Evaluation of NEMO Communications Using Hybrid Measurement

Jean LORCHAT and Romain KUNTZ

Keio University, Jun Murai Lab
5322 Endo, Fujisawa-shi, Kanagawa 252-8520, Japan
E-mail: {lorchat|kuntz}@sfc.wide.ad.jp

***Abstract*— In this paper, we introduce a new apparatus to evaluate communications performance, which combines both active and passive measurements. This approach is very suited for moving networks (NEMO) in ITS environments, as we will show in a detailed scenario and experiment. The experiment uses the currently available NEPL implementation of NEMO based on the GNU/Linux operating system to demonstrate the actual feasibility of the scenario. Then the hybrid measurements approach makes it possible for us to thoroughly analyze the outcomes, be they achievements or failures, of this very architecture.**

I. INTRODUCTION

In today's Internet, we expect to have more and more equipments connected at the same time while being mobile. Such constraints require to have a permanent connectivity anywhere, anytime, while moving in the Internet topology. The IPv6 and NEMO Basic Support protocols have been standardized at the IETF as a solution to the scalability and mobility problems raised by the actual and most used version of the Internet Protocol (IPv4).

An important feature of NEMO Basic Support is the use of a Mobile Router that hides the mobility of the network to the nodes attached to this router. In addition, using NEMO Basic Support a Mobile Router can seamlessly hand over from one access technology to another, which allows to maintain communications between nodes in the moving network and their peers outside of the moving network. From the ITS point of view, these features make NEMO Basic Support a very likely and fit architecture [1] as recommended by the ISO TC104 WG16 draft standard : Communications, Air interface, Long and Medium range (CALM)[1].

To evaluate performance of the NEMO to NEMO communications case, which can be used for both the ITS Vehicle to Vehicle (V2V) communication scheme and the Vehicle to Infrastructure (V2I) scheme, we propose a new hybrid evaluation framework that uses both passive measurements from the NEMO router itself, and active measurements between pairs of NEMO routers. This allows to keep track of the protocol running state while being able to tell the impact of each protocol mechanism on the network conditions.

This paper is organized as follows. In section II we overview an actual NEMO Basic Support implementation: NEPL (NEMO Platform for Linux). Then we introduce in section III the hybrid evaluation framework made of both active and passive measurement tools. In section IV we present the ITS scenario that is going to be used for the experiment, whose results are shown and analyzed in section V.

[1]http://www.calm.hu

II. THE NEMO ARCHITECTURE

A. NEMO Basic Support

Network Mobility support in IPv6, as presented in [2], allows a whole IPv6 network to stay connected to the Internet, without disruptions, while moving its point of attachment in the network topology.

The NEMO Basic Support protocol [3] has been designed to ensure session continuity and reachability while moving, transparently to all the nodes (Mobile Network Nodes, MNN) in the moving network. A router, known as the Mobile Router (MR), connects the moving network (NEMO) to the Internet. The current location of the MR, represented with its Care-of Address (CoA) is registered to a Home Agent (HA) located in the MR's Home Link. While the MR is on the move, the Home Agent maintains a binding between its location (its CoA), its identifier (its Home Address, HoA) and the IPv6 prefix advertised in the NEMO (the Mobile Network Prefix, MNP). Such information are exchanged between the HA and the MR by the mean of the Binding Update and Binding Acknowledgement messages.

The connection is maintained between the Mobile Router and its Home Agent thanks to a bi-directional IPv6-in-IPv6 tunnel. The Home Agent which is aware of the Mobile Router's location can thus forward all the packets destined to the MR's HoA or the MNN's addresses through the tunnel. Conversely, the MR and MNN can reach any other node in the Internet via the Home Agent, through the tunnel.

The first contemplated usage of this technology is the ITS, to connect in-vehicle networks [4] (such as sensor networks or access networks deployed in public transportation) to the Internet. We further present an application of this technology in the ITS field in section IV. Personal Area Networks (PANs) are another usage, as shown with the E-Bicycle testbed [5]. This demonstration platform aims at integrating all the technologies around NEMO Basic Support, such as multihoming or AAA mechanisms.

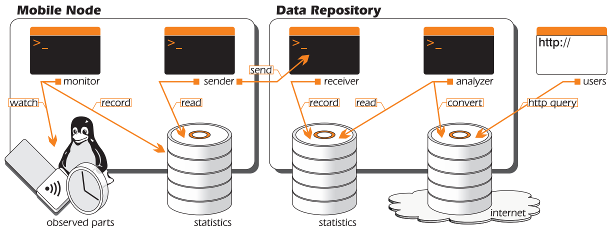

Fig. 1. The SONAR architecture

B. NEPL: NEMO Platform for Linux

NEPL (NEMO Platform for Linux)[2] is a freely available NEMO Basic Support implementation for Linux on 2.6 kernel. It is based on MIPL2 (Mobile IPv6 for Linux) and has been developed and tested in cooperation between the Go-Core Project (Helsinki University of Technology) and the Nautilus6 Project[3].

NEPL currently supports Home Agent and Mobile Router, Implicit and Explicit registration modes and Dynamic Home Agent Address Discovery (DHAAD). Preferences can be allocated to several network interfaces to automatically choose the best one available for communications. The Mobile Router is thus said multihomed and can use sequentially different Internet access technologies according to their availabilities. Such handover, known as vertical handover, allows to benefit from different access technologies by always using the best one available.

III. Data Gathering and Evaluation System : SONAR

The standardization of protocols that handle moving networks raises questions about their performance. It is thus important to define tools that can be used to evaluate the new protocols, in order to seek potential faults and provide research community with actual data from real life experiments. These issues are addressed by the SONAR[4] evaluation system, the passive part of our hybrid measurement approach.

The SONAR architecture is summarized in Fig.1. It is organized in a distributed fashion where each node collects local data to be stored in a statistics engine and sends it periodically to a central server gathering information from all mobile nodes. These two separate entities comprise several modules.

On the mobile node side, the monitoring module collects statistics periodically and according to specific events. The parts observed by the monitoring module include parts from the link layer (i.e. network interfaces) and the network layer (i.e mobility protocols). Every set of data is recorded with an accurate timestamp in the local statistics engine. The sender module then periodically connects to the data repository server to transfer these statistics.

[2]http://www.mobile-ipv6.org
[3]http://www.nautilus6.org
[4]http://sonar.nautilus6.org

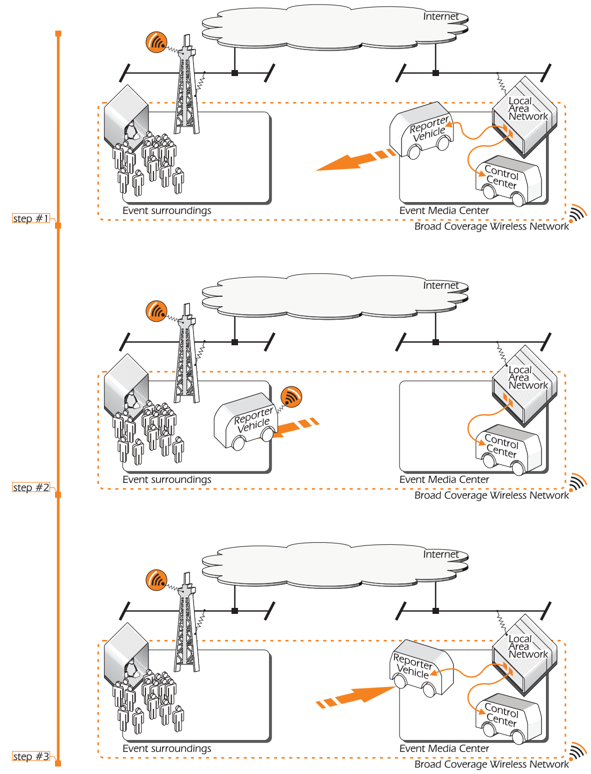

Fig. 2. TV Journalist Scenario

On the data repository side, the receiver module collects data from all SONAR clients in order to store them in a large database. This database is queried on a daily basis by the analyzer module to generate detailed reports of the new sessions that were recorded during the previous day. These reports are made available to the public via a web interface.

IV. Scenario and Tools

A. NEMO to NEMO communications

We present the TV journalist scenario as an example (see Fig.2). Journalists need to be mobile while exchanging various information to their control center. The journalist's in-vehicle network embeds several IPv6 devices such as a video-camera for shooting an event, computers for video processing, video-conference devices, and sensors to get the environment information.

The in-vehicle network's gateway is a Mobile Router running NEMO Basic Support. It allows to maintain the sessions running between this vehicle and the infrastructure network while the vehicle is on the move. This Mobile Router is multihomed, and can connect to the Internet using different access technologies, such as broad coverage wireless access (Satellite, WiMax, Wireless LAN), wired access (Ethernet), or cellular networks. The Mobile Router can thus always choose the best access available, and switch from one to another without disruptions for all the nodes located in the in-vehicle network. We can thus have a permanent and mobile information system.

The journalist's vehicle is first located in the event media center (Fig.2, step #1). All the vehicle's information (video, audio, sensors' values) are sent to the control center using a wired but broadband access. Once an event needs to be covered by the journalist, the vehicle can switch to a broad coverage and wireless access and move to the event surroundings (Fig.2, step #2). The handover can be done between both technologies with a minimum impact to the information exchange between the vehicle and the control center thanks to NEMO Basic Support.

During the event, the control center may also move and switch from its broadband access to a wireless access. The control center thus also embeds a NEMO. While on the move, the control center will perform NEMO to NEMO communication with the journalist's vehicle. It is mandatory that both vehicles embed such NEMO to get uninterrupted communications while each one is on the move.

Once the reportage is finished, the vehicle comes back to the event media center (Fig.2, step #3). It can at this time benefit again from the wired and broadband connectivity in order to transfer for example high quality video of the reportage to the control center for a later usage.

The underlying architecture presented in this scenario can apply to many other situations. Emergency cases, such as mountain rescue [6] or public safety (MESA Project [7]) are some of its other applications.

B. Tools

1) The Mobile Routers and the Home Agent: Our testbed consists in two NEMO representing the journalist's vehicle (NEMO.1) and the control center (NEMO.2). Both Mobile Routers MR1 and MR2 are registered to the same Home Agent. The whole architecture is running the GNU/Linux operating system, based on a 2.6.14 kernel and patched with the mobility extensions provided by MIPL2. The NEMO Basic Support implementation used is NEPL (NEMO Platform for Linux) from 20th of February 2006. It is available as a snapshot on the MIPL2 website[5].

Multihoming is one of the key feature to achieve the scenario previously presented. The Mobile Router MR1 has two network interfaces connected to the Internet: one Ethernet and one wireless (Wifi) interface. A priority is assigned to each interface, Ethernet being the most preferred interface. Thus, when MR1 is connected to the Ethernet network, all the traffic going out or coming in the NEMO uses the Ethernet interface.

If MR1 disconnects from the Ethernet network, it automatically performs a handover to the wireless network. The traffic is then redirected to the Wifi interface. When the Ethernet connectivity is recovered, MR1 performs a handover back to the Ethernet network, and the traffic is redirected again to the Ethernet network.

All the handover procedures are transparent to the MNNs in the NEMO, with a minimum impact on the connectivity offered to the MNNs.

[5]http://www.mobile-ipv6.org

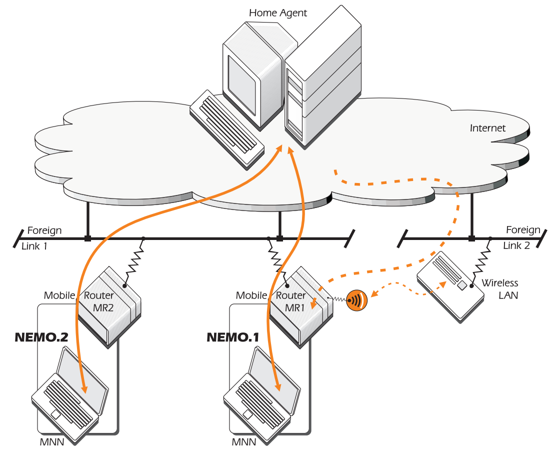

Fig. 3. Topology of the Experiment

2) The Video-conference system: We used the Gnomemeeting software[6] as a videoconference tool between both MNNs. It is IPv6-compliant and allows to have both the audio and the video stream between each correspondent.

3) The Handovers evaluation: RUDE/CRUDE: An IPv6 modified version of the Realtime UDp Emitter (RUDE) tool and its Collector (CRUDE)[7] are used in the testbed to perform active measurement of the mobile network. It is able to send and receive UDP flows with sub-microsecond precision. Each MNN sends an UDP flow to the MNN in the other mobile network using RUDE, while recording the incoming flow with CRUDE. The analysis of these results allows us to evaluate instant packet loss, delay and jitter.

4) The Mobility Statistics: SONAR: The SONAR architecture we described in section III, is installed on both MRs. It allows to perform passive evaluation of the system by collecting statistics of the traffic and link information. The statistics collected by SONAR that we use in this evaluation are: the timestamp, the care-of address information, and the traffic statistics.

By post-processing these specific values of the SONAR trace, we are able to detect the handover events, and get the load for each interface of the mobile router.

V. RESULTS, HANDOVER EVALUATION

In this section, we first introduce the results obtained using the active monitoring tools RUDE and CRUDE. As explained in section IV-B.3 these results show the state of the connectivity as seen by UDP applications running on nodes in the mobile network.

Then the results coming from the SONAR system as described in section IV-B.4 are shown, in order to witness to what happens on the mobile router's interfaces.

All these plots are part of the global results of the experiment that lasted for twenty minutes. In this paper we only show selected parts of the experiment where a handover happens.

[6]http://www.ekiga.org
[7]http://rude.sourceforge.net

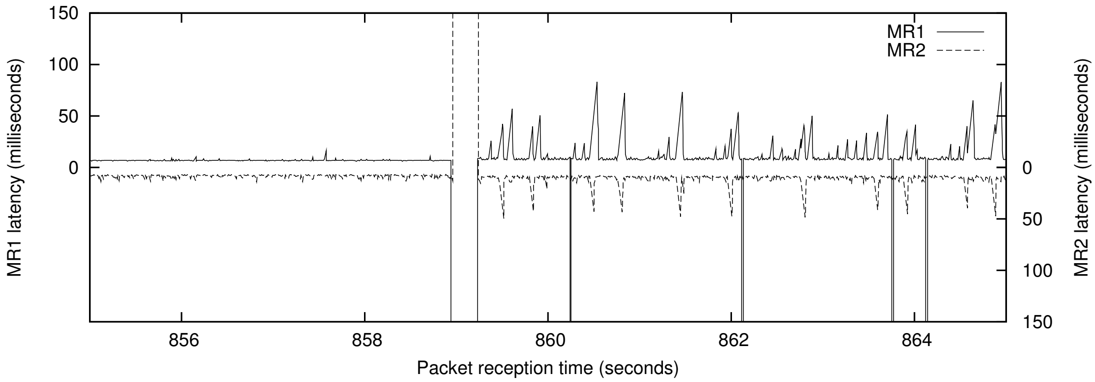

Fig. 4. Handover latency, from Ethernet to Wifi

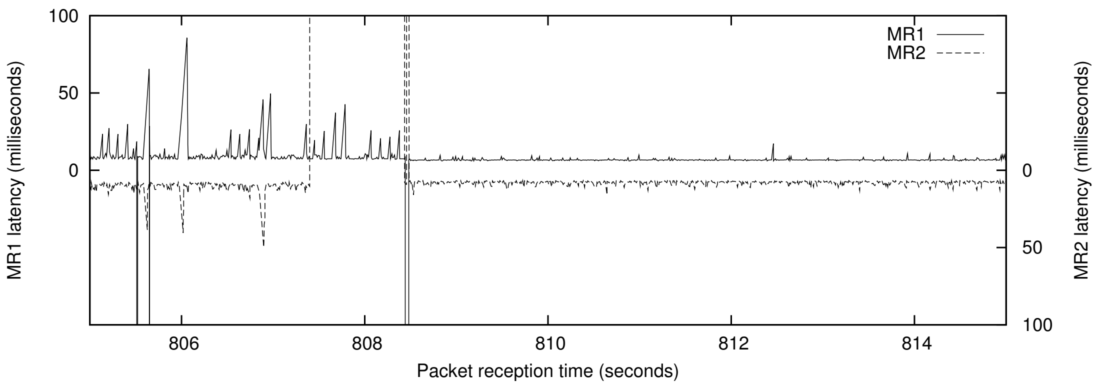

Fig. 5. Handover latency, from Wifi to Ethernet

With respect to the scenario we described in section IV, we show both types of handovers: from Ethernet to Wifi access technology as well as the other way.

A. Active measurements results

Fig.4 and Fig.5 show the traffic latency seen from the receiver side. Packets are plotted according to their arrival time on the horizontal axis while the vertical axis value depends on the latency computed as the difference between the packet transmission time and the packet arrival time. In this experiment we used a constant bitrate UDP flow with 64 bytes sized packets at a 100 packets per second rate. This gives a 10 milliseconds resolution for the latency figures.

Latency seen by both networks is plotted on each figure, with MR1 attached network positive values in the upper part of the plot, and positive values for MR2 attached network in the lower part and using the right-hand axis. In both cases, when a negative value is plotted for latency, it means that packets were lost.

The first type of handover (from Ethernet to Wifi) is triggered by a link-layer event describing loss of link to the upper layers. Since connection is broken, the MR resorts to another available interface with a lesser preference, namely Wifi. As we can see in Fig.4, the disconnection occurs little before the 859th second of the experiment. From this point, no packet is received during about 300 milliseconds.

This happens because the Binding Update information on the Home Agent is outdated and needs to be refreshed with the new Care-of Address of the Mobile Router that is used on the wireless link. As soon as this information reaches the Home Agent, connection towards MR1 is restored.

The second type of handover occurs when the Ethernet interface becomes available in addition to the Wifi interface. In this case, a new Binding Update is sent to the Home Agent because the Ethernet interface has a greater preference in our testbed. Such an event is shown in Fig.5. Since no link is ever broken, there are no packets lost on MR1 reception side (apart from the sporadic losses caused by the nature of the wireless link). However, there are packets lost in the other way because the NEPL policy prevents packets from leaving the MR as soon as the new interface is chosen while the address is not registered to the Home Agent. This happens between the 807th and 808th second of the experiment.

B. Passive measurement results

There are several pieces of information that we could extract from the SONAR results. The first one is the exact date of a handover. These results were already used in order to plot the latency around a handover in Fig.4 and Fig.5. But we are also able to make sure that the handover was effective by looking at the traffic for both the Wifi and Ethernet interfaces on MR1.

These results are shown for the same period of time as both handovers we described in section V-A. In Fig.6 and

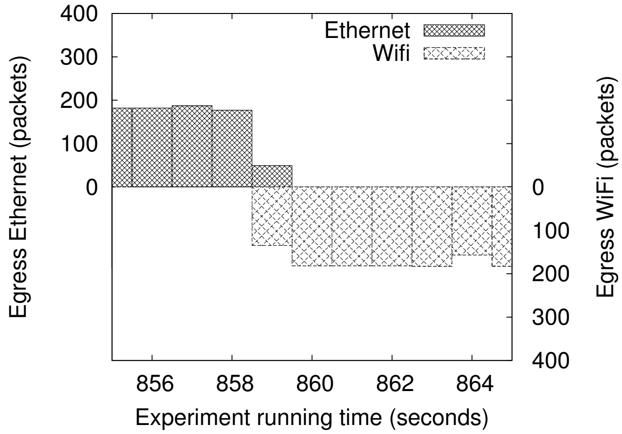

Fig. 6. Egress output traffic, from Ethernet to Wifi, on MR1

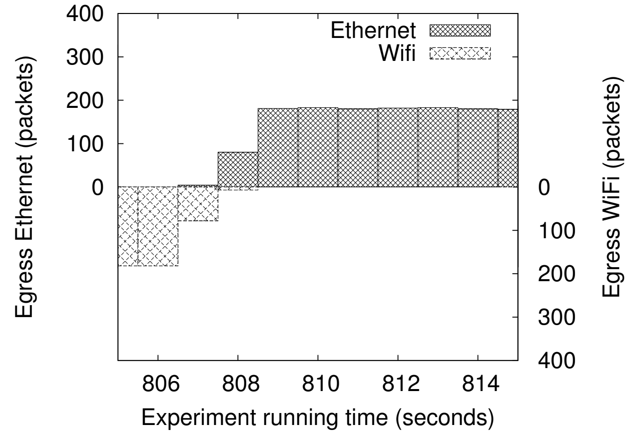

Fig. 8. Egress output traffic, from Wifi to Ethernet, on MR1

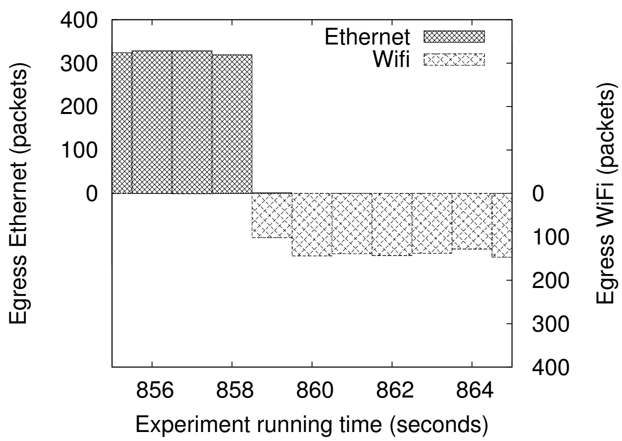

Fig. 7. Egress input traffic, from Ethernet to Wifi, on MR1

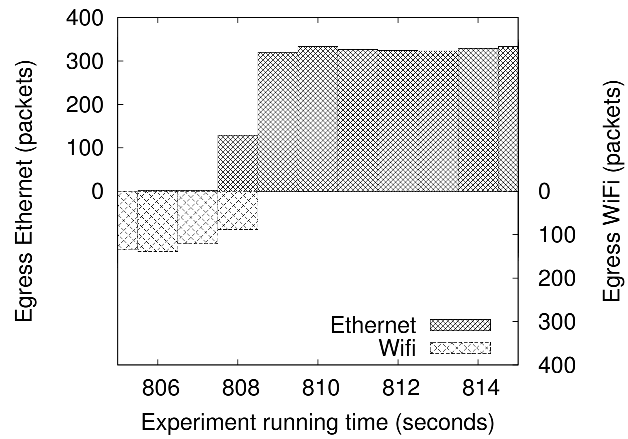

Fig. 9. Egress input traffic, from Wifi to Ethernet, on MR1

Fig.7, we can see the evolution of traffic on both interfaces regarding respectively outbound and inbound traffic. In the case of the inbound traffic, we can see that it switches from Ethernet to Wifi interface during the 859th second of this experiment. In the case of the output traffic though, there is some reminiscing traffic on Ethernet during the same second, because the link-layer trigger does not prevent queued packets from being accounted and then dropped. In both cases, the traffic in the 859th second is lower than subsequently because corresponding nodes have to wait for the HA to receive and process the Binding Update that will make MR1 reachable again. This is the 300 milliseconds gap that was discussed earlier.

Regarding the handover from Wifi to Ethernet interface, Fig.8 shows the outbound traffic for both interfaces. During the handover, the NEPL policy blocks the traffic between the 807th and 808th second waiting for the Binding Acknowledgement message from the Home Agent to arrive. Traffic then resumes to normal through the 808th second. About inbound traffic, even though there is a handover, the active measurements results are confirmed by the fact that there is no drop in traffic. It only moves from Wifi interface to the Ethernet interface during the 807th second.

Eventually we can see that in both handover cases, the input traffic on the Ethernet interface is greater than the input traffic on the Wifi interface. This comes from the traffic on the Ethernet Foreign Link of our testbed, which has more broadcast and multicast packets than the Wifi Foreign Link.

C. Results summary

To evaluate the scenario and the testbed that we have defined, we resorted to a twofold mechanism. Using active measurements we were able to take snapshots of the mobile network state with respect to latency and packet loss. At the same time, the passive monitoring tool was accounting traffic on all interfaces and watching over NEPL bindings.

By looking at all the figures in the previous sections (Fig.4 through Fig.9) we were able to show that different handovers have different effects. From the corresponding nodes standpoint, when handing over from two available interfaces, the change is transparent, whereas there is a delay in the case of a handover from a disabled interface to a less preferred interface. From the mobile network standpoint, both handover types break the communications as long as the Home Agent reply has not been received and processed.

Although the NEPL policy mechanism can be blamed for the latter, it is still the right behavior because the MR can not assume that sending the Binding Update message will result in receiving a Binding Acknowledgement.

VI. Conclusion

In this paper we used the NEMO architecture as a way to achieve ITS communications, and introduced a new way to evaluate the performances of a such architecture, based on hybrid active/passive measurements. In order to validate the efficiency of the whole architecture, we focused on a practical experiment of NEMO to NEMO communications using freely available implementations and tools. The methodology that we used for this testbed allowed us to thoroughly study the performances of these softwares in a real scenario.

Although the system as it is defined here is entirely useable and achieves decent performance, we could spot some caveats in the current standards that need further investigation as to how they could be solved : handing over from a disabled interface can be properly fixed by having the MR register multiple Care-of Addresses (MCoA [8]) with the Home Agent, one for each interface. Switching from one binding to another can even be further accelerated by using link-layer triggers as defined by the IETF DNA[8] working group.

Moreover, the detailed results have shown that the hybrid measurement approach can lead to very useful statistics and thus an active measurement module should be added to the SONAR architecture.

Eventually, we were able to show that the NEMO to NEMO communication case can be of real interest to the ITS communications scheme because NEMO is a well established open standard with many implementations, including open source initiatives, with a highly scalable design.

[8]http://www.ietf.org/html.charters/dna-charter.html

Acknowledgments

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