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Implementation of a HMIPv6 extension in the INET and xMIPv6 simulation framework with dynamic MAP discovery for OMNeT 4.x

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Abstract - In order to perform a simulative evaluation of the Hierarchical Mobile IPv6 protocol (HMIPv6) OMNeT++ simulation environment was used. OMNeT++ simulation package – INET framework and xMIPv6 was enhanced with an extension for HMIPv6, which includes Neighbor Discovery protocol, IPv6 router and the implementation of a Mobility Anchor Point (MAP). The simulation model was implemented as defined in RFC 5380 Hierarchical Mobile IPv6 – HMIPv6 Mobility Management. Enhancements are recognized in terms of an upgraded Router advertisement (RA) packet with option data about the MAP. We used dynamic MAP discovery, based on MAP option propagation in Router Advertisements from the MAP to the Mobile Node through certain (configured) router interfaces, within the routers in a network.

I. INTRODUCTION

The increase of mobile users, emergence of different radio access technologies and the increasing importance of IP services over wireless as well as wired networks, raises a number of new challenges. Delay sensitive applications, such as VoIP, have to guarantee IP service continuation during handover. In that sense Mobile IP (MIP) and Mobile IPv6 (MIPv6) were proposed to provide application-transparent IP-based mobility support.

Mobile IP is designed for mobility management of IP networks, but may result with high latency, packet loss and signaling overhead during handoff. Therefore, efficient handover implementation requires advanced mobile mechanisms that enhance Mobile IP, as well as adequate QoS support suited to real-time applications.

Hierarchical Mobile IPv6 (HMIPv6) is proposed to improve the performance of MIPv6, on signaling load and potentially reduce long handover latencies. In order to perform a simulative evaluation of the Hierarchical Mobile IPv6 protocol (HMIPv6) we used the OMNeT++ simulation environment and its communication networks simulation package INET Framework.

With the objective to implement a HMIPv6 simulation model for OMNeT++ 4.x, enhancements to the INET framework were needed, since the Extensible MIPv6 (xMIPv6) simulation model only provides mechanisms for the implementation of various MIPv6 protocol extensions.

We enhanced the INET Framework simulation model with an extended RA packet containing a MAP option, and upgraded the INET framework with dynamic MAP discovery. With this enhancement a valid HMIPv6 simulation model for OMNeT 4.x was established, for further simulation enhancements, in terms of simulation accuracy and validation tests.

II. THEORETICAL BACKROUND

Hierarchical mobility management for Mobile IPv6 is designed to reduce the amount of signaling between the Mobile Node, its Correspondent Nodes, and its Home Agent. HMIPv6 introduces a new entity called the Mobility Anchor Point (MAP), which acts as a local Home Agent (HA) for Mobile Node, to limit the amount of Mobile IPV6 signaling outside the local domain, and improve the performance of Mobile IPv6 in terms of handover speed [1]. When a Mobile Node performs handover between two access routers within the same MAP domain, it will send a BU (Binding Update) only to the MAP, not to its HA [2].

HMIPv6 protocol was developed to separate micro-mobility and macro-mobility, in regard to this RFC 5380 introduces extensions to Mobile IPv6 and IPv6 Neighbour Discovery to allow for local mobility handling. HMIPv6, as an extension of Mobile IP for micro-mobility management, involves three phases:

- MAP Discovery,
- MAP Registration,
- Packet Forwarding.

A. *MAP discovery*

The process of MAP Discovery continues as the Mobile Node moves from one subnet to the next. Every time the Mobile Node detects movement, it will also detect whether it is still in the same MAP domain. The Router Advertisement used to detect movement will also inform the mobile node, through Neighbor Discovery and the MAP option, whether it is still in the same MAP domain. The mobile node will always need to know the original sender of any received packets to determine if route optimization is required [1].

For a HMIPv6-aware implementation the Mobile Node will first register with a MAP by sending it a BU containing its Home Address and on-link address (LCoA). The Home Address used in the BU is the RCoA.

The MAP must store this information in its Binding Cache to be able to forward packets to their final destination when received from the different correspondent nodes or HAs. As the Mobile Node roams within a MAP domain, it will continue to receive the same MAP option included in Router advertisements from its AR. If a change in the advertised MAP's address is received, the Mobile Node must act on the change by sending Binding Updates to its HA and Correspondent nodes (CN) [1].

MAP Discovery is based on propagating the MAP option in Router Advertisements from the MAP to the Mobile Node through configured router interfaces within the routers. Router Advertisements are used for MAP Discovery by introducing a new option.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |    Length     | Dist  |  Pref |R|  Reserved   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Valid Lifetime                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                  Global IP Address for MAP                    +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 1. Neighbour Discovery Extension: The MAP Option [1]

The access router is required to send the MAP option (Figure 1. in its Router Advertisements, which are send while informing about its link presence within the IPv6 Neighbor Discovery protocol. The Router Advertisement message format has an ICMP header and message structure, like Figure 2. shows.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |     Code      |          Checksum             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Cur Hop Limit |M|O|  Reserved |       Router Lifetime         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Reachable Time                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Retrans Timer                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Options ...
+-+-+-+-+-+-+-+-+-+-+-+-
```

Figure 2. Router Advertisement Message Format [3]

Router Advertisements contain prefixes that are used for determining whether another address share the same link (on-link determination).

The MAP option must be available to all access routers (ARs), to be able to advertise it. The HMIPv6 specification introduces two different methods that access routers can be triggered to advertise a MAP option (MAP discovery):

- Static Configuration – Network operator manually configures all the ARs to send the MAP option, or
- Dynamic MAP discovery – Based on propagating the MAP option in Router Advertisements from the MAP to the Mobile Node through certain (configured) router interfaces within the routers.

We chose the implementation of dynamic MAP discovery.

B. *MAP registration*

Once the MAP has been discovered and selected, the next phase is MAP registration. MN needs to configure an RCoA on the MAP link, using the prefix advertised in the MAP option, and create a binding between the RCoA and LCoA at the MAP. The MN has to send an LBU message to the newly discovered MAP. The LBU message format is shown in Figure 3.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Sequence #           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|A|H|L|K|M|      Reserved       |           Lifetime            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3. Local Binding Update [1]

A new flag is added: the M flag, which indicates MAP registration. When a Mobile Node registers with the MAP, the M and A flags must be set to distinguish this registration from a BU being sent to the HA or a correspondent node. If flag M is set to 1 it indicates a MAP registration.

The MN uses RCoA as the source IP address in all its packets, but tunnels them to the MAP using LCoA as the source IP address for the tunnel. In the next phase the MAP forwards packets towards the HA and CN's.

C. *Packet forwarding*

Following a successful registration with the MAP, a bi-directional tunnel between the Mobile Node and the MAP is established. All packets sent by the Mobile Node are tunneled to the MAP, which acts like a HA. The BAck message outer header contains the Mobile Node's LCoA in the source address field and the MAP's address in the destination address field for all outgoing packets. The inner header contains the Mobile Node's RCoA in the source address field and the peer's address in the destination address field.

For incoming packets the tunnel has to check the addresses with the changed source and destination address fields. MAP establishes a binding cache entry for RCoA, which enables packet forwarding of incoming packets to LCoA. For contrary direction a binding entry between the destination address of the tunnel and the interior package is established, to ensure internal packet forwarding to the HA and the CN's.

III. SIMULATION MODEL

To perform a simulative evaluation of the Hierarchical Mobile IPv6 protocol (HMIPv6) OMNeT++ simulation environment was used. OMNeT++ is an extensible, modular, component-based C++ simulation library and framework, primarily for building network simulators [4].

OMNeT++ requires the INET Framework, which is an open-source communication networks simulation package for the OMNeT++ simulation environment. The INET Framework contains models for several wired and wireless networking protocols, including UDP, TCP, SCTP, IP, IPv6, Ethernet, PPP, 802.11, MPLS, OSPF, and many others [5].

Since the earlier released Extensible MIPv6 (xMIPv6) simulation model [6], [7] does not scale well to new developments in the INET framework, enhancements to the INET framework were needed, to enable the implementation of HMIPv6 in the latest versions of OMNeT++ 4.x and INET Framework.

Authors [7] released IPv6SuiteWithINET simulation model to the OMNeT++ community with the base MIPv6 implementation in OMNeT++ 3.2, and assured that HMIPv6 protocol has been implemented, but needed to undergo validation tests, to be released in the coming months.

The available xMIPv6 simulation material was used as a base for our INET simulation model with HMIPv6 extension, which was implemented in accordance to RFC 5380 Hierarchical Mobile IPv6 – HMIPv6 Mobility Management. Several upgrades and modifications to the INET Framework simulation model were needed to create a working simulation model for HMIPv6, using thereby the latest RFC specification, and latest versions of OMNeT++ 4.x and INET Framework.

IV. Simulation Results

The process of MAP discovery is needed to inform Mobile Nodes about the presence of the MAP and the distance of the MAP from the Mobile Node, and it continues as the Mobile Node moves from one subnet to the next. Every time the Mobile Node detects movement, it will also detect whether it is still in the same MAP domain.

The INET Framework simulation model was enhanced in a way that the RA packet contains a MAP option (Figure 4. which includes the MAP's global IP address, valid lifetime field which indicates the validity of the MAP's address and consequently the time for which the RCoA is valid, and other information like the distance vector from the MAP to the current access router (measured in hops, but need not be interpreted as the number of hops between MAP and the Mobile Node. Distance is set to 1 if the MAP is on the same link as the Mobile Node), the preference for this particular MAP (decimal value of 15 indicates the highest availability).

We upgraded the INET framework with an implementation of dynamic MAP discovery. In our simulation model the MAP_1 node was configured to act like a MAP on two network interfaces – Firstly as a MAP to the Internet (Internet Gateway node), whose network prefix is used for RCoA calculation, and secondly as a MAP toward to the Mobile Node which visits the MAP domain to forward packets, i.e. bi-directional tunneling, which enables sending of RA packets with MAP option, to routers in the downstream network.

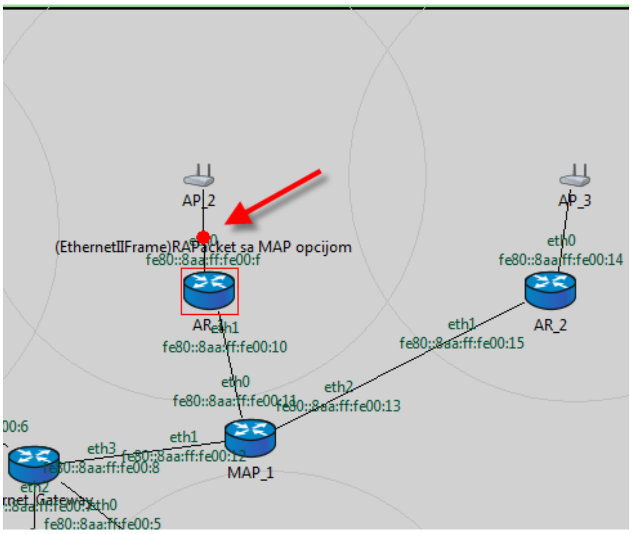

Figure 4. Router Advertisement packet with additional MAP option

Figure 5. shows the sequence diagram for the RA packet with MAP option in the HMIPv6 simulation model. AR_1 and AR_2 Router6 modules receive RA packets with MAP option from the MAP. Router6 modules were enhanced and configured to carry MAP options through interfaces connected with WLAN access points (AP_2 and AP_3), previously increasing Distance field for 1.

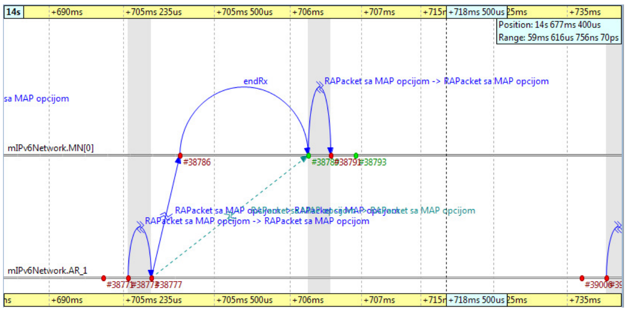

Figure 5. MAP option sequence diagram

At the end of the MAP discovery phase, the HMIPv6-aware Mobile Node MN[0] receives the Router Advertisement with MAP option, obtains the MAP IP address, obtains the Distance field of the MAP form current access router, and verfies if the lifetime is equal zero for the current MAP (a valid lifetime of zero indicates a MAP failure). If it is non-zero then MN[0] has to select a MAP with higher preferences. We enhanced the MN[0] WirelessHost6 module to process RA packets with MAP option.

Once the MN[0] has discovered and chosen MAP_1, it configures RCoA address, using the network prefix, advertised in the MAP option, and creates a binding between RCoA and LCoA at the MAP, assuming MN[0] has already configured a valid LCoA. Our INET framework simulation model was enhanced in the way that MN[0] sends the LBU packet to the newly discovered MAP (Figure 6.

The source IP address is a valid LCoA address, while RCoA is the Home Address in the LBU message. MAP_1 performs DAD (Duplicate Address Detection) procedure for the RCoA and sends BAck, which is identical to the MIPv6 BAck packet.

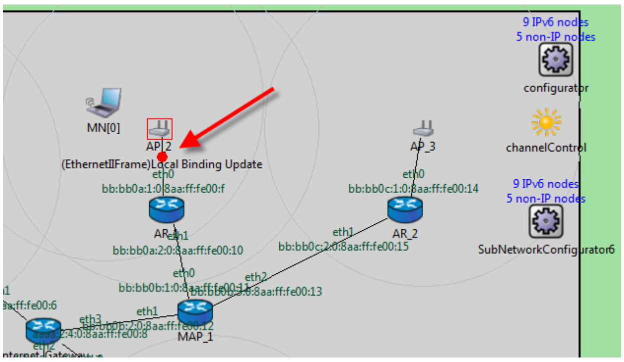

Figure 6. MN[0] sends LBU to discovered MAP

If BAck does not contain type 2 router header with the RCoA, MN[0] will reject BAck, previously controlling the error code in BAck, to check if a new RCoA should be calculated and a new LBU message send. Figure 7. shows the LBU message sequence diagram.

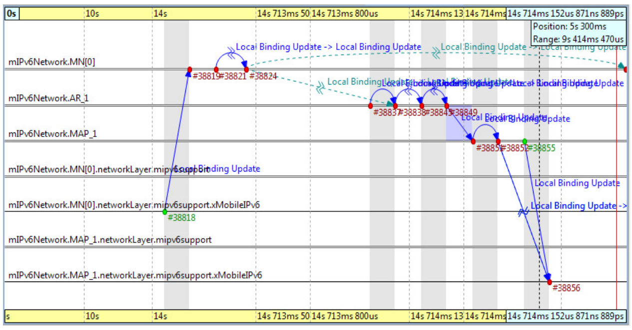

Figure 7. LBU sequence diagram

If a successful binding with the MAP cannot be done, MN[0] will approach the basic MIPv6 and send BU message to the Home Agent (HA) using LCoA as CoA address. If the binding with the MAP, MN[0] will use its RCoA as CoA with Home Agents and Correspondent Nodes. MN[0] has to wait for the BAck, before sending BU messages to Home Agents, or introducing the Return Routability procedure with Correspondent Nodes.

It should be noted that when binding the RCoA with the HA and Correspondent Nodes, the binding lifetime must not be larger, than the Mobile Node's binding lifetime with the MAP, which is received in the Binding Acknowledgement.

Following a successful registration with the MAP, a bi-directional tunnel between the Mobile Node and the MAP is established. All packets sent by the Mobile Node are tunneled to the MAP, which acts like a Home Agent. The BAck message outer header contains the Mobile Node's LCoA in the source address field and the MAP's address in the destination address field for all outgoing packets. The inner header contains the Mobile Node's RCoA in the source address field and the peer's address in the destination address field.

For incoming packets the tunnel has to check the addresses with the changed source and destination address fields. MAP establishes a binding cache entry for RCoA, which enables packet forwarding of incoming packets to LCoA. For contrary direction a binding entry between the destination address of the tunnel and the interior package is established, to ensure internal packet forwarding to the HA and the CN's.

The structure of the simulation model was defined in the NED (Network Description) language, and the enhancement implies a new module, i.e. SubNetworkConfigurator6 (Figure 8. needed to configure an IPv6 subnet in OMNeT++ 4.x. SubNetworkConfigurator6 module configures subnet prefixes for MAP_1, AR_1 and AR_2.

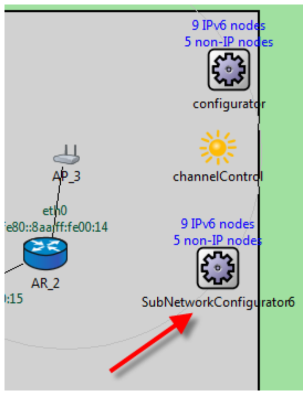

Figure 8. SubNetworkConfigurator6 module

The following table contains all files used in the simulation model, including their role description.

TABLE 1 INET FRAMEWORK FILES ENHANCED WITH HMIPV6 EXTENSION

File	Description
\inet\examples\mobileipv6\ HMIPv6Network.ned	Network topology definition in NED language
\inet\examples\mobileipv6\ omnetpp.ini	Configuration folder for simulation mode control
\inet\src\networklayer\autorouting \ipv6\ SubNetworkConfigurator6.cc	Configures IPv6 adressess and routing tables for hierarhy network topology
\inet\src\networklayer\icmpv6\ IPv6NeighbourDiscovery.cc	Implements Neighbor Discovery protocol for IPv6 (RFC 2461)
\inet\src\networklayer\icmpv6\ IPv6NDMessage_m.cc	HA information, HA Prefix information, MAP Option, etc.
\inet\src\networklayer\xmipv6\ xMIPv6.cc	Implements RFC 3775 Mobility Support for IPv6
\inet\src\nodes\ipv6\ Router6.ned	IPv6 router NED module

V. CONLUSION

We implemented an INET simulation model with HMIPv6 extension in accordance to RFC 5380 Hierarchical Mobile IPv6 – HMIPv6 Mobility Management. In that sense we enhanced the INET Framework simulation model with an extended RA packet containing a MAP option. Further we upgraded the INET framework with an implementation of dynamic MAP discovery. We made it possible for our simulation Mobile Node MN[0] to send the LBU packet to the newly discovered MAP.

Since a valid HMIPv6 simulation model for OMNeT 4.x has been established, further simulation enhancements are enabled in terms of simulation accuracy and validation tests. Further work will be directed to the development of an extended resource management scheme, which takes into account the QoS requirements of handover, such as packet delay, jitter and loss guarantees, and reduces the overall handover latency.

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