Evaluation of Mobile IPv6 Based on an OPNET Model

Deguang Le  Xiaoming Fu  Dieter Hogrefe
Telematics Group, University of Göttingen 37083, Germany
Phone: +49(551)39-14402; Fax: +49(551)39-14403
E-mail: {le,fu,hogrefe}@cs.uni-goettingen.de

Abstract: IPv6, as the next generation Internet protocol, has been proposed and developed by IETF to replace the traditional IPv4. Compared to traditional IPv4, one of the key advantages of IPv6 is its inherent mobility feature called MIPv6 with which the mobile devices such as Laptop computers, PDAs etc. keep connectivity alive while roaming on the Internet. This paper is a study of the MIPv6 issues using the OPNET IPv6 model. An introduction of MIPv6 is described at first. Then it presents the MIPv6 model of OPNET simulator, including all kind of supported features and configurations of mobility entities like MN, CN and HA. And then the simulation of MIPv6 testbed in the institute of informatics of Göttingen University and results are presented. Finally, it presents the conclusion and our future work.

Keywords: Mobile IPv6; OPNET; Handover

1 Introduction

In the past few years, Internet has become ubiquitous and popular in our life. Internet is an IP network that operates basing on the TCP/IP stack. As we know, IPv4 is the current network layer protocol of this protocol stack. However, it has only 32 bits for addressing in the network and seems not enough for the future increasing users. Apart from this limitation of address issue, other disadvantages such as less QoS support, larger routing tables will be problems in the future network environment. Therefore, Internet Protocol version 6 (IPv6) [1], a new IP protocol has been proposed and developed by Internet Engineering Task Force (IETF) to replace IPv4. Besides, the fast Internet evolution together with the enormous growth of wireless technologies has resulted in a strong convergence trend towards the Internet as uniform network for mobile as well as fixed network. Future Internet will allow users to maintain service continuity while moving across the Internet. To support mobile devices roaming Internet, which dynamically change their access points to the Internet, IETF integrates IPv6 with mobility support called Mobile IPv6 (MIPv6) [2]. Compared to MIPv4, MIPv6 provides features such as IPv6 route advertisements [3] for movement detection and stateless address auto-configuration [4]. Besides, the route optimization has also been incorporated into MIPv6. As such, it is therefore the primary candidate for global mobility management in the next generation mobile networks.

This paper is organized as follows: we begin with introduction of mobility support in IPv6 and give details on the feasibility of the IP layer handover mechanisms available in Section 2. Section 3 presents the MIPv6 simulation model developed in the OPNET, which support many standard MIPv6 specifications and technologies, and illustrates the configuration of MIPv6 model in simulation entities. In Section 4, we evaluate MIPv6 based on OPNET MIPv6 simulation model [5] by simulating the MIPv6 testbed of institute of informatics in Göttingen University and analyze the results of application performance, signalling traffic etc. Finally, Section 5 presents the conclusion and our future work.

2 Mobile IPv6 Technology

In MIPv6, each Mobile Node (MN) is identified with a static IPv6 address called home address. The MN can always be reached using the fixed home address. When a MN is on its home link, it acts as a fixed host; When the MN is attached to a foreign link, it requires a new Care of Address (CoA). The CoA provides information about the MN’s current location, so the HA or CN shall map the home address to its corresponding CoA by binding mechanism for location management and packets routing. The MN registers the CoA with the HA (i.e. home registration), and it may also inform the acquired CoA to CNs (i.e. correspondent registration). There are two possible routing mechanisms between the MN and the CN. The first is bidirectional tunnelling, which does not require MIPv6 support from the CN. The second is route optimization, which requires the MN to register its current CoA binding at the CN. Therefore, packets from the CN can be routed directly to the CoA of MN. The basic sequences of communication and interactions between entities for the two routing mechanisms are depicted in figure 1.
The following subsections detail the major functional elements of MIPv6 that make use of MIPv6 features.

1. Movement Detection
When a MN moves, it must detect its current location. In MIPv6, a MN can determine its current location by listening to the router advertisements and comparing the network prefix of the source address within this advertisement with the network prefix of its home link. If the network prefix of the source address within the router advertisement equals the network prefix of the home address of MN, then the MN is on its home link. Otherwise the MN is on a foreign link.

2. Acquisition of the CoA
When a MN attaches to a foreign link, it will need to acquire a new CoA. To obtain a CoA, the MN can use either stateful or stateless address auto-configuration methods. In the first situation, the MN obtains a CoA from a Dynamic Host Configuration Protocol for IPv6 (DHCPv6) [6] server. In the latter situation, by using the Neighbor Discovery protocol [3], a MN is able to find the network prefix at any point of attachment that it might select and then adds a unique interface identifier to form a CoA for that point of attachment. After a CoA is obtained or formed, it must be checked whether this is a unique address or not by Duplicate Address Detection (DAD) mechanism [4].

3. Registration and Binding Management
When a MN moves to a foreign link and acquires a CoA, it then registers to the HA or CNs in its list to inform them of its current location by using the IPv6 Mobility header [2]. Mobility header messages related to the management of bindings include Binding Update message, Binding Acknowledgement message, Binding Refresh Request message etc. The MN performs the binding registration by sending a Binding Update message to the HA or CNs. The HA or CNs reply to the MN by returning a Binding Acknowledgement message. In the correspondent registration, as a part of this procedure, a return routability test is performed in order to authorize the establishment of the binding. The Binding Refresh Request message is mainly used to refresh binding when nearing the end of the current binding lifetime.

4. Location Tracing and Packets Routing
Finally, after registering and binding, the CN can trace the MN and route packets to it continuatively. In bidirectional tunnelling mechanism, Packets from the CN to the MN are routed to the home address of MN, the HA shall uses proxy Neighbour Discovery [3] to intercept any IPv6 packets addressed to the MN’s home address on the home link. Each intercepted packet is tunnelled to the MN’s current CoA [7]. Packets to the CN are tunnelled from the MN to the HA, which is called reverse tunnelling, and then routed normally from the home network to the CN (see figure 1, a).

In route optimization, the HA no longer exclusively deals with the address mapping, but each CN can have its own binding cache. In the direction from the MN to the CN, packets sent by the MN are delivered to the CN with the Home Address option in the Destination Option Extension header when the MN is away from its home network. In this case, the MN sets the IPv6 header’s source address as its CoA and adds a Home Address option with the MN’s home address to IPv6 header. When the CN receives the packet from the MN, it replaces the MN’s home address to be the IPv6 header’s source address before delivering the packet to the upper layer. This way, the MN not only keeps mobility transparent to its upper software, but also passes the packet through any router implementing ingress filtering [8]. In the opposite direction, when sending packets to the MN, the CN checks its cached bindings for an entry for the packets’ destination address. If a cached binding for this destination address is found, the CN uses Type 2 Routing header to route packets to the MN by specifying the CoA as the destination address in IPv6 header and the MN’s home address as the final destination in the Routing header. When the MN receives packets, the MN processes this Routing header and delivers packets to the upper layer using the MN’s home address as if the MN was at home (see figure 1, b). If a cached binding for this destination address is not
found, for example the binding is timeout or the CN originates a communication with the MN etc., the CN does not know the current location of MN. In this case, it shall send packets using the MN's home address as destination address. The MN’s HA will intercept the packets and tunnels them to the current location of MN (see figure 1, a). When the MN receives packets from its HA, it knows that the CN is not aware of its current CoA and will inform the CN of the current CoA by sending a Binding Update message to the CN, so that the CN later can send packets to the MN directly.

3. MIPv6 Model Overview

In order to perform mobility operations, the OPNET MIPv6 model [5] has been designed and developed with many standard MIPv6 definitions and extensions such as Extension headers (including Mobility, Routing and Destination Extension headers), Neighbour Discovery, Router Advertisements (including movement detection, stateless address auto-configuration and HA address detection) and Duplicate Address Detection etc. OPNET also includes the MIPv6 entities models: MN, CN and HA. And The OPNET MIPv6 model supports two routing mechanisms for communication between the MN and the CN: bidirectional tunnelling and route optimization [2]. Therefore, researchers can observe and analyze the simulation results demonstrated in the MIPv6 model and compare with the real MIPv6 network environment. In the following subsections, the characteristics of the MIPv6 model are presented by configuring node models for MIPv6.

(1) Mobile Node Configuration

In OPNET MIPv6 model, the node models of wlan_wkstn_adv and wlan_server_adv can be configured as MNs by setting the Node Type attribute in the attributes dialog box: IP->Mobile IP Host Node Parameters->Mobile IPv6 Parameters. To enable route optimization or not, we set the Route Optimization attribute to Enabled or Disabled. The IP address of HA can be learned from the HA’s router advertisements when the MN is at home network. However, if the MN is initially away from the home network and more than one access routers exists, we need to specify the IP address of HA in the Home Agent Address attribute. We can also set the number of lost router advertisements that constitutes a network layer handover indication by specifying the Mobility Detection Factor attribute. Besides, the binding and return routability parameters can be configured respectively in the Binding Parameters and Return Routability Parameters. In MN, the global IP address should use the same network prefix as the IP address of HA. Figure 2 shows the example of MN configuration with wlan_wkstn_adv model.

In figure 2, the Node Type attribute is set as Mobile Node, and Route Optimization attribute is enabled. The IP address of HA is 2001:0638:0600:0101::1 with network prefix 64, and The global IPv6 address of MN is 2001:0638:0600:0101::2 with the same network prefix as the HA. And other parameters are set as default. When a node is configured as the MN, it has the ability to support MIPv6 applications.

(2) Correspondent Node Configuration

In OPNET MIPv6 model, the CN functionality is included in the MN functionality. To configure a node as the CN, the Node Type attribute can be set to Mobile Node or Correspondent Node. Similarly, the route optimization can be enabled or disabled for CNs in the node models of mipv6_ppp_wkstn_adv, mipv6_ppp_server_adv, mipv6_ethernet_wkstn_adv and mipv6_ethernet_server_adv. Besides, all regular workstation nodes behave as CNs with no route optimization support. Figure 3 shows the CN configuration with mipv6_ethernet_server_adv model.

(3) Home Agent Configuration

The home agent functionality is configurable on a per-interface basis for router nodes. A route can have many interfaces that act as home agents; each need to be configured individually. The home agent interface can be a wireless interface or wired interface. An interface is configured as a home agent through the IP->Mobile IP Router Parameters->Mobile IPv6 Parameters attribute in the attributes dialog box of router node. Figure 4 shows the configuration of home agent.
In order the MN can learn of the closest home agent, the home agent also needs to have router advertisement functionality. The route advertisement functionality can be configured in the Router Advertisement Parameters attribute: IP-IPv6 Parameters-Interface Information-Router Advertisement Parameters, which can enable or disable router advertisement and set how often advertisements are sent. Normally, router advertisement intervals should be set to a value that is short enough to keep the routing tables accurate. If the router advertisement interval is too big, nodes locations may change too much before an update is sent. Besides, the Advertise interval attribute should be set to Auto-Calculate. Figure 5 shows the configuration of router advertisement parameters in HA. In figure 5, the Router Advertisement is enabled and the Router Advertise Interval is the function of uniform (0.5, 1) in second.

4. Analysis and Evaluation of MIPv6

Configuring simulation and analyzing the simulation results will help to realize the MIPv6 deployment in an actual network environment. Hence this section analyzes and evaluates MIPv6 by mean of a simulation performed using OPNET MIPv6 model. The simulation scenario is constructed according to our MIPv6 testbed environment in the Institute of Informatics of Goettingen University. The simulation results demonstrate how the MIPv6 can be done and the performance can be achieved through the network model of MIPv6 testbed in the Institute of Informatics of Goettingen University.

(1) Simulation Setup

According to our MIPv6 testbed, the simulation scenario, depicted in figure 6, is composed by the Center Routers (CRs) and CNs that are connected to the CR1. Each wired connection is modelled as 100Mbps duplex link with 0.1ms delay. In the testbed, each of four Access Routers (ARs) consists of two interfaces, thereinto, the wireless interface supports IEEE802.11b and the wired interface is connected to CRs. The AR of HA represents the wireless home network with home agent function while each of other ARs represents a different wireless IP subnet of foreign network. The ARs provide total coverage area with radius of approximately 300 meters, and the MNs move within the coverage area.
constant value of 1024 bytes as input for the real time video traffic application. The incoming stream interarrival time and the outgoing stream interarrival time were configured with constant 0.01s. The links and devices in the testbed were all configured with background traffic. The MN roams in the range of ARs, starts out at its home network, and switches to AR1, AR2 and AR3 in deterministic path with rate of 10m/s. This case allows for full control of the mobility and handover rate of the observed node.

Figure 7 shows the video conferencing traffic received statistics, from which some gaps in the communication can be observed. Each gap is produced every time the MN changes its current AR triggering MIPv6 registration/binding procedures to notify its HA and its CN of the new CoA. While the registration/binding procedures update the HA and the CN, all application traffic directed to the MN will be interrupted.

The application response time will be directly affected by the MIPv6 routing mechanisms, i.e. bidirectional tunnelling and route optimization, used by the MN in order to communicate with the CN. Figure 8 shows the responses time with bidirectional tunnelling mechanism and route optimization mechanism. From the graph we can see that the application delay with route optimization mechanism is reduced compared to the case using tunnelling mechanism. When using route optimization mechanism the IPv6 extension headers including Routing Extension header and Destination Extension header will be used to transport the data traffic directly between the MN and the CN. In this case, the application response time will be mainly produced by only one time the data traffic passes through the CRs. When using bidirectional tunnelling mechanism, the tunnels will be needed for the communication between the MN and the HA. In this case the application response time will be mainly produced by the two times the data traffic must pass through the CRs.

TCP is the most widely used transport layer protocol. We simulate FTP application to understand the impact of MIPv6 mobility on the congestion control mechanism of TCP. In our simulation, we used the standard TCP Reno model with slow start algorithm, and configured the segment size as 1440 bytes to avoid fragmentation. We set the buffer size of AR larger than the Congestion Window (CWND) of TCP in order to avoid packet loss due to buffer overflow, which eliminates the impact of buffer factor. The FTP server was sending a file of 16Mbytes to the MN while the MN moving from the HA towards the AR3. Figure 9 shows the indication of how TCP CWND performs during the handover in the mobile environments.

In figure 9, the horizontal axis indicates the time in which the file is being transmitted and vertical axis indicates the size of CWND in terms of byte. At 23 second when the FTP server of CN starts to transmit the file, the size of CWND starts to increase gradually. At
the time when the communication is broken during the handover, the TCP sender does not transmit packets because it does not receive ACKs from the receiver for the same reason, and the size of CWND decreases drastically. This decrease is due to the three consecutive packet losses occurred in the ARs, where although the FTP server retransmits the lost packet, because retransmit timeout is occurred by the subsequent packet loss, the size of CWND after retransmit timeout is given as:

\[ CWND_{afterRTO} = \min(CWND_{beforeRTO}/2, Receive\_Buffer\_Size/2) \]

where \( CWND_{afterRTO} \) is the size of CWND after retransmit timeout, and \( CWND_{beforeRTO} \) is the size of CWND before retransmit timeout. In this way, TCP reduces the throughput through the congestion control mechanism because it considers the packet losses due to the handover as the congestion of the network. This simulation demonstrates why current TCP does not show good performance in MIPv6.

Following, we observe the different networks (ARs) visited by the MN during moving (see figure 10). As showed in figure 10, the bar in the graph represents an AR visited by the MN, the bar width represents the time the MN used the AR until it moves to a different one. We can see that the data traffic switch inter the different ARs when the MN moves with ongoing communication.

![Fig. 10 Visited access routers during handover](image)

B. Signalling Impact on MIPv6

As we know in section 2, MIPv6 defines BUs and BAs etc. signalling for handover control, which introduces control traffic. And the Routing and Destination Extension headers are employed for data traffic routing in the route optimization mechanism, or IPv6 header encapsulation is employed for data traffic routing in tunnelling mechanism, which incurs overhead. Besides, the transmission of the registration messages between the MN and the HA induces considerable handover latency. In this subsection, we study the impact of signalling on MIPv6.

The control traffic represents the MIPv6 signalling messages sent/received by the current node, which can be the MN, CN or HA. It includes Binding and Routability Test messages etc. In figure 11, the control traffic generated by MIPv6 mobility messages is measured in bits per second. From figure 11, we can see the control traffic of route optimization is greater obviously than the one of bidirectional tunnelling. This is because in route optimization mechanism the MN must not only register its CoA to the HA but also update binding to the CN, whereas in bidirectional tunnelling mechanism the MN needs only register its CoA to the HA.

![Fig. 11 The control traffic of MN](image)

Overhead is a critical issue in wireless environments where there is constrained bandwidth resource. Figure 12 investigates the overhead ratio for MIPv6 routing mechanism of route optimization and bidirectional tunnelling. In figure 12, the Route Optimization Overhead (%) represents the traffic overhead ratio due to addition of IPv6 Extension headers, when sending data traffic using MIPv6 route optimization mechanism. It is computed as follows:

\[ Overhead\_Ratio\_Route\_Optimizatiion = \frac{Total\_Extension\_Header\_size}{Original\_Packet\_Size} \]

The Tunneled Traffic Overhead (%) represents the traffic overhead ratio due to IPv6 header encapsulation when sending data traffic through MIPv6 tunnelling. It is computed as follows:

\[ Overhead\_Ratio\_Tunnel = \frac{Outer\_Packet\_IP\_Header\_size}{Inner\_Packet\_Total\_Size} \]
We can see from the graph that in each handover it takes about 1s for registration procedure both route optimization and bidirectional tunnelling mechanism. This time indicate that the current registration mechanism is inefficient and there is need to improve it.

5. Conclusions

This paper described the MIPv6 technology and presented the MIPv6 model of OPNET simulator. Besides, using the simulator, we assessed the MIPv6 testbed. We observed the application traffic and visited ARs of MN during moving, the application response time was measured in different routing mechanisms, and we demonstrated the adverse effect of handover procedure of MIPv6 on the congestion control in the transport layer. We also evaluate the impact of MIPv6 signalling in different routing mechanisms. The simulation and results of our testbed have been performed and demonstrated to show how to model real networks and provide some insights in the influence of the protocols on application traffic. Therefore, we will focus on the protocol enhancement including smooth handover, improvement of congestion control and signalling optimization etc. in the further work.

Acknowledgements

The research has been carried out with the support of funding from the China Scholarship Council (CSC). The use of OPNET Modeler in the research was facilitated through OPNET’s university program.

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