# An Accurate Simulation Model for Mobile IPv6 Protocol

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***Abstract*— We present an overview of the Mobile IPv6 simulation model implemented by using OMNeT++ [1] simulation framework. We attempted to create a very accurate model of the Mobile IPv6 protocol. The simulation model consists of three key components: i) a class inheritance approach for specifying a node to behave as a host or router, ii) same approach for defining the Mobile IPv6 roles of mobile node, correspondent node or home agent, and iii) conceptual data structures necessary for storing binding information and for responding to the received Mobile IPv6 signaling messages.**

**An example network consisting of a mobile station moving through a series of IPv6 subnets is used to demonstrate the model's capabilities. The handover behaviour is consistent with the mathematical analysis and will be used in future papers to investigate underlying issues with MIPv6.**

## I. INTRODUCTION

Over the last two decades, arguably the main change in telecommunication networks has been the deployment of wireless access technologies. Wireless access has lead to creation of a plethora of mobile devices with a wide range of communication, computing, and storage capabilities. With wireless interfaces providing ease of use, these devices have become increasingly popular.

The current Internet is based on an architecture created in 1969 as the ARPANET. However, it does not support the needed features and architectural structures for mobility. Because of that, the existing general mobility support solutions in the IP world have tried to hide the dynamic change of IP addresses from the upper layers.

Mobility for IPv6, or Mobile IPv6 (MIPv6) [2] was developed to allow an IPv6 node to change points of network attachment without disrupting applications or services. In the MIPv6 specification, three network roles: mobile node, correspondent node and home agent are essentially defined. A mobile node is a node that can change its point of attachment from one link to another, while still being reachable via its home address. The mobile node maintains two IPv6 addresses, home address and care-of address. The home address is used as a permanent address of the node and is also used as an identifier by the transport sessions. The care-of address is essentially used as a current location identifier of the mobile node by the home agent. It also allows the correspondent node to send packets directly to the mobile node. A correspondent node is a peer node with which a mobile node is communicating. A home agent is a router on the mobile node's home link with which the mobile node notifies its current care-of address. While the mobile node is away from home, the home agent intercepts packets on the home link destined to the mobile node's home address, encapsulates them, and tunnels them to the mobile node's registered care-of address.

Our research group focuses on developing simulation systems for investigations into the performance and scalability of IPv6 and Mobile IPv6 protocols over the Internet. To do our research, we have developed a comprehensive set of models [3] for simulating fixed IPv6 networks. We have also recently added an accurate model of IEEE802.11b [4] to the simulation suite. Accurate modeling of MIPv6 protocol in the simulation will allow us to extend our research into MIPv6 protocol performance analysis, such as signaling and handover optimisations, network mobility, and multicast mobility.

In the next section, the overall design of our model is discussed, which includes our approach in obtaining an accurate MIPv6 simulation model. The accuracy of the model is assessed in the following section by comparing performance results obtained from the mathematical analysis. A short section then covers additional support and functionalities that may be added to the model. Finally, the last section concludes with some remarks to review the overall discussion that is presented.

## II. DESIGN OF THE MOBILE IPV6 MODEL

The MIPv6 simulation model contains functionalities such as handling of various IPv6 headers [5] and conceptual data structures to manage different aspects of the protocol. The implementation is designed in a way such that each module in the protocol stack handles a specific type of IPv6 header or an ICMP message. Figure 1 depicts the kernel of the protocol. The MIPv6 model interacts with higher layer protocols via `LocalDeliver` and `Send` modules. The IPv6 packet is sent to the network through `Output` and received from `PreRouting`. The ICMPv6 Ping echo and reply messages are processed in the `ICMP` module.

### A. Host and Router

According to Neighbour Discovery in IPv6 [6], the main difference between a host and router is the handling of different control messages necessary for neighbour

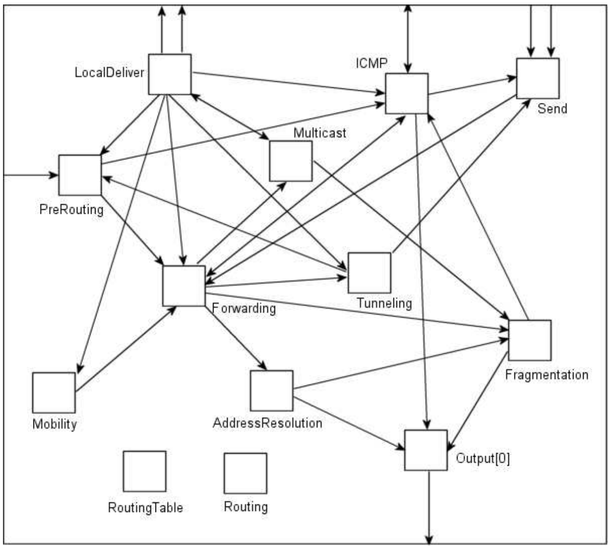

Fig. 1. Kernel of MIPv6 protocol

discovery such as router advertisement, router solicitation, neighbour advertisement and neighbour solicitation. Therefore, a class inheritance approach (shown in Figure 2) is used to express the relationships between a router and host as it also allows the transition between the two roles. Only one instance of inherited class is created depending on whether the node is a router or host at startup . The instance is created in `Neighbour Discovery`, a simple module that resides in `ICMP` module. This approach provides extensibility when adding MIPv6 extensions, particularly the signaling and handover optimisations by allowing new subclasses to reuse the capabilities of the base class as well as override certain functions to test different algorithms accordingly.

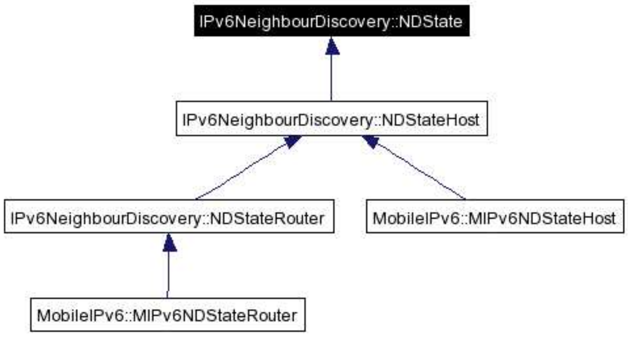

Fig. 2. Class inheritance diagram of neighbour discovery

### B. *Mobile Node, Correspondent Node and Home Agent*

The mobile node, correspondent node and home agent process the messages differently. This is done in the `Mobility` module depicted in 1. The `Mobility` module also implements a class inheritance approach as shown in Figure 3. The base class `MIPv6MobilityState` provides the common behaviour for the different MIPv6 roles. The assignment of a node to a specific MIPv6 role is done via XML configuration.

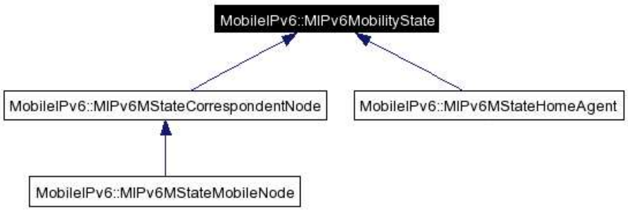

Fig. 3. Class inheritance diagram of MIPv6 network role

### C. *Conceptual Data Structure*

In the MIPv6 specification, the conceptual data structures are described as follows:

*Binding Cache:* A cache of bindings[1] for other nodes. This cache is maintained by home agents and correspondent nodes. Each entry in the cache contains information about the home address that is visible for the upper layer protocols and the care-of address that corresponds to the home address.

*Binding Update List:* This list is maintained by each mobile node. The list has an item for every binding that the mobile node has or is trying to establish with another node. Both correspondent and home registrations are included in this list. Entries from the list are deleted as the lifetime of the binding expires.

*Home Agents List:* Home agents need to know which other home agents are on the same link. This information is stored in the Home Agents List. The list is used for informing mobile nodes during dynamic home agent address discovery.

Figure 4 shows the design of MIPv6 conceptual data structures. The base class `MIPv6CDS` contains the binding cache. The mobile node interface contains binding update list and the home agent contains the home agent list. The instance of specific interface is instantiated in `Mobility` module. As the node is assigned to a particular MIPv6 role, the specific class instance is created accordingly.

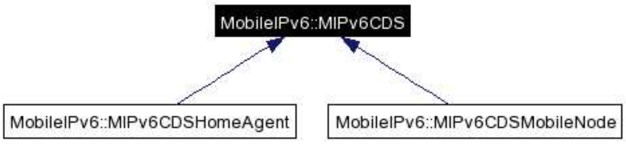

Fig. 4. Design of MIPv6 conceptual data structures

## III. MOBILE IPV6 NETWORK SIMULATIONS

This section demonstrates the capabilities and correctness of the model by comparing the handover result with

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[1] binding is the association between the home address and the care-of address

mathematical analysis based on the protocol described in the MIPv6 specification. The configuration of the test network is seen in Figure 5. Each router connects to an access point forming a wireless subnet. A mobile node roams across different subnets and returns to its home network eventually. A correspondent node connecting to one of the routers acts as server for the mobile node. The mobile node sends an ICMP Ping echo to the correspondent node and the correspondent node acknowledges with an ICMP Ping response. This demonstrates connectivity between the mobile node and correspondent node while the mobile node changes points of attachments. Table I shows a list of parameters configured in this experiment.

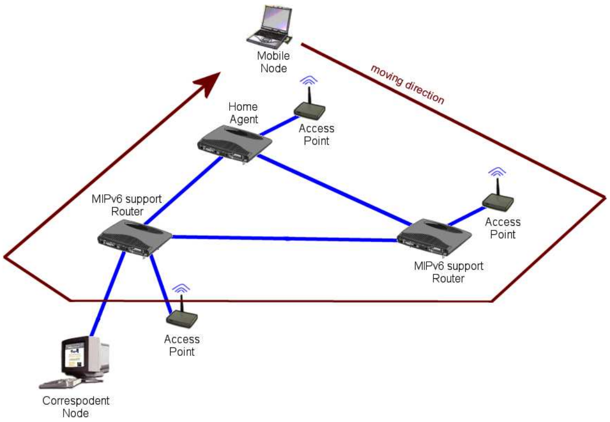

Fig. 5. A test scenario for the MIPv6 simulation model

| Simulation Model | Parameter | Value |
|---|---|---|
| Mobility | MN_MoveSpeed | 3m/s |
| Ping Application | PingInterval | 0.05s |
| MIPv6 | MaxRtrAdvInterval** | 1s |
| | MinRtrAdvInterval** | 0.25s |
| | AllowedMissedRtrAdv | 1 |
| | RetransTimer | 1s |
| | DupAddrDetectTransmits | 1 |

** parameters configured for router only

TABLE I

LIST OF PARAMETERS IN MIPV6 TEST NETWORK

Figure 6 illustrates disruption of the ICMP stream and Figure 7 shows the complete results of 10 simulation runs generating 30 handovers in total. The average handover latency in Figure 6 is 2332ms.

The MIPv6 handover latency is caused by three major components: movement detection, duplicate address detection, and a delay interval for a router to reply with a router advertisement upon a receipt of a router solicitation.

The router periodically sends an unsolicited multicast router advertisement at least once every RtrAdvInterval seconds, the actual interval is randomly computed to be between MaxRtrAdvInterval and MinRtrAdvInterval. If the mobile node does not receive a router advertisement within RtrAdvInterval seconds, AllowedMissedRtrAdv decrements by one. When AllowedMissedRtrAdv reaches zero, the movement detection is triggered. Hence, the mobile node starts performing handover operation. Let $x$ denote as the actual router advertisement interval between zero and RtrAdvInterval. The delay caused by the movement detection can be expressed by the following equation:

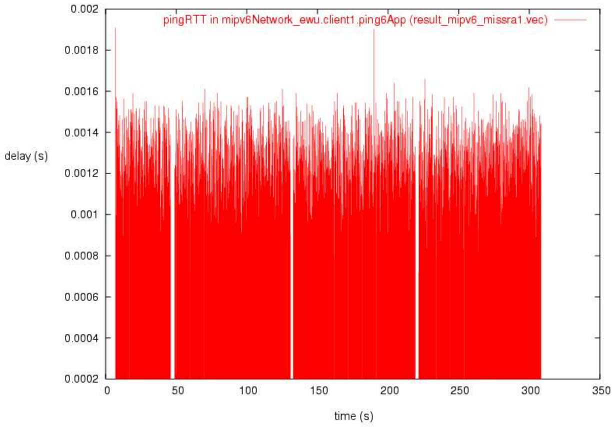

Fig. 6. One simulation sample for showing disruption of ICMP stream

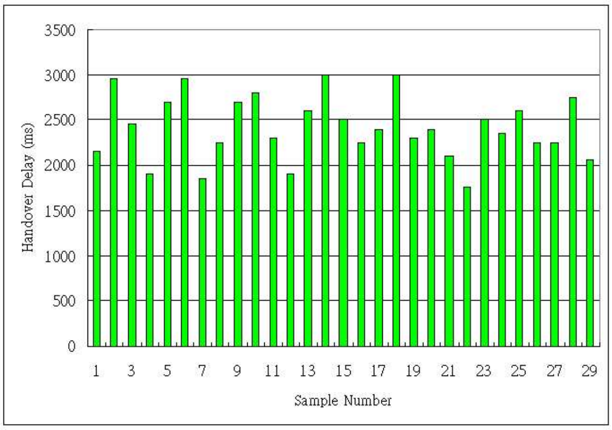

Fig. 7. Handover latencies

$$\begin{aligned} Delay_{\text{movement detection}} =& x \in [0, RtrAdvInterval) \times \\ & (i+1) \qquad (1) \\ where & \\ i =& AllowedMissedRtrAdv \end{aligned}$$

Note that if AllowedMissedRtrAdv is zero the movement detection is triggered as soon as one router advertisement is missed. Due to the high probability of packet loss in the wireless network environment, the mobile node may not receive unsolicited router advertisements. Consequently, the MIPv6 handover process is triggered while the mobile node is still in the same subnet. To avoid this, AllowedMissedRtrAdv is generally set to one or higher.

Another dominating component to the handover latency is the delay during the duplicate address detection operation. A node must perform a duplicate address detection when it attaches to a new link and reconfigures a new care-of address. During the duplicate address detection, the node has to wait for at least RetransTimer seconds, to check if any neighbouring node responds with a solicited neighbour advertisement. If the mobile node does recieve one, then a neighbouring node already has the same IP address. The duplicate address detection delay can be expressed by following equation:

$$Delay_{\text{duplicate address detection}} = RetransTimer \times j \quad (2)$$
$$where$$
$$j = DupAddrDetectTransmits$$

The third component is a random delay interval, RA_DELAY_TIME, computed within the range of 0 to 500ms. A router does not immediately reply with a solicited router advertisement upon receipt of a router solicitation. It waits for this random delay time and then sends the router advertisement. Let $y$ be the actual delay interval. This avoids an outburst of solicited router advertisements if there are multiple routers on the same link.

Therefore, the theoretical MIPv6 handover latency can be expressed as follows:

$$\begin{aligned} Delay_{Handover} =& Delay_{\text{movement detection}} + \\ & Delay_{\text{duplicate address detection}} + \\ & y \in [0, RA\_DELAY\_TIME] \end{aligned} \quad (3)$$

By adapting the values of the parameters used in the experiment (shown in Table I) into Equation 3, we can obtain a possible range of values for theoretical handover delays.

The minimum value can be:

$$\begin{aligned} Delay_{Handover}(min) =& 0+ \\ & 1+ \\ & 0 \\ =& 1s \end{aligned}$$

where,

RetransTimer = 1 second
DupAddrDetectTransmits = 1

For the minimum possible value of the handover delay, the router advertisement is received instantly, hence assuming the router advertisement interval is extremely small.

The maximum value of the delay can be:

$$\begin{aligned} Delay_{Handover}(max) =& 1+1+ \\ & 1+ \\ & 0.5 \\ =& 3.5s \end{aligned}$$

where,

AllowedMissedRtrAdv = 1
RetransTimer = 1 second
DupAddrDetectTransmits = 1
RA_DELAY = 0.5 seconds

For the maximume possible value of the handover delay, we assuming that first router advertisement is missed and the second one is received at the longest time, which is near MaxRtrAdvInterval.

Therefore, the theoretical handover delay values range from 1 seconds to 3.5 seconds. In the experiment, the average handover delay of 2.123 seconds falls within the range provided by the mathematical analysis.

## IV. FUTURE ADDITIONS

Most of the MIPv6 functionalities have been implemented in the simulation model. However, there is a number of attributes, which is still under consideration and may be implemented in the future. It includes:

- Return Routability Procedure
- Full Proxy Neighbour Discovery
- Improve robustness of handover process when the mobile node returns home
- Dynamic Home Agent Address Discovery
- Router renumbering at home

## V. CONCLUSION

In this paper, we present an overview of the MIPv6 simulation model implemented under OMNet++ simulation framework. Accurate modeling of MIPv6 protocol in the simulation will allow us to extend our research into MIPv6 protocol performance analysis, such as signaling and handover optimisations, network mobility, and multicast mobility. The example network in the paper demonstrates the capabilities and verifies the correctness of the model. The handover performance obtained from the example network produces a delay we theoretically expected.

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