established between the TLMR and the HA of the VMN

B. Analysis

Let's consider again the example of Figure 2 where a VMN is switching from oMR to nMR network. After configuring a new CoA using the router advertisement message, the VMN performs registration with its Home Agent by sending a binding update message. This packet contains the new CoA of the VMN as a source address, the HA address as the destination address and a home address option field set to the home address of the VMN. The new CoA option will contain the CoA of the VMN. Each Intermediate MR on the egress path (nMR) adds a new entry in its route table for the home address of the VMN where it sets the source address of the received BU message as the next hop. Then, it swaps the source address of the packet to its CoA. To avoid any ingress filtering mechanism [11], the home address of the BU message is added to the security policy, so that packets originated from this address can be forwarded. Finally, when the packet is sent by the MR (named also TLMR) to the VMN's HA, it has the CoA of TLMR as the source address and the route tables of different MRs will contain the information contained in table 1.

a) Inbounds packets:

Packets forwarded to the VMN home address are routed to the HA of the VMN using ordinary IPv6 routing. The HA encapsulates the packets and tunnels them directly to the MR CoA avoiding pinball problems. The TLMR looks up for an entry in its route table which correspond to the inner destination address of the packet (VMN home address) and forwards the packets to the next MR (nMR) and so on, until the packets arrive to the VMN.

b) Outbounds packets

Because it received a RA containing the field "R" set to 1, the VMN does not encapsulate packets when sending them to the CN. Encapsulation to the correspondent Home Agent is achieved by the TLMR. Since the ingress filtering mechanism is updated at MRs level by the BU message, packets are allowed to be forwarded within the nested mobile network

c) Maintaining route table

BU messages sent periodically by MIPv6 nodes to their correspondent Home Agents as described in [2] are also used to maintain the route tables in each MR. Hence, there is no need to introduce additional signaling messages to achieve these updates.

C. Extension for the case of a nested MR

The proposed architecture can be easily extended to support the case of MR node. As discussed above, with NEMO solution, MRs associate their Care of Addresses (CoA) with their network prefix in the Binding Update (BU) messages sent to their Home Agents. The unique extension to [10], is to add an entry for the MR prefix at the MRs located on the egress path. Hence, when a MR receives a BU message with a prefix registration, it swaps the source address of the packet to its CoA like with the case of nested VMN and adds an entry to its route table for the prefix stored in the BU. The next hop of this entry will be the source address of the BU.

D. Security Considerations

One of major NEMO threats can happen when an attacker redirects the mobile node's traffic to another address by changing the CoA field in the BU. In order to prevent this and according to [12], a Mobile IPv6-enabled node must use the Alternate Care-of Address mobility option in Binding Updates to store its primary CoA. This field is protected by the ESP (Encapsulating Security Payload) [13] mechanism and the HA can check if the source address of the BU is really the CoA of the MNN by comparing it to the alternate CoA filed. If we apply this recommendation in the proposed solution, the BU will be discarded because the source address is not equal to VMN CoA. To avoid this we propose to store the TLMR' CoA in the alternate CoA option before sending the BU. The CoA of the TLMR will be broadcasted and forwarded to all the MNNs in the nested mobile network by the RA message sent by each intermediate MR.

V. HANDOFF LATENCY ANALYSIS

After describing the solution proposed in [10] to eliminate the pinball problem, we illustrate in the following how this proposal reduces the handoff latency not only in a micro mobility scenario but also within a macro mobility one.

A. Local handoff (micro mobility)

Consider the case where the VMN performs a local handoff in the same nested mobile network between the oMR and the nMR. We have shown in section II.A the path followed by the BU sent by the VMN to reach its HA. We can conclude the lack of optimization introduced by NEMO since the packet is not routed directly to the HA VMN. With our solution, the VMN quickly becomes reachable, as soon as the BU reaches the cross-over MR

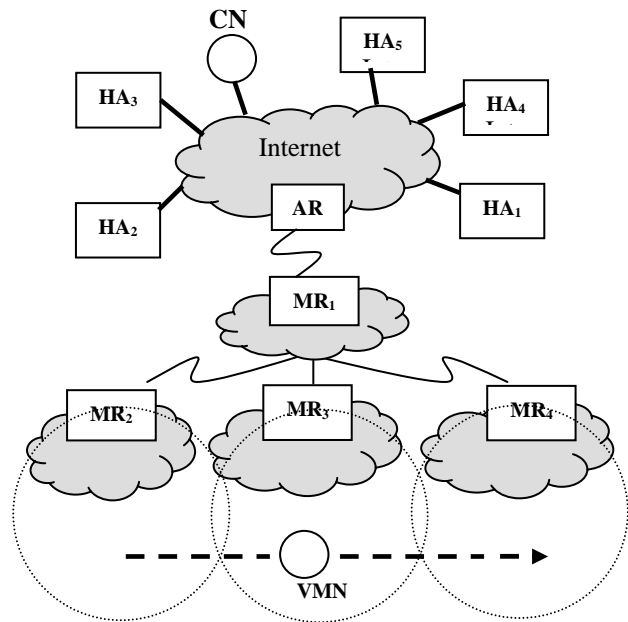
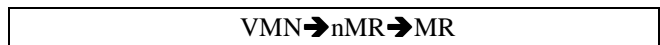


Figure 3. Network model

(at the intersection between the old and the new path) which, in the case of Figure 2, is the TLMR. In fact, when the TLMR receives the BU message sent by the VMN, it will update the entry in its route table corresponding to the Home Address of the VMN with the nMR CoA as the next hop. Thus, the VMN can now receive packets from a CN before the BU reaches the HA. Hence, the registration phase delay is reduced to the delay of the following path:



Then, when the handoff occurs inside the nested network, the mobility is managed locally and there is no need to wait for the BU to reach the HA. The registration phase delay is then reduced to just the delay to attain the cross over router.

B. Non local handoff (macro mobility)

We have seen in the previous section how our proposal reduces the handoff latency in the case of local handoff inside the nested network. As we said before, this conclusion is also extended to the macro mobility scenario. Suppose that the VMN is moving from its Home network (or any another mobile network) to a nested mobile network. As described in section I.A, the VMN will send a BU to its HA. However, it uses the CoA option instead of the source address in binding the home address. The packet is forwarded directly the HA of the VMN without going through additional destinations. The path followed by the BU message to reach the HA is the following:



It seems obvious that the path is now much shorter than the one achieved by the NEMO solution and shown in section II.A

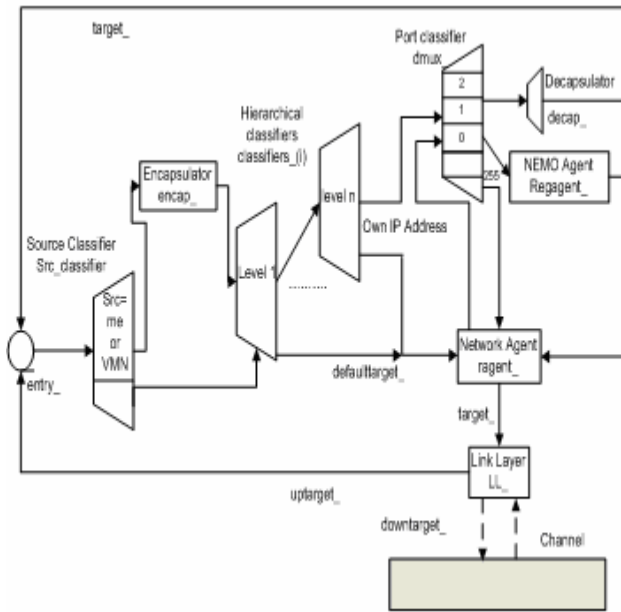


Figure 4. Schematic of MR node

VI. PERFORMANCE

In this section, we present some comparative performance results with the NEMO basic support protocol. Simulations are performed using the Network Simulator NS2 (Release 2.27) [14] with the Mobiwan extension [15]. The performances of TCP and UDP traffic during handoffs in a two-nested level mobile network are evaluated. The impact of the handoff latency on packet losses and packet delays are also reported.

A. Implementations details

The Mobiwan extension provides an implementation of mobile IPv6 which is not included within the NS2.27 version. For the needs of our simulations, we have introduced new entities and functionalities to the mobiwan extension in order to achieve NEMO and our proposal operations. Indeed, a MR agent is created and patched to the Mobiwan module. This was realized by combining some BS (Base Station) functionalities to the MN Agent capabilities. Broadcasting router advertisement, responding router solicitation, encapsulating and decapsulating packets; all these operations are developed and integrated in the new MR entity. Figure 4 describes a schematic of the MR entity. Outbound packets are classified by the src_classifier to be encapsulated or directly forwarded, while inbound packets are filtered by the port classifier dmax_. An enhanced version of this entity is also implemented in order to achieve our proposal where encapsulation and decapsulation are only achieved by the TLMR. An interface between the NEMO agent (at the MR level) and the route table is created for updating route entries when receiving BU message.

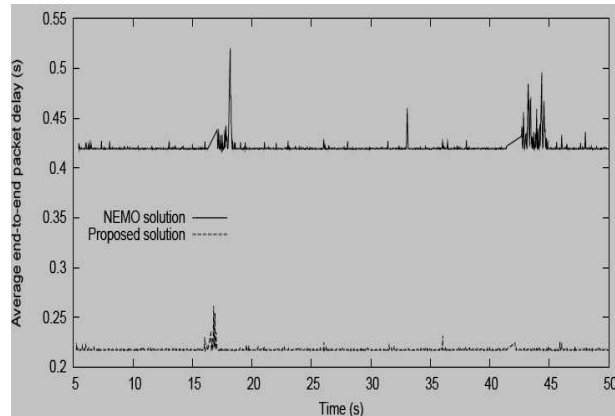


Figure 5: End-to-End Packet delay

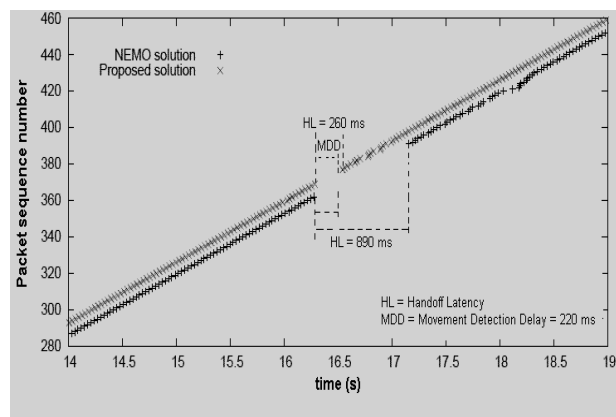


Figure 6: Detailed handoff procedure for both solutions

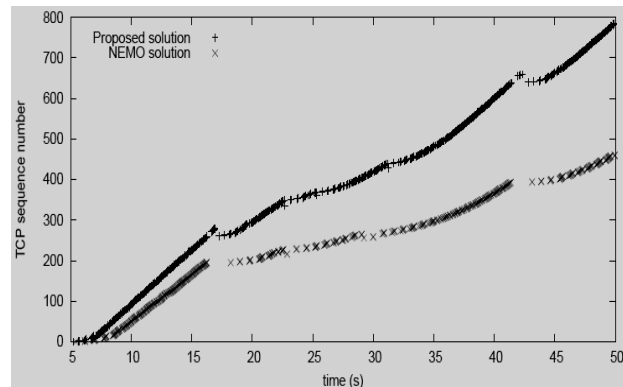


Figure 7: Handoff performances for TCP traffic

B. Network model

We considered a two-level nested mobile network as depicted in Figure 3. HA1 to HA4 are respectively the home agents of MR1 to MR4. HA5 is the Home Agent of the VMN node. All home networks are connected to each other through the Internet using backbone links with a delay equal to 100 ms.

During the simulation, the VMN performs a first handoff at time 16.26s between MR2 and MR3. A second handoff between MR3 and MR4 takes place at time 43.80s.

C. Traffic model

Two traffic scenarios are considered in the simulations. In the first scenario, the CN generates a CBR traffic composed of 500 byte packets with an inter-arrival time of 30ms. In the second scenario a FTP over TCP connection is established between the CN and VMN.

D. Simulations results for UDP traffic

End-to-end packet delay measurements are depicted in Figure 5 and compared to NEMO performances. The results show that the proposed solution significantly reduces the end to end packet delay. Indeed, the proposed solution uses a unique tunnel regardless of the number of nested levels in the mobile network. For the simulated network model, composed of 2 nested levels, the gain is about 200ms, 100ms for each level. This result is very important for time sensitive applications that require stable network conditions. Moreover, the proposed solution considerably reduces the handoff latency compared to NEMO. After the movement detection phase, the latency of the registration procedure is limited to the delay required by the BU message to reach MR1.

Figure 6 presents a close up on the first handoff that occurs at 16.28 ms. The movement detection phase has the same duration with both solutions. The MDD (Movement Detection Delay) is about 220 ms. However, with the proposed solution, the VMN becomes reachable only 40 ms after the end of the MD phase. This gives a total handoff latency of 260 ms. With NEMO, the VMN requires more time to receive packets sent by the CN. The handoff processes takes a total time of 890 ms. The handoff latency is reduced by about 530 ms in the case of a two-level nested mobile network. This gain directly impacts the packet loss ratio in the case of UDP traffic and the packet throughput in the case of TCP traffic (see next results for TCP). In the UDP simulated scenario, 8500 data bytes are recovered compared to NEMO.

E. Simulations results for TCP traffic

Figure 7 illustrates the behavior of a TCP flow. As shown, and since the proposed solution reduces both the handoff latency and the end-to-end packet delay, the TCP flow behaves better. TCP is in fact very sensitive to delays and delay variation. It uses a timer and detects and reacts to hypothetical congestion after timeouts.

With the proposed solution, the VMN continues receiving packets from the CN before this last realizes the packet loss. Thus, to recover packet lost during handoff, VMN sends "triple-duplicate" ACKs and avoids the TCP slow start algorithm. This is not the case with the NEMO solution where the CN must wait for the expiration of the retransmission timer to restart the Exponential Backoff algorithm which results in higher delays reduction of the number of nested tunnels as described in

VII. CONCLUSION

In this paper, we tackled the performances of the handoff mechanism in nested mobile networks. First, we analyzed the behavior of the Network MObility (NEMO) protocol in the context of nested architectures. We

showed that in these conditions, the NEMO solution can not guarantee seamless mobility and low handoff delays, mainly because of the pinball problem due to an excessive usage of tunneling and encapsulation. Moreover, we also proved that the NEMO protocol drastically reduces the performances of communication between mobile nodes inside the nested mobile networks.

We then presented enhancements to reduce the registration phase delays and moderate the effect of the pinball problem. The proposed solution meaningfully reduces handoff latency and packet losses. It achieves better throughput and lower end-to-end delays with both TCP and UDP flows. It also optimizes communications within the nested mobile network and hence enables anticipated handoff solution like the Fast Handoff.

Security of the proposed architecture is also discussed and some enhancements have been introduced to avoid specific threats. However, others threats and attacks have to be studied and taken into account. Indeed, since the proposed solution reduces tunneling usage, intermediate nodes and Mobile Routers are able to read parts of the packet headers that were hidden with NEMO. The authors are currently exploring how trust establishment and data protection can be achieved at low cost to extend the current proposal and propose a secure solution while retaining most of the predicted benefits and high performances.

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