Comparative study of Mobile IPv4 and Mobile IPv6

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Sammanfattning

Comparative study of Mobile IPv4 and Mobile IPv6

Summary
This thesis has compared the Mobile IPv4 and Mobile IPv6 to find out which of them performs better when it comes to send datagram from the correspondent node to the mobile node. The tests that were made to measure performance were latency, TCP/UDP throughput, loss and delay, as well as time measurement for connectivity loss for the mobile node while roaming. The tests were done using Cisco equipments and Microsoft Windows 7 Professional OS. Due to the hardware and software used, the route of datagram was the same in both scenarios since Cisco routers and Microsoft Windows 7 OS does not support route optimization for Mobile IPv6. The results showed that Mobile IPv4 performed better in all the tests done.
Preface

This thesis has been done as a part of my bachelor degree in Network technology with IT-security. However, this thesis could not have been finalized without the help and support of several teachers in the Department of Economics and IT. In particular I would like to thank Andreas de Blanche for his support and comments to improve this study.
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<td>Access Router</td>
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<td>CN</td>
<td>Correspondent Node</td>
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<td>CoA</td>
<td>Care-of Address</td>
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<td>DHCPv6</td>
<td>Dynamic Host Configuration Protocol for IPv6</td>
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<td>MNP</td>
<td>Mobile Network Prefix</td>
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<td>MR</td>
<td>Mobile Router</td>
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<td>NEMO</td>
<td>Network Mobility (Network that Moves)</td>
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<td>RR</td>
<td>Return Routability</td>
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1 Introduction

With standard IPv4 and IPv6 routing protocols, the IP address changes when a node connects to a new point of access to the network. This will break the on-going TCP, UDP sessions. The internet traffic mostly used today is TCP which is defined by the combination of port number and IP address on both sides of the established connection. When one of these four parts changes the connection will be lost and needs to be reestablished. In order to avoid disruption and keep on-going TCP connection, the IP addresses and ports used during the TCP session should not be changed. Mobile IP protocol was chosen by IETF to solve this problem [17]. Mobile IP provides the nodes with two IP addresses, the first is the home address and the second address is known as care-of address that changes depending on the network it is connected to [7,13].

Mobile IP is designed to work for IPv4 and IPv6. So far almost all mobile devices use Mobile IPv4. Today as the number of Mobile devices increase with PDA’s, laptops, cellular phones, etc. the demands on internet are growing and the capacity of Mobile IPv4 is not enough. In order to satisfy the increasing demands Mobile IPv6 is meant to take over after Mobile IPv4. As it does so Mobile IPv6 is designed to be more efficient with a built in support for mobility.

A lot of literature has described how to implement a mobility network for IPv4 and IPv6 in Linux/Unix environment [14, 15]. For Microsoft OS there is some information how to implement Mobile IPv6 using Windows XP with SP1 [15]. Few studies have been made to compare Mobile IPv4 and Mobile IPv6. However the study of Chang et al. compared the TCP traffic in Mobile IPv4 and Mobile IPv6 and concluded that the performance in Mobile IPv6 network did better than in Mobile IPv4 network. However this study was made in Network Simulator NS-2 [16].

This study will use the physical deployments of Cisco equipments and Microsoft Windows 7 Professional OS to study the differences in performance between Mobile IPv4 and Mobile IPv6.

The report starts with a description of the research aim and research questions in section 2. It is followed by the mobility section (3) which describes how mobility works. Then the methodology of the thesis is described in section 4, followed by the results of the tests in section 5. Section 6 discusses the results of the thesis and finally section 7 draws the conclusion of the whole project.
2 Research Aim and Research Questions

As we know IPv4 is being replaced by IPv6 due to the increased demand from mobility devices. However, as has been seen above there is a lack of research on what this change actually means for the performance of mobility. This thesis aims at comparing Mobile IPv4 and Mobile IPv6 in terms of performance on latency, TCP/UDP throughput, and connectivity loss while roaming. Thus the study will explore the effects of the future implementation of Mobile IPv6 for mobile devices.

The overarching research question that the thesis will answer is:

1. Which one of Mobile IPv4 and Mobile IPv6 performs better when it comes to sending traffic between Correspondent Node and Mobile Node?

In order to answer the overarching question the thesis will answer the following specific questions:

- What is the latency in Mobile IPv4 and Mobile IPv6?
- What is the TCP throughput in Mobile IPv4 and Mobile IPv6?
- What are the UDP throughput, loss, and delay in Mobile IPv4 and Mobile IPv6?
- How long is the connectivity loss between Correspondent Node and Mobile Node while roaming from foreign network to another foreign network in Mobile IPv4 and Mobile IPv6?

3 Mobility

Mobile IP aims at maintaining the IP connectivity without changing IP address of mobile devices while moving within networks. Mobile IP gave the nodes liberty to move from home network to foreign networks and keep connectivity while Care-of address (CoA) informs about their current locations. All the mobile nodes (MNs) have two addresses, one home address (HoA) and one Care of Address (CoA) which enable them to roam but still be connected to the home network. In Mobile IPv4 (MIPv4), when roaming, the mobile node (MN) uses a Foreign Agent (FA) to get assigned its CoA, However, in Mobile IPv6 (MIPv6), when the MN roams it communicates via Access Router (AR) to obtain its CoA [1].

3.1 Terminology

In order to understand how mobility works, it is important to know the elements of Mobile IP. There are three different types of devices in a MIPv4 Network, a MN, a Home Agent (HA), and a FA as shown in Figure 3.1.1.
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**Figure 3.1.1** Elements of basic Mobile IPv4 topology.

**Mobile Node (MN):** Also known as a roaming device. A mobile node can be a router or an end node running a Mobile IP client stack. In addition, the mobile node can change its point of attachment while maintaining connectivity to its Home Network [4].

**Home Agent (HA):** The router that takes care of Mobile Node’s traffic delivery by tunneling datagram while MN is in a foreign network [4].

**Foreign Agent (FA):** Is the router on the mobile node’s visited network providing the MN with routing services. It detunnels the datagram sent by the home agent to the mobile node [4].

In MIPv6, there is no need for Foreign Agent as in MIPv4 since the MN instead connects to the foreign link and uses an AR when roaming as shown in Figure 3.1.2.

**Figure 3.1.2** Elements of basic Mobile IPv6 topology.

**Access Router (AR):** Is the default router of the Mobile Node [12]. It is a standard IPv6 router with no modifications [17].

After a brief review of the elements of Mobile IP network, another important concept is the Care-of Address.
Care-of Address (CoA): The end point of the tunnel that delivers datagram to the MN. The MN can have several CoA but the one that is registered with its home agent is considered the primary CoA [7].

In addition there are three main phases in the IP Mobility protocol, Agent Discovery, Registration, and Tunneling.

Agent Discovery: Both home agent and foreign agent advertise their availability over a network link where they offer their services. When a new node joins the mobility network, it sends a solicitation message in order to discover if there are any available agents [6].

Registration: The registration is done when the MN is in a foreign network and registers its CoA with its home agent. The MN does so through registering either directly with its HA or by communicating with the FA that then registers the CoA with the mobile node’s HA [8].

Tunneling: To send traffic to the MN, the HA and FA create a tunnel between them. It can be encrypted if desired [6].

Some additional terms are used.

Home Address (HoA): Is the IP that the MN has on its home network [11].

Return Routability (RR): Facilitates a secure connection between the CoA and the home address when there is no security association in use between the MN and the correspondent node (CN) [11].

Visited Network: Is the network used by the MN to access the Internet when roaming [11].

3.2 Mobile IP Operation

Mobile IP has two different identifiers for the Mobile hosts, a routing identifier and an endpoint identifier. The original IP address assigned for the Mobile host when it is at home network is known as endpoint identifier. The endpoint identifier is called the mobile host’s home address (HoA) [17]. On the home network a HA is responsible for storing information about the MNs that has a permanent home address in its network. When the MN moves to a foreign network a special last hop router, known as a foreign agent in MIPv4 and Access Router in MIPv6, informs about the visiting mobile nodes in its network. However, it is still the MN’s home agent that maintains its CoA and recognizes its movements in a foreign network. Therefore, whenever another node attempts to communicate with the MN it uses its permanent HoA to
send packets. Then it is the HA that redirects the packets to the last hop router using the stored information about its current location [1].

3.2.1 Basic Operation of Mobile IPv4

Mobile IPv4 has three main parts that handle the mobility, a Home Agent, a Foreign Agent, and a Mobile Node. Every MN in Mobile IPv4 has two IP addresses, a static home address that is used to identify higher layer connections (e.g., TCP) and a care-of address which is used for routing purposes.

When the MN is moving to a different foreign network, CoA changes at every new foreign network. This is because the CoA is located at the FA. When moving the MN sends a message to its HA which contains the binding between the new CoA and the HoA. This procedure is known as home-agent registration [17]. During home agent registration the MN maintains the binding between the HoA and the CoA at the home agent [17].

Since the MN is registered with its home network even when away from home, a correspondent node (CN) that sends packets to the MN will do so by sending them to the mobile node’s home address. Then the HA forwards the packets to the mobile node’s CoA, which is registered with the home agent. The HA sends packets by tunneling them, the FA decapsulates them and, as such, the packets will appear to have MN’s home address as a destination address.

In the opposite direction the packets from MN to CN are routed by using the standard IP routing mechanism. Thus the MN uses the HA as its source address in the IP header. According to Mobile IPv4 standardization this routing process forms a triangle routing between the HA, FA, and CN [3]. Figure 3.2.1 show how datagram are sent from CN to MN and in the opposite direction in Mobile IPv4.

![Figure 3.2.1: Operation of Mobile IPv4 Datagram Route.](image-url)
### 3.2.1.1 Mobile IPv4 Data Delivery Process

In the mobile IPv4, the sender (CN) delivers datagram to the IP address of the MN. The HA intercepts the packet, encapsulates it, and tunnels it to the foreign agent which is responsible for assigning a care-of address to the mobile node and forwarding the packets to the MN. Then the foreign agent forwards the packet to the MN at its foreign location. However, when the MN sends packets to the CN, they are diverted along a direct path through FA to CN.

This delivery process is known as Triangle Routing. Triangle Routing means that the data takes a longer path to arrive at its destination. Thus the triangle routing causes a problem since it delays the delivery of the datagram and places an unnecessary load on networks and routers.

### 3.2.2 Basic Operation of Mobile IPv6

Similar to Mobile IPv4, Mobile IPv6 has three main parts that handles the mobility, a Home Agent (HA), an Access Router (AR), and a Mobile Node (MN). When the mobile node is within its home network, it is counted as a normal host when receiving and sending packets and communicates via standard IP routing mechanisms. If the mobile node changes location to a new network, it will have an additional IP address, a CoA that can be obtained through mechanisms such as Stateless auto-configuration or DHCPv6 (Dynamic Host Configuration Protocol for IPv6) [7, 10, 17].

The communication process between HoA and CoA is called home-agent binding update. When in a foreign network, the MN sends a binding update message to the home agent to register its CoA. The HA answers with a binding acknowledgment. In this process, all the nodes communicating with a MN are called Correspondent Node. When communicating with CN the MN sends the registration directly to CN, which is called correspondent registration. However, if CN wants to communicate with MN it can be done by one of two ways; Bidirectional Tunneling or Route Optimization [7, 10, 17].

Bidirectional Tunneling is when the CN sends packets to the HA which then encapsulates them in IPv6 and forwards them to the CoA of the MN. In the reverse direction, packets from MN are sent to the HA through a reverse tunnel and from the HA to the CN using a regular routing process. This operation does not require correspondent registration or Mobile IPv6 on the CN [7, 10]. Figure 3.2.2 shows the operation of bidirectional tunneling.
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Figure 3.2.2: Operation of Mobile IPv6 with Bidirectional tunneling.

Route Optimization implies direct communication between MN and CN without going via HA. This involves correspondent registration, where the MN registers its CoA with the CN, and through the Return Routability (RR) procedure this binding is authorized. To send packets directly to MN, CN uses a special routing header called type2, which allows the data to be routed between MN and CN without passing through the home agent. This can be done after a successful RR procedure when using route optimization [7, 10, 17]. (Figure 3.2.3)

Figure 3.2.3: Operation of Mobile IPv6 with Route Optimization.

Mobile IP route optimization is not possible in Mobile IPv4 which makes Mobile IPv6 a more efficient alternative for data transfer since it has a shorter path. As packets in this way do not need to go through HA, this eliminates congestion at the mobile node’s home agent and home link. Thus, this leads to better performance.
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when a great number of MNs are in motion, for example in a VoIP (Voice over IP) scenario [7, 10].

Mobile IPv6 can have multiple home agents as well as supports the reconfiguration of the home network. Through Dynamic Home Agent Address Discovery, the MN can find out the IP address of its HA on the home link. In addition the MNs can discover its home link’s new prefixes by using the Mobile Prefix Discovery mechanism [7, 10].

3.2.2.1 Mobile IPv6 Data Delivery Process

Mobile IPv6 uses route optimization which allows the shortest path to be used and eliminates the congestion at the mobile node's home agent and home link. Thus the data packets are sent directly from CN to the MN's foreign location. If the CN is not IPv6 compatible, the data transfer will resemble the delivery method of mobile IPv4 since the data transfer is done via HA. However the HA intercepts the data packets and tunnels them using IPv6-over-IPv6 tunneling to the mobile node's care-of address. In mobile IPv6 the data packets include a new routing extension header that contains the mobile node's home address [7, 10].

3.3 Mobile Network (NEMO)

One of the difficulties of MIPv6 is that all the mobile nodes must support the new protocol stack to use mobility function [18]. Network Mobility also known as “network that moves” or NEMO [RFC3963] is an extension to MIPv6 that offers a solution by providing a moving router (Mobile Router) [7]. The Mobile Router (MR) is the only device that needs to support MIPv6 and NEMO. In this way the mobile nodes connected to the MR do not have to be MIPv6 or NEMO capable [2].

NEMO processes and messages are the same as in MIPv6, however the MN is replaced by a MR [7]. In NEMO the MR has a fixed network prefix known as mobile network prefix (MNP), it obtains the MNP from the home network. When the MR is at home, it acts as standard subnetwork, and when it is in a foreign network, the MR registers the HoA, instead of the MN as in MIPv6. In addition it registers the MNP connected to it. The nodes connected to the MR can communicate as if they are in the home network. The datagram sent from MN’s to CN first go to MR, which then sends them to HA. The communication between the MR and HA agent is same as in MIPv6 [18]. However in the current NEMO specification, route optimization is not supported yet and the communication between MN’s and CN always passes through the HA [7].

Figure 3.3.1 shows a topology of NEMO. NEMO is mostly used in transportation, such as busses and trains where many users that may not be MIPv6 capable connect to same network without modifying their devices.
3.4 Connectivity when Mobile Node Moves

When Mobile Node moves between two different access points on the same subnet, CoA remains the same, and thus the connectivity is not affect for the Mobile IP host. While when the Mobile Node moves to a new subnet, it obtains a new CoA [17]. On the new network the MN sends the binding updates to its home agent and CN. However until the MN has obtained the CoA there is a time gap when the CN sends packets to the old CoA which is not valid anymore. During this time gap the MN loses connectivity and the packets are discarded [2]. Due to this loss of connectivity sensitive traffic, such as voice, will have a detectable break in the communication while web browsing can work almost without problems [17].

4 Methodology

The method that will be employed to study and compare the performance of MIPv4 and MIPv6 will be based on the creation of two different scenarios, one with MIPv4 configuration and another with MIPv6 configuration, but where everything else is the same. The tests will then consist of latency test, TCP and UDP tests to measure throughput, loss, and delay as well checking the connectivity between CN and MN while roaming from foreign network to another.
4.1 Test Environment

The Mobile IP topology that was used in the test process consists of a HA, FA, CN and a MN in MIPv4 and a HA, AR, CN and a MN in MIPv6.

4.1.1 Topology

The physical topology uses a Mobile network model, with four Cisco 2800 routers, whereof two Cisco 2811 and two Cisco 2801. Three routers are connected through a switch and a fourth router acts as a MN and MR at the same time enabling mobility access to all its connected hosts. Figure 4.1.1 below shows the topology for MIPv4.

![Figure 4.1.1: MIPv4 physical topology.](image)

Figure 4.1.2 shows the route between CN and MN in MIPv4 topology.

```
C:\>tracert 93.15.20.20
Tracing route to MN [93.15.20.20]
over a maximum of 30 hops:
  1  <1 ms  <1 ms  <1 ms  192.168.30.1
  2  1 ms  <1 ms  <1 ms  192.168.10.1
  3  1 ms  1 ms  1 ms  172.16.10.1
  4  1 ms  <1 ms  <1 ms  MN [93.15.20.20]
```

Figure 4.1.2: MIPv4 traffic path from CN to MN.
The topology will look the same when testing MIPv4 and MIPv6, only the Foreign Agent (FA) in MIPv4 is replaced with an Access Router (AR) in MIPv6. This is illustrated below in Figure 4.1.3.

![MIPv6 physical topology](image)

Figure 4.1.3: MIPv6 physical topology.

Figure 4.1.4 shows the route between CN and MN in MIPv6 topology.

```
C:\> tracert 2001:40::4015
Tracing route to 2001:40::4015 over a maximum of 30 hops
1    <1 ms    <1 ms    <1 ms  2001:30::1
2     1 ms     1 ms     1 ms  2001:1::1
3     2 ms     1 ms     1 ms  2001:2::ea04:62ff:fe25:1850
4     6 ms     1 ms     1 ms  2001:40::4015
```

Figure 4.1.4: MIPv6 traffic path from MN to CN.

In addition, when doing the connectivity tests while roaming a new router was added to work as a second FA in MIPv4, and as a second AR in MIPv6, as shown in Figure 4.1.5. To test the connectivity loss while roaming the handover took place between FA and FA 2 in MIPv4, and between AR and AR 2 in MIPv6.
4.1.2 Software

Two Cisco Router Platforms were used, Cisco 2811 and Cisco 2801. The Cisco 2811 ran IOS Software (C2800NM-ADVIPSERVICESK9-M), Version 12.4(24)T3 with 512MB RAM. This router was used as Home Agent and Mobile Router in both the MIPv4 and MIPv6 scenarios. The Cisco 2801 ran IOS Software (C2801-ADVIPSERVICESK9-M), Version 12.4(19a) with 384MB RAM. This router was used as CN-Rtr (R3) and FA in MIPv4, and as CN-Rtr (R3) and AR in MIPv6. The reason for using two different IOS versions is that the network mobility (NEMO) basic support protocol is available only for IOS Version 12.4(20)T and later (here Cisco 2811). The tests of MIPv6 required NEMO on two of the routers but not on the other two. This is not a requirement in MIPv4 but the same routers were used for all tests to make the test environments as similar as possible. During the tests, the CN and MN were running Windows 7 Professional Operating System.

Router mobile configurations were used in both scenarios with MIPv4 and MIPv6 respectively. For the different devices on the topology, the following configurations have been used for MIPv4 (see appendix 1):

- HA Router with Home Agent configuration (Cisco 2811).
- FA Router with Foreign Agent configuration (Cisco 2801).
- CN-Rtr (R3) with Basic IPv4 configuration (Cisco 2801).
- MR Router with Mobile Router configuration which acts as a MN and MR at the same time (Cisco 2811).

For MIPv6 the following configurations were used (see appendix 2):

- HA Router with Home Agent NEMO configuration (Cisco 2811).
- CN-Rtr (R3) and AR Routers with basic IPv6 configuration (Cisco 2801).
- MR Router with Mobile Router NEMO configuration which acts as a MN and MR at the same time (Cisco 2811).

Since the tests are carried out in Microsoft Windows 7 environment the MNs are not MIPv4 and MIPv6 capable. This is the reason for the fourth router acting as a MR as well as MN, as seen in Figure 4.1.1 and Figure 4.1.3 above.

One of the particularities of MIPv4 on Cisco Routers is that the configuration will create a dual tunnel, one between the HA and FA as well as another one inside the first one between the HA and MR. The dual tunnel is necessary because in MIPv4 on Cisco routers there is a route only to the home address on the FA which, if no second tunnel was in place, would create a routing loop as packets destined to the mobile network would follow the standard routing and return to the HA [4]. To simplify the understanding of the process, Figure 4.1.6 shows the output of show ip mobile tunnel, where the IP 192.168.9.1 is the HA address (for full configuration see Appendix 1).

```
Total mobile ip tunnels 2
Tunnel0:
  src 192.168.9.1, dest 192.168.10.2
  encap IP/IP, mode reverse-allowed, tunnel-users 1
  Input ACL users 0, Output ACL users 0
  IP MTU 1480 bytes
  Path MTU Discovery, mtu: 0, ager: 10 mins, expires: never
  outbound interface FastEthernet0/0
  HA created, CEF switching enabled, ICMP unreachable enabled
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 4676000 bits/sec, 674 packets/sec
  0 packets input, 0 bytes, 0 drops
  4828784 packets output, 1185618217 bytes

Tunnel1:
  src 192.168.9.1, dest 172.16.10.1
  encap IP/IP, mode reverse-allowed, tunnel-users 1
  Input ACL users 0, Output ACL users 0
  IP MTU 1460 bytes
  Path MTU Discovery, mtu: 0, ager: 10 mins, expires: never
  outbound interface Tunnel0
  HA created, CEF switching enabled, ICMP unreachable enabled
```

Figure 4.1.6: Dual tunnel on MIPv4.

Route optimization in MIPv6, which above has been described as the feature that makes MIPv6 more efficient than MIPv4, requires a MIPv6 capable CN. This is currently not possible in a Microsoft Windows 7 environment as the one used for the tests in this project. Only in Windows XP with service pack one, Windows CE .NET v4.2, or Windows Mobile™ 2003-based embedded devices is the route optimization possible. However, it requires the access to the MS MIPv6 Tech Preview Network Protocol which is not available for public download [9]. In addition, as Cisco routers for MIPv6 require NEMO configuration to redistribute the Mobile Network, route optimization is not supported [7] (see section 3.3 Mobile Network). Thus, in this
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project, MIPv6 datagram have been routed via HA which is also the case in MIPv4. The route process for MIPv6 is shown above in Figure 4.1.4.

4.2 Tests

The tests that have been carried out aim at measuring the performance of the MIPv4 and MIPv6 networks in Cisco Router environment. The tests measure the latency, TCP throughput, UDP throughput, loss, and delay and the connectivity loss between CN and MN while roaming from foreign network to another foreign network.

The route process for MIPv6 is shown above in Figure 4.1.4.

4.2 Tests

The tests that have been carried out aim at measuring the performance of the MIPv4 and MIPv6 networks in Cisco Router environment. The tests measure the latency, TCP throughput, UDP throughput, loss, and delay and the connectivity loss between CN and MN while roaming from foreign network to another foreign network.

The latency tests were done by using Ping utility between CN and the MN. The tests were carried out 5 times in both MIPv4 and MIPv6 scenarios in order to measure packets sent, received and loss as well as approximate round trip time.

Different TCP tests were carried out between CN and MN to measure data transfer and bandwidth in MIPv4 and MIPv6. The tests were done by using iperf. The tests that were performed were the following:

- TCP default test where the TCP default test has a window size of 8 Kbytes (depends on OS, 8 Kbytes in Windows 7 OS) and runs for 10 seconds.
- TCP with tuned window size of 24 Kbytes and default time of 10 seconds.
- TCP with tuned windows size of 64 Kbytes, 3 minutes and a buffer length of 16000 Kbytes.

During these tests the MN acted as a server and the CN acted as a client. The iperf TCP tests measure data transfer and throughput.

On the other hand, UDP tests measure throughput, delay jitter and datagram loss. In the same way as for TCP, iperf was used to test UDP traffic from CN which acted as a client to MN which acted as a server. The following tests were used:

- UDP default test where the UDP default test has a UDP buffer size of 8 KBytes and a runs for 10 seconds sending 1470 byte datagram.
- UDP test with tuned bandwidth of 10 Mbits/sec during 3 minutes.

To measure the connectivity loss while roaming from foreign network to another foreign network in MIPv4 and MIPv6 an extended ping was used from the CN to the MN. To simulate handoffs between the visited networks the Ethernet cable between FA/AR and MR was unplugged and then plugged in between FA 2/AR 2 and MR (see Figure 4.1.5 above). The Ethernet cables were kept easily accessible to ensure fastest possible switching between cables. The log messages from the Mobile Router showed that the interface went down for two seconds when the cable was connected to the new foreign network. The tests were made 5 times on MIPv4 and MIPv6 each. The connectivity loss will be shown in results section using the log message from the HA to demonstrate the time needed to delete the existing tunnel from the old FA/AR and creating a new tunnel. In addition, the speed of the whole process, from the
removal of the Ethernet cable to that connectivity was established between CN and MN, was timed by using a stopwatch.

All tests in both MIPv4 and MIPv6 were carried out between 5 or 10 times depending on the test and the average values were then calculated and are what has been used to display the results in this report.

5 Results

The performance of MIPv4 and MIPv6 is presented below in four steps, firstly through describing the results of the latency, secondly the TCP throughput, thirdly the UDP throughput, loss and delay, and lastly through describing the connectivity loss of MIPv4 and MIPv6 while roaming. The test results are presented in tables and figures below. The values presented in the figures are the average values of each test.

5.1 Ping Tests

Ping tests showed that, in both scenarios the packet sent and received were equal and thus there was no packet loss. When it comes to approximate round trip time, MIPv4 had 1ms minimum and maximum and thus the average was 1ms as well. The Table 5.1.1 below shows the results of MIPv4 round trip time.

Table 5.1.1: MIPv4 Ping tests round trip times in milli-seconds.

<table>
<thead>
<tr>
<th>MIPv4 Ping tests</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>1,0</td>
<td>1,0</td>
<td>1,0</td>
</tr>
<tr>
<td>Test 2</td>
<td>1,0</td>
<td>1,0</td>
<td>1,0</td>
</tr>
<tr>
<td>Test 3</td>
<td>1,0</td>
<td>1,0</td>
<td>1,0</td>
</tr>
<tr>
<td>Test 4</td>
<td>1,0</td>
<td>1,0</td>
<td>1,0</td>
</tr>
<tr>
<td>Test 5</td>
<td>1,0</td>
<td>1,0</td>
<td>1,0</td>
</tr>
<tr>
<td>Average</td>
<td>1,0</td>
<td>1,0</td>
<td>1,0</td>
</tr>
</tbody>
</table>

But MIPv6 had 1 ms average minimum and 2 ms average maximum and the average of all five tests was 1.2 ms, as shown in Table 5.1.2 below.

Table 5.1.2: MIPv6 Ping tests round trip times in milli-seconds.

<table>
<thead>
<tr>
<th>MIPv6 Ping tests</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>1,0</td>
<td>4,0</td>
<td>2,0</td>
</tr>
<tr>
<td>Test 2</td>
<td>1,0</td>
<td>2,0</td>
<td>1,0</td>
</tr>
<tr>
<td>Test 3</td>
<td>1,0</td>
<td>1,0</td>
<td>1,0</td>
</tr>
<tr>
<td>Test 4</td>
<td>1,0</td>
<td>1,0</td>
<td>1,0</td>
</tr>
<tr>
<td>Test 5</td>
<td>1,0</td>
<td>2,0</td>
<td>1,0</td>
</tr>
<tr>
<td>Average</td>
<td>1,0</td>
<td>2,0</td>
<td>1,2</td>
</tr>
</tbody>
</table>
The Figure 5.1.1 shows a comparison between MIPv4 and MIPv6 of the approximate round trip time in ms. As we can notice, the time taken for round trip which is based on the five tests showed that the difference was not so big but MIPv4 was faster than MIPv6.

![Figure 5.1.1: MIPv4 and MIPv6 round trip times in milli-seconds.](image)

**5.2 TCP Throughput**

Three different TCP tests were carried out between CN and MN to measure data transfer and throughput in MIPv4 and MIPv6. The test results for MIPv4 and MIPv6 are shown below in tables 5.2.1 – 5.2.6 starting with the results for the TCP default test (Table 5.2.1 and Table 5.2.2)

Table 5.2.1: MIPv4 TCP default tests.

<table>
<thead>
<tr>
<th>MIPv4 tests</th>
<th>Mbytes Transferred</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>47,1</td>
<td>39,4</td>
</tr>
<tr>
<td>Test 2</td>
<td>60,9</td>
<td>50,9</td>
</tr>
<tr>
<td>Test 3</td>
<td>55,4</td>
<td>46,4</td>
</tr>
<tr>
<td>Test 4</td>
<td>52,9</td>
<td>44,3</td>
</tr>
<tr>
<td>Test 5</td>
<td>56,5</td>
<td>47,3</td>
</tr>
<tr>
<td>Average</td>
<td>54,5</td>
<td>45,6</td>
</tr>
</tbody>
</table>
Comparative study of Mobile IPv4 and Mobile IPv6

Table 5.2.2: MIPv6 TCP default tests.

<table>
<thead>
<tr>
<th>MIPv6 tests</th>
<th>Mbytes Transferred</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>29,6</td>
<td>24,9</td>
</tr>
<tr>
<td>Test 2</td>
<td>35,8</td>
<td>30,0</td>
</tr>
<tr>
<td>Test 3</td>
<td>29,5</td>
<td>24,7</td>
</tr>
<tr>
<td>Test 4</td>
<td>31,4</td>
<td>26,3</td>
</tr>
<tr>
<td>Test 5</td>
<td>33,2</td>
<td>27,9</td>
</tr>
<tr>
<td>Average</td>
<td>31,9</td>
<td>26,7</td>
</tr>
</tbody>
</table>

The second test of the TCP throughput with tuned window size 24 Kbytes is shown in Table 5.2.3 and Table 5.2.4 below.

Table 5.2.3: MIPv4 TCP test with tuned window size 24Kbytes.

<table>
<thead>
<tr>
<th>MIPv4 tests</th>
<th>Mbytes Transferred</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>92,9</td>
<td>78,0</td>
</tr>
<tr>
<td>Test 2</td>
<td>91,9</td>
<td>77,0</td>
</tr>
<tr>
<td>Test 3</td>
<td>107,0</td>
<td>89,6</td>
</tr>
<tr>
<td>Test 4</td>
<td>107,0</td>
<td>89,3</td>
</tr>
<tr>
<td>Test 5</td>
<td>104,0</td>
<td>87,3</td>
</tr>
<tr>
<td>Average</td>
<td>100,5</td>
<td>84,2</td>
</tr>
</tbody>
</table>

Table 5.2.4: MIPv6 TCP test with tuned window size 24Kbytes.

<table>
<thead>
<tr>
<th>MIPv6 tests</th>
<th>Mbytes Transferred</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>59,6</td>
<td>50,1</td>
</tr>
<tr>
<td>Test 2</td>
<td>62,1</td>
<td>51,9</td>
</tr>
<tr>
<td>Test 3</td>
<td>62,4</td>
<td>52,4</td>
</tr>
<tr>
<td>Test 4</td>
<td>62,1</td>
<td>52,1</td>
</tr>
<tr>
<td>Test 5</td>
<td>62,3</td>
<td>52,3</td>
</tr>
<tr>
<td>Average</td>
<td>61,7</td>
<td>51,7</td>
</tr>
</tbody>
</table>

Table 5.2.5 and Table 5.2.6 show the results of the third TCP test running for 3 minutes with 64 Kbytes window size and buffer length of 16000 Kbytes.

Table 5.2.5: MIPv4 TCP test with tuned window size, time and buffer length.

<table>
<thead>
<tr>
<th>MIPv4 tests</th>
<th>Gbytes Transferred</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>1,85</td>
<td>88,4</td>
</tr>
<tr>
<td>Test 2</td>
<td>1,89</td>
<td>89,9</td>
</tr>
<tr>
<td>Test 3</td>
<td>1,89</td>
<td>90,0</td>
</tr>
<tr>
<td>Test 4</td>
<td>1,92</td>
<td>91,3</td>
</tr>
<tr>
<td>Test 5</td>
<td>1,92</td>
<td>91,3</td>
</tr>
<tr>
<td>Average</td>
<td>1,89</td>
<td>91,3</td>
</tr>
</tbody>
</table>
Table 5.2.6: MIPv6 TCP test with tuned window size, time and buffer length.

<table>
<thead>
<tr>
<th>MIPv6 tests</th>
<th>Gbytes Transferred</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>1,19</td>
<td>56,8</td>
</tr>
<tr>
<td>Test 2</td>
<td>1,19</td>
<td>56,5</td>
</tr>
<tr>
<td>Test 3</td>
<td>1,19</td>
<td>56,9</td>
</tr>
<tr>
<td>Test 4</td>
<td>1,19</td>
<td>56,8</td>
</tr>
<tr>
<td>Test 5</td>
<td>1,20</td>
<td>56,9</td>
</tr>
<tr>
<td>Average</td>
<td>1,19</td>
<td>56,9</td>
</tr>
</tbody>
</table>

When comparing MIPv4 with MIPv6 in each of the three different tests, the results showed that MIPv4 performed better in all tests. For this reason, only the results for the last test are presented here to compare MIPv4 and MIPv6 (see Figure 5.2.1 and Figure 5.2.2 below). The results for the TCP tests show that MIPv4 transfers 1,894 Gbytes of data and MIPv6 1,192 Gbytes during three minutes. When it comes to throughput, MIPv4 had 90,18 Mbits/sec and MIPv6 56,78 Mbits/sec. Thus, as both of these comparisons illustrate, MIPv4 transferred more data and at faster speed.

Figure 5.2.1: Data transfer with tuned TCP window size 64kbytes during 3 minutes.

Figure 5.2.2: Throughput with tuned TCP window size 64kbytes during 3 minutes.

5.3 **UDP Throughput, Loss, and Delay**

In a similar way, different UDP tests were carried out between CN and MN to measure loss and delay of packets sent. The test results are shown below in the tables 5.3.1 – 5.3.4 starting with the UDP default tests.

Table 5.3.1: MIPv4 UDP default tests (Tests 1 to 10 same results).

<table>
<thead>
<tr>
<th>MIPv4 tests</th>
<th>Transfer Mbytes</th>
<th>Throughput</th>
<th>Jitter ms</th>
<th>Loss</th>
<th>Total</th>
<th>Datagram % lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1 - 10</td>
<td>1,25</td>
<td>1,04</td>
<td>0</td>
<td>0</td>
<td>894</td>
<td>0</td>
</tr>
<tr>
<td>Average</td>
<td>1,25</td>
<td>1,04</td>
<td>0</td>
<td>0</td>
<td>894</td>
<td>0</td>
</tr>
</tbody>
</table>
The results of the UDP default test showed that MIPv4 had no delay jitter (0.00), no data loss (0 packets) and, thus, no datagram loss (0%). MIPv6 had a delay jitter of 0.37, a data loss of 0.8 packets and a datagram loss of 0.089%. The default test did not show a big difference between MIPv4 and MIPv6. This could be due to the default datagram of 1470 byte that are sent in 10 seconds which is not much on 100 Mbits/sec links as used in the MIPv4 and MIPv6 scenarios (see Table 5.3.1 and Table 5.3.2 above for results).

Table 5.3.3 and Table 5.3.4 show the results of the UDP test during 3 minutes and 10Mbits/sec bandwidth.

### Table 5.3.2: MIPv6 UDP default tests.

<table>
<thead>
<tr>
<th>MIPv6 tests</th>
<th>Transfer Mbytes</th>
<th>Throughput</th>
<th>Jitter ms</th>
<th>Loss</th>
<th>Total</th>
<th>Datagram % lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>1,25</td>
<td>1,04</td>
<td>1,246</td>
<td>2</td>
<td>894</td>
<td>0,22</td>
</tr>
<tr>
<td>Test 2</td>
<td>1,25</td>
<td>1,04</td>
<td>1,455</td>
<td>0</td>
<td>894</td>
<td>0</td>
</tr>
<tr>
<td>Test 3</td>
<td>1,25</td>
<td>1,05</td>
<td>0,291</td>
<td>3</td>
<td>894</td>
<td>0,34</td>
</tr>
<tr>
<td>Test 4</td>
<td>1,25</td>
<td>1,04</td>
<td>0</td>
<td>0</td>
<td>894</td>
<td>0</td>
</tr>
<tr>
<td>Test 5</td>
<td>1,25</td>
<td>1,04</td>
<td>0</td>
<td>0</td>
<td>894</td>
<td>0</td>
</tr>
<tr>
<td>Test 6</td>
<td>1,25</td>
<td>1,03</td>
<td>0,338</td>
<td>2</td>
<td>893</td>
<td>0,22</td>
</tr>
<tr>
<td>Test 7</td>
<td>1,25</td>
<td>1,04</td>
<td>0</td>
<td>0</td>
<td>894</td>
<td>0</td>
</tr>
<tr>
<td>Test 8</td>
<td>1,25</td>
<td>1,04</td>
<td>0,133</td>
<td>1</td>
<td>894</td>
<td>0,11</td>
</tr>
<tr>
<td>Test 9</td>
<td>1,25</td>
<td>1,04</td>
<td>0,24</td>
<td>0</td>
<td>894</td>
<td>0</td>
</tr>
<tr>
<td>Test 10</td>
<td>1,25</td>
<td>1,05</td>
<td>0</td>
<td>0</td>
<td>894</td>
<td>0</td>
</tr>
<tr>
<td>Average</td>
<td>1,25</td>
<td>1,04</td>
<td>0,3703</td>
<td>0,8</td>
<td>893,9</td>
<td>0,089</td>
</tr>
</tbody>
</table>

### Table 5.3.3: MIPv4 Tuned UDP test.

<table>
<thead>
<tr>
<th>MIPv4 tests</th>
<th>Transfer Mbytes</th>
<th>Throughput</th>
<th>Jitter ms</th>
<th>Lost</th>
<th>Total</th>
<th>Datagram % lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>212</td>
<td>9,87</td>
<td>0</td>
<td>1371</td>
<td>152754</td>
<td>0,9</td>
</tr>
<tr>
<td>Test 2</td>
<td>210</td>
<td>9,79</td>
<td>0,003</td>
<td>2736</td>
<td>152732</td>
<td>1,8</td>
</tr>
<tr>
<td>Test 3</td>
<td>213</td>
<td>9,92</td>
<td>0</td>
<td>542</td>
<td>152658</td>
<td>0,36</td>
</tr>
<tr>
<td>Test 4</td>
<td>213</td>
<td>9,90</td>
<td>0,904</td>
<td>818</td>
<td>152592</td>
<td>0,54</td>
</tr>
<tr>
<td>Test 5</td>
<td>205</td>
<td>9,53</td>
<td>0,845</td>
<td>6641</td>
<td>152719</td>
<td>4,3</td>
</tr>
<tr>
<td>Average</td>
<td>210,6</td>
<td>9,802</td>
<td>0,3504</td>
<td>2421,6</td>
<td>152691</td>
<td>1,58</td>
</tr>
</tbody>
</table>
Table 5.3.4: MIPv6 Tuned UDP test.

<table>
<thead>
<tr>
<th>MIPv6 tests</th>
<th>Transfer Mbytes</th>
<th>Throughput</th>
<th>Jitter ms</th>
<th>Lost</th>
<th>Total</th>
<th>Datagram % lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>201</td>
<td>9,37</td>
<td>2,831</td>
<td>8949</td>
<td>152655</td>
<td>5,9</td>
</tr>
<tr>
<td>Test 2</td>
<td>210</td>
<td>9,77</td>
<td>0,946</td>
<td>2562</td>
<td>152494</td>
<td>1,7</td>
</tr>
<tr>
<td>Test 3</td>
<td>193</td>
<td>8,99</td>
<td>3,618</td>
<td>14971</td>
<td>152840</td>
<td>9,8</td>
</tr>
<tr>
<td>Test 4</td>
<td>183</td>
<td>8,50</td>
<td>3,606</td>
<td>22469</td>
<td>152818</td>
<td>15</td>
</tr>
<tr>
<td>Test 5</td>
<td>212</td>
<td>9,86</td>
<td>0</td>
<td>1557</td>
<td>152830</td>
<td>1</td>
</tr>
<tr>
<td>Average</td>
<td>199,8</td>
<td>9,298</td>
<td>2,2002</td>
<td>10101,6</td>
<td>152727,4</td>
<td>6,68</td>
</tr>
</tbody>
</table>

In the tuned UDP test the difference between MIPv4 and MIPv6 was bigger. As shown in Figure 5.3.1 MIPv4 had an average data transfer of 210,6 and MIPv6 199,8. When it comes to throughput (Figure 5.3.2), MIPv4 had less loss since it had 9,802 Mbits/sec while MIPv6 had 9,298 Mbits/sec of 10 Mbits/sec.

The tests also showed that MIPv4 had a jitter delay of 0,3504 while MIPv6 had 2,2002 (Figure 5.3.3). When it comes to datagram loss MIPv4 had 1,58% while MIPv6 had 6,68% (Figure 5.3.4).
5.4 Connectivity Loss while Roaming

As mentioned before under tests (section 4.2), to measure the connectivity loss while roaming an extended ping was used from CN to MN while moving from the first foreign network to the second foreign network.

The figures below on topology (Figure 5.4.1 and Figure 5.4.3) show the same IP addressing as the one used in the tests. To simplify the understanding of the figures on log messages from HA router the reader can refer to these topology figures.

Figure 5.4.1 shows the MIPv4 route after moving from the FA to the FA 2.

![Figure 5.4.1: MIPv4 Roaming from FA to FA 2.](image)

As seen in Figure 5.4.2 below on MIPv4, when connected to FA2, the log message from the HA shows that a new tunnel was created with source address HA and destination FA2. The previously existing tunnel between HA and FA was deleted as shown in red in the Figure 5.4.2. The HA then inserts a second tunnel to carry the mobile networks connected to MR. This process took 11 seconds from that the old tunnel was deleted to that the new tunnel was up.
Comparative study of Mobile IPv4 and Mobile IPv6

However, the timing of the connectivity test in MIPv4 showed that the communication between the CN and the MN went through 3 consecutive Request timed out and was reestablished after a total of 15 sec. The process of switching the Ethernet cable between FA and FA2 was made five times to limit the effect of differences in my speed when changing the cable. When switching the Ethernet cable the interface went down for an average of two seconds. These two seconds are included in the total 15 seconds.

The tests in MIPv6 were carried out in the same way as in MIPv4. However, in MIPv6 the Ethernet cable was switched between AR and AR 2 as seen in Figure 5.4.3.
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As seen in Figure 5.4.4 below on MIPv6, when connected to AR 2, the log message from the HA shows that a second HA option was found via the new CoA of AR 2. As shown in red in the log output, the previous tunnel with AR was deleted and a new tunnel with a new source address was created. This took in total 11 seconds until the new tunnel was up, the same as in MIPv4.

| 13:14:17.763: MIPv6-Reg: Second HA option found |
| 13:14:17.763: MIPv6-Reg: BU from 2001:10::1111 |
| 13:14:17.763: flags AHlK |
| 13:14:17.763: sequence 128, lifetime 60 (0xF) |
| 13:14:17.763: MIPv6-Reg: Care of Address option: |
| 13:14:17.783: MIPv6-Reg: Stopping LineProtoTimer for Tunnel0 |
| 13:14:17.783: MIPv6-Reg: Timer started for 2001:10::1111, lifetime 60 |
| 13:14:17.783: MIPv6-Reg: Binding Ack to 2001:10::1111, lifetime 60 (0xF) |
| 13:14:17.783: sequence 128, lifetime 60 (0xF) |
| 13:14:28.779: %LINEPROTO-5-UPDOWN: Line protocol on Interface Tunnel0, changed state to up |

Figure 5.4.4: Roaming process from AR to AR2 (MIPv6).

When it comes to the total time it took for the whole process of reestablishing CN to MN connectivity in MIPv6 it was 30 seconds. The connection went through an average of 4 Request timed out and 12 unreachable messages, thus, considerably longer than in MIPv4. In the same way as in MIPv4, the total 30 seconds also include the two seconds of interface down while switching the Ethernet cable.

6 Discussion

After all tests were done and reviewed, the results showed that the MIPv4 had better performance than MIPv6. When it comes to latency, MIPv4 had less latency than MIPv6. In TCP tests, we can notice a big difference between MIPv4 and MIPv6 in the datagram transferred. In addition the UDP tests showed that MIPv4 had better performance than MIPv6 in particular concerning jitter and packet loss. Finally the connectivity while roaming shows that MIPv6 needed almost twice as much time to reestablish connectivity than MIPv4.

As discussed before, the advantages with MIPv6 is that it has mobility built in not in extensions as with MIPv4. MIPv6 does not require a special router to act as foreign agent which is needed for MIPv4. The most important advantage of MIPv6 is that it has route optimization which allows the traffic to travel directly between CN and MN.
without passing through HA. However, as discussed before, route optimization does not work with MIPv6 NEMO as well as in Windows 7 environment which is the latest version of Microsoft Windows. This might seems strange since Windows XP Professional with SP1 has the ability to work with basic functionality as CN and then one would assume that with technological advances route optimization should work on the later Windows OS versions as well.

As route optimization did not work with MIPv6, the datagram takes the same route as MIPv4. This means that one could expect that the performance of sending traffic will be almost the same. However the test results showed that this was not the case and MIPv4 performed better than MIPv6 in all tests. In order to find out why MIPv4 performed better additional tests were carried out to see if the packets were lost on the network or if the reason is something else. First I checked the output packets and input packet on the desired interfaces to see if there is any congestion on the network, the tests showed that the number of packet left the interface connected to the CN was almost the same when it arrives on the interface connected to MN in both MIPv4 and MIPv6. This means that all packets send were received by the other side but that MIPv4 was able to send more than MIPv6 under a specific time.

Since this didn’t show where the problem was, I carried out new tests to send traffic between two hosts running Windows 7 Professional OS connected to the same Cisco switch, the results showed that the traffic send in the two cases were almost the same and thus the OS does not have any effect in performance if it is with IPv4 or IPv6.

Since none of the previous two test showed why IPv4 performs better than IPv6 in the topology used, an extra test was carried out to send traffic between two hosts connected to the same Cisco router with basic IPv4 and basic IPv6 (not Mobile IP), the results show that the performance was still better in MIPv4 than in MIPv6. This tells us that the difference is not because of the mobility implementation but the case is the same also when comparing a standard IPv4 and IPv6 in Cisco routers as shown in the following tables and figures.

Table 6.1: IPv4 TCP default tests.

<table>
<thead>
<tr>
<th>IPv4 tests</th>
<th>Mbytes Transferred</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>95,3</td>
<td>79,7</td>
</tr>
<tr>
<td>Test 2</td>
<td>98,1</td>
<td>82,1</td>
</tr>
<tr>
<td>Test 3</td>
<td>98,1</td>
<td>82,0</td>
</tr>
<tr>
<td>Test 4</td>
<td>96,9</td>
<td>81,0</td>
</tr>
<tr>
<td>Test 5</td>
<td>97,8</td>
<td>81,8</td>
</tr>
<tr>
<td>Average</td>
<td>97,2</td>
<td>81,3</td>
</tr>
</tbody>
</table>
Table 6.2: IPv6 TCP default tests.

<table>
<thead>
<tr>
<th>IPv6 tests</th>
<th>Mbytes Transferred</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>54,3</td>
<td>45,4</td>
</tr>
<tr>
<td>Test 2</td>
<td>57,7</td>
<td>48,3</td>
</tr>
<tr>
<td>Test 3</td>
<td>59,5</td>
<td>49,8</td>
</tr>
<tr>
<td>Test 4</td>
<td>58,6</td>
<td>49,0</td>
</tr>
<tr>
<td>Test 5</td>
<td>58,5</td>
<td>48,9</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>57,7</strong></td>
<td><strong>48,2</strong></td>
</tr>
</tbody>
</table>

Figure 6.1: Data transfer with default TCP.

Figure 6.2: Throughput with default TCP.

The results of all the additional tests that I made in order to find out what part of the network affects the results of MIPv6 show that neither the congestion, OS nor switch was decreasing the performance of MIPv6. However, the last tests where traffic was sent through a Cisco router using a basic configuration for IPv4 and IPv6 showed that Cisco router has lower performance when it comes to IPv6 implementation.

7 Conclusion

This comparative study of MIPv4 and MIPv6 has shown that MIPv4 performs better than MIPv6 in latency, TCP/UDP throughput as well as connectivity loss while roaming. During handover the time measured for MIPv6 was 30 seconds which was the double of MIPv4 (15 seconds). The TCP tests showed that MIPv4 performed better than MIPv6. This can be illustrated by the TCP default test where MIPv4 had a throughput of 45,6 Mbits/sec compared to 26,7 Mbits/sec for MIPv6. In the tests of UDP datagram loss MIPv4 had 1,58 percent datagram loss while MIPv6 had 6,68 percent, thus again demonstrating MIPv4 superiority in this study. Through additional tests, the study has also showed that the Cisco router has lower capacity when running IPv6 and thus it is the same in MIPv6. This study has also discussed that NEMO and Windows 7 do not support Route Optimization. This can be seen as additional disadvantage of Cisco routers when running MIPv6. However, there is a need for more studies on Cisco routers when running IPv6 to decide if the Cisco router capacity and lack of route optimization support are the problems that made MIPv6 perform lower than MIPv4, as was suggested in this study.
References

1. Emmelmann, Marc, Bochow, Bernd & Kellum, C. Christopher (2010). Vehicular Networking: Automotive Applications and Beyond, Great Britain: Wiley


A. Appendix 1: MIPv4 Configuration

i. Home Agent

```
hostname Home-Agent
boot-start-marker
boot-end-marker
logging message-counter syslog
no aaa new-model
dot11 syslog
ip source-route

ip cef
no ipv6 cef
multilink bundle-name authenticated

voice-card 0

archive
log config
hidekeys
```
interface Loopback1
  ip address 192.168.9.1 255.255.255.255
!
interface FastEthernet0/0
  description ### Link to Sw1 ###
  ip address 192.168.10.1 255.255.255.0
duplex auto
  speed auto
!
interface FastEthernet0/1
  no ip address
  shutdown
duplex auto
  speed auto
!
interface Serial0/0/0
  no ip address
  shutdown
  no fair-queue
clock rate 2000000
!
interface Serial0/0/1
  no ip address
  shutdown
clock rate 2000000
!
router mobile
!
router ospf 1
  log-adjacency-changes
  redistribute mobile subnets
  network 192.168.9.0 0.0.0.255 area 0
  network 192.168.10.0 0.0.0.255 area 0
!
ip forward-protocol nd
no ip http server
no ip http secure-server
!
ip mobile home-agent
ip mobile virtual-network 172.16.10.0 255.255.255.0
ip mobile host 172.16.10.1 virtual-network 172.16.10.0 255.255.255.0
ip mobile mobile-networks 172.16.10.1
  network 93.15.0.0 255.255.0.0
ip mobile secure host 172.16.10.1 spi 100 key ascii cisco algorithm md5 mode prefix-suffix
!
!
control-plane
!
!
!
!
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ii. Foreign Agent

interface FastEthernet0/0
    description ### Link to SW1 ###
    ip address 192.168.10.2 255.255.255.0
duplex auto
speed auto
interface FastEthernet0/1
    description ### Link to MR ###
    ip address 192.168.20.1 255.255.255.0
    ip mobile foreign-service
    ip irdp
    ip irdp maxadvertinterval 5
    ip irdp minadvertinterval 3
    ip irdp holdtime 10
    duplex auto
Comparative study of Mobile IPv4 and Mobile IPv6

iii. Mobile Router – Mobile Node

hostname Mobile-Router

boot-start-marker
boot-end-marker
|
logging message-counter syslog
|
no aaa new-model
|
dot11 syslog
ip source-route
|
ip cef
|
no ipv6 cef
|
multilink bundle-name authenticated
|
|
voice-card 0
|
|
archive
  log config
  hidekeys
|
|
interface Loopback1
  ip address 172.16.10.1 255.255.255.0
|
interface FastEthernet0/0
  description ### Link to FA ###
  ip address 192.168.20.2 255.255.255.0
  ip irdp
  ip mobile router-service roam
  ip mobile router-service solicit
duplex auto
speed auto
no routing dynamic
!
interface FastEthernet0/1
description ### Roaming Interface for Mobile Devices ###
ip address 93.15.20.1 255.255.255.0
duplex auto
speed auto
!
interface Serial0/0/0
no ip address
shutdown
no fair-queue
clock rate 2000000
!
interface Serial0/0/1
no ip address
shutdown
clock rate 2000000
!
routing mobile
!
ip forward-protocol nd
no ip http server
no ip http secure-server
!
ip mobile secure home-agent 192.168.9.1 spi 100 key ascii cisco
algorithm md5 mode prefix-suffix
ip mobile router
  address 172.16.10.1 255.255.255.0
  home-agent 192.168.9.1
!
!
control-plane
!
!
!
!
line con 0
line aux 0
line vty 0 4
login
!
scheduler allocate 20000 1000
end
B. Appendix 2: MIPv6 Configuration

i. Home Agent

```
! hostname Home-Agent
! boot-start-marker
boot-end-marker
! logging message-counter syslog
! no aaa new-model
! dot11 syslog
ip source-route

ip cef

ipv6 unicast-routing
ipv6 cef

multilink bundle-name authenticated

voice-card 0

archive
log config
hidekeys

```
interface FastEthernet0/0
    description ### Link to SW1 ###
    no ip address
duplex auto
speed auto
ipv6 address 2001:1::1/64
ipv6 ospf 100 area 0

interface FastEthernet0/1
    description ### Home Network Interface ###
    no ip address
duplex auto
speed auto
ipv6 address 2001:10::1/64
ipv6 address 2001:10::FDFF:FFFF:FFFF:FFFE/64 anycast
ipv6 enable
ipv6 nd advertisement-interval
ipv6 nd ra interval msec 100
ipv6 mobile home-agent preference 100
ipv6 mobile home-agent
ipv6 ospf 100 area 0

interface Serial0/0/0
    no ip address
shutdown
no fair-queue
clock rate 2000000

interface Serial0/0/1
    no ip address
shutdown
clock rate 2000000

ip forward-protocol nd
no ip http server
no ip http secure-server

ipv6 router ospf 100
    router-id 1.1.1.1
    log-adjacency-changes
    redistribute nemo

ipv6 router nemo

ipv6 mobile home-agent
    host_group grp-1
        nai jamal.darwich@student.hv.se
        address 2001:10::1111
        authentication spi hex 100 key ascii cisco
        exit

control-plane

Appendix
ii. Mobile Router – Mobile Node

! hostname Mobile-Router
! boot-start-marker
! boot-end-marker
! logging message-counter syslog
! no aaa new-model
! dot11 syslog
ip source-route
! ip cef
! ipv6 unicast-routing
ipv6 cef
! multilink bundle-name authenticated

voice-card 0
!
Comparative study of Mobile IPv4 and Mobile IPv6

interface Loopback1
  no ip address
  ipv6 address 2001:10::1122/128

interface FastEthernet0/0
  description ### Roaming Interface to AR ###
  no ip address
  duplex auto
  speed auto
  ipv6 address autoconfig
  ipv6 enable
  ipv6 nd ns-interval 5000
  ipv6 mobile router-service roam

interface FastEthernet0/1
  description ### Mobile Network Interface ###
  no ip address
  duplex auto
  speed auto
  ipv6 address 2001:40::4001/64
  ipv6 enable
  ipv6 nd advertisement-interval
  ipv6 nd ra interval msec 1000

interface Serial0/0/0
  no ip address
  shutdown
  no fair-queue
  clock rate 2000000

interface Serial0/0/1
  no ip address
  shutdown
  clock rate 2000000

ip forward-protocol nd
no ip http server
no ip http secure-server

ipv6 mobile router
host group grp-1
  nai jamal.darwich@student.hv.se
  address 2001:10::1111
  authentication spi hex 100 key ascii cisco
  exit
  home-network 2001:10::1111/64 discover
  home-address home-network ::1111
  explicit-prefix
  register lifetime 60
register retransmit initial 1000 maximum 1000 retry 3
register extend expire 20 retry 3 interval 1

control-plane

line con 0
line aux 0
line vty 0 4
login

scheduler allocate 20000 1000
end