UNIVERSITY OF CYPRUS
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Master’s Thesis

Investigate IPv6 mobility and roaming issues

Christos Charalambous

Supervisor: Associate Professor Andreas Pitsillides

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List of Acronyms

AP: Access Point.

AR: Access Router.

ARP: Address Resolution Protocol.

BC: Binding Cache.

BR: Binding Request.

BU: Binding Update

BUL: Binding Update List.

CN: Correspondent Node.

CoA: Care-of Address.

DAD: Duplicate Address Detection.

DHCP: Dynamic Host Configuration Protocol.

DHCPv6: Dynamic Host Configuration Protocol version 6.

DNS: Domain Name System.

FA: Foreign Agent.

FBACK: Fast Handover Binding Acknowledgement.

FBU: Fast Handover Binding Update.

GSM: Global System for Mobile Communication.

HA: Home Agents.

HACK: Handover Acknowledgement.

Haddr: Home Address.

HAL: Home Agent List.

HI: Handover Initiation.

HLR: Home Location Register.

HMIPv6: Hierarchical Mobile Internet Protocol version 6.

ICMP: Internet Control Message Protocol.

ICMPv6: Internet Control Message Protocol version 6.

ID: Identification.

IEEE: Institute of Electrical and Electronics Engineers.

IETF: Internet Engineering Task Force.

IP: Internet Protocol.

IPv4: Internet Protocol version 4.

IPv6: Internet Protocol version 6.

LAN: Local Area Network.

MAC: Media Access Control.

MIP: Mobile Internet Protocol.

MIPv4: Mobile Internet Protocol version 4.

MIPv6: Mobile Internet Protocol version 6.

MN: Mobile Node.

MTU: Maximum Transmission Unit.

NA: Neighbor Advertisement.

ND: Neighbor Discovery.

NewAR: New Access Router.

NewCoA: New Care-of Address.

NS: Neighbor Solicitation.

NUD: Neighbor Unreachability Detection.

OldAR: Old Access Router.

OldCoA: Old Care-of Address.

PDA: Personal Desktop Assistant.

PrRtAdv: Proxy Router Advertisement.

QoS: Quality of Service.

RA: Router Advertisements.

RCoA: Regional Care-of Address.

RFC: Request For Comments.

RO: Route Optimisation

RS: Router Solicitation.

RtSolPr: Router Solicitation for Proxy.

TCP: Transport Control Protocol.

UDP: User Datagram Protocol.

VC: Video Conferencing

VoIP: Voice Over Internet Protocol

WLAN: Wireless Local Area Network.

Abstract

Mobility is becoming more and more important in our days mostly because of the need to support always-on network services like videoconferencing, VoIP etc. In recent years there is an increase in demand from end-users to access network resources from anywhere and at any time from all kind of devices. An additional demand is for the mobile users to receive uninterrupted services.

To overcome the mobility problem, protocols such as MIPv4 (Mobile IPv4) were designed. Mobile IP offers the ability to users to move (roam) through different subnetted networks without loosing their connectivity. As the new IPv6 protocol is emerging and in order to support the IPv6 nodes a new Mobile protocol MIPv6 was designed. This protocol allows an IPv6 node to be mobile, and arbitrarily change its location on the IPv6 Internet while still maintain its existing connections.

This thesis investigates IPv6 mobility and roaming issues by simulation. In order to better understand the MIPV6 protocol it was necessary first to have a good understanding of the IPv6 protocol in theory and implementation. For that reason the IPv6 protocol was also implemented on live networks. Furthermore by using the simulation tool OPNET for different mobility scenarios an attempt was made to investigate the strengths and weaknesses of the MIPv6 by examining the various parameters of a MIPv6 environment that could influence the quality of the provided network services.

In order to investigate mobility and roaming issues in MIPv6 an extensive set of MIPv6 scenarios were designed and implemented in this thesis. For each scenario various simulations were run examining different parameters that could influence the MIPv6 operation and quality of service. The results reveal that MIPv6 can be greatly influenced from the setting of parameters like Access Point Transmit Power or Mobile Node Mobility Detection Factor either when these parameters are changed alone or in combination. This thesis, guided by the results from the simulation scenarios offers some understanding of the behavior of the MIPv6 protocol, and how the parameters influence its behavior, and hence their operational setup is discussed.

It is worth noting that there is no similar work as in my knowledge where so many parameters are tested. Some of these parameters are studied in other work but not the same way as in this thesis. This approach allows one to understand better MIPv6 and better tune the values of these parameters to a real environment.

Chapter 1

Introduction

Internet technology is widespread throughout the world, offering access to varieties of information and resources. Traditionally, however, the service is only available when people settle down in their offices, homes or any other authorized areas, typically by plugging a physical jack into a wall. Although the development of wireless communication technologies has made wireless Internet access possible, and more and more portable devices, such as PDAs (Personal Digital Assistants), digital cellular phones, laptop computers and so on provide Internet access functionality, it does not mean that Internet communication activities can remain uninterrupted while users are moving.

Mobile computing and portable computing are two different concepts. If mobile users only need to be able to launch communication sessions actively before other network nodes can communicate with them when they are roaming, and do not mind re-establishing sessions every time they change their access link, portable computing is sufficient to offer the service. However, mobile computing provides mobile users anytime, anywhere bidirectional reliable access, and that includes the requirement that ongoing communication sessions do not need to be restarted even when the point of attachment to the Internet changes.

Since the Internet Protocol [IP], the core protocol of the Internet, was originally designed for fixed networks, IP addresses are associated with a fixed network location, and they are required to remain unchanged during an IP session. Obviously, this is unable to satisfy the requirements of mobile computing. Therefore, Mobile IP was proposed by the IETF [Internet Engineering Task Force] in order to offer mobile users a seamless computing environment.

The basic idea of Mobile IP is to allow a mobile node to have a temporary IP address in addition to its original fixed IP address. The temporary address is associated with the current point of attachment to the Internet, while the original fixed IP address represents the location where other network nodes think the mobile node is always located. This makes it possible that during the movement of the mobile node, its original fixed IP address remains unchanged, and therefore an ongoing IP session will not be interrupted.

However, before Mobile IP can be widely deployed, there are still many technical obstacles, including handover performance, routing efficiency and security issues. As a result, many Mobile IP supplemental protocols have also been proposed by the IETF in order to enhance the overall performance and functionality of Mobile IP. It is worth stating at this point that security issues are out of the scope of this thesis although it is recognised that security methods can influence the performance of the MIPv6 protocol as well as the general response of the whole mobile environment.

In the OSI [Open System Interconnection] model, Mobile IP can be regarded as a network layer routing protocol. Due to the fact that mobility performance is the outcome of the cooperation of different layers, merely focusing on the IP layer performance is not sufficient. In other words, the Mobile IP operation heavily depends on lower layer mechanisms, and has direct implications on upper layer performance.

For example, since IP layer communications can only be performed after the link layer connectivity has been established, the link layer connectivity set-up time directly affects the Mobile IP signalling latency. Moreover, since Mobile IP affects the routing path of IP packets, packet losses, delays and reorderings may occur, degrading the QoS (Quality of Service) and affecting the congestion control mechanism of upper layers.

To be able to conclude this thesis it was first necessary to have a good understanding of the internet related technology. A very good knowledge of the IP protocol and its use in the networks set up was also necessary in order to set-up and implement the IPv6 environment in live networks. To achieve the previous statement a good understanding of the IPv6 protocol was necessary. It was also important to study and understand the features of Mobile IPv6 protocol and how those could be implemented in a network. For that reason a literature review was performed from various resources including papers, books and articles.

For the simulation part it was necessary to study and learn how to work with the network software tool OPNET. More specifically the tool was used to simulate all the scenarios of MIPv6 in a wireless simulated infrastructure while mobile nodes were using different network applications. For that reason it was also important to have some knowledge on the Wireless LAN network.

The thesis objective was to investigate the IPv6 mobility and roaming issues by simulation and understand the behavior of the MIPv6 protocol. Also to examine different parameters that could influence the MIPv6 operation and quality of service when the values of these parameters are changed alone or in combination. Finally propose best parameters values from the results that could be used for MIPv6 optimisation before setting up a MIPv6 environment.

Specifically this thesis is divided into five Chapters and three Appendices,

Chapter 1, is the introduction to the whole thesis where a very brief reference is made on the thesis subject.

Chapter 2, is the literature review where an elaboration is made on the MIPv6 protocol. An overview of the mobile technology is given and a quick reference is made on mobility issues.

Chapter 3, discusses performance evaluation in the presence of mobility, where it is explained what this thesis is using to achieve its objectives. An explanation is given about the main design issues as well the scenarios and sub-scenarios (named Tests) that were used for the simulation.

Chapter 4, is the chapter of Results and Analysis, where the findings from the various scenarios from the previous chapter are presented and analysed. Also, this thesis results are compared with related work from various papers.

Chapter 5, is the final chapter where some conclusions are formulated and some further recommendations are made.

Appendix 1, tabulates the main MIPv6 parameters that were used for all the simulated scenarios

Appendix 2, has the tables of MIPv6 results from all the different scenarios

Appendix 3, includes supplementary graphs extracted from the simulated scenarios.

Chapter 2

Review of literature

2.1 Introduction

In this chapter a literature review is presented in order to give all the necessary information needed by the reader to understand the thesis based theory. It starts with a reference to mobility and continues with explanation of the MIPv6 protocol. It gives a brief comparison between the protocols MIPv4 & MIPv6 and examines the mobility issues for the MIPv6 protocol. Since this thesis is using wireless technology to examine Mobility a quick reference to wireless technology and its features is given. Also the handover which is a very significant process of mobility is explained.

2.2 Mobility – A necessity in today's networks

It is a fact that a vast number of electronic devices is in the market that were designed to offer the best network services to users while traveling. These devices to be able to offer what they were designed for they need to embed technology that will allow them to move across the various and different in size networks. A user only cares about the network services and nothing else. The quality of these services is very important and any long delays or interruptions are unacceptable. Security is an issue but it is not that critical for the average user.

Consider the following scenarios,

i. a user travels in his car using his mobile phone. Mobility offers him the ability to keep talking while moving across the cells and changing mobile base stations.

ii. a user is walking in a University Campus listening to streaming music using his PDA which is connected to the wireless network (802.11 protocol).

Both scenarios can be made true only because of mobility technology and its features like roaming and handover. In both cases it would be unacceptable if there was any kind of interruption or huge delays. To make the above scenarios possible though is not an easy task. Very well designed networks are needed in order to handle the continuous movement of a big number of users and of course all these networks have to communicate with each other with the minimum latency.

It is estimated that in few years the mobile subscribers will be hundreds of millions. All these users will need to roam through different networks while traveling and of course receive the same quality of services. It is very important that technology can support these users and the developing technology is called mobility.

2.3 Mobile Network Architecture

This section explains Mobile IP basic concepts. It applies to either Mobile IPv4 or Mobile IPv6.

2.3.1 Mobile IP Terminology

The terminology in Table 1 is necessary for the understanding of this thesis.

Table 1 - Mobility Related Terminology

Mobile Node (MN)	An IP node capable of changing its point of attachment to the network. A Mobile Node may either be a Mobile Host (no forwarding functionality) or a Mobile Router (forwarding functionality).
Correspondent Node (CN)	A peer node with which a mobile node is communicating. The correspondent node may be either mobile or stationary.
Home Agent (HA)	A router on a mobile node's home link with which the mobile node has registered 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.
Home Address (HoA)	An IP address assigned to a mobile node, used as the permanent address of the mobile node. This address is within the mobile node's

	home link. Standard IP routing mechanisms will deliver packets destined for a mobile node's home address to its home link
Binding Update (BU)	A message indicating a mobile node's current mobility binding, and in particular its care-of address.
Care-of-Address (CoA)	An IP address associated with a mobile node while visiting a foreign link; the subnet prefix of this IP address is a foreign subnet prefix. A packet addressed to the mobile node which arrives at the mobile node's home network when the mobile node is away from home and has registered a Care-of Address will be forwarded to that address by the Home Agent in the home network.
Foreign subnet prefix	A bit string that consists of some number of initial bits of an IP address which identifies a node's foreign link within the Internet topology.
Home subnet prefix	A bit string that consists of some number of initial bits of an IP address which identifies a node's home link within the Internet topology (i.e., the IP subnet prefix corresponding to the mobile node's home address.
Binding	The association of the home address of a mobile node with a careof address for that mobile node, along with the remaining lifetime of that association.
Registration	The process during which a mobile node sends a Binding Update to its home agent or a correspondent node, causing a binding for the mobile node to be registered.

2.3.2 Mobile IP Functionality

Mobile IP is an open standard, defined by the Internet Engineering Task Force (IETF) that allows users to keep the same IP address, stay connected, and maintain ongoing applications while roaming between IP networks. Mobile IP is scalable for the Internet because it is based on IP meaning any media that can support IP can support Mobile IP.

Mobile IP provides ubiquitous connectivity for users, whether they are within their enterprise networks or away from home. Mobile IP is part of both IPv4 and IPv6 standards.

Mobile IP Overview

In IP networks, routing is based on stationary IP addresses. A device on a network is reachable through normal IP routing by the IP address it is assigned on the network.

However, problems occur when a device roams away from its home network and is no longer reachable using normal IP routing. This causes the active sessions of the device to be terminated. Mobile IP enables users to keep the same IP address while travelling to a different network (which may even be operated by a different wireless operator), thus ensuring that a roaming individual can continue communication without sessions or connections being dropped.

How Mobile IP Works

The Mobile IP process has three main phases, which are discussed in the following sections.

- Agent Discovery—A Mobile Node discovers its Foreign and Home Agents

- Registration—The Mobile Node registers its current location with the Foreign

Agent and Home Agent

- Tunneling—A reciprocal tunnel is set up by the Home Agent to the care-of address (current location of the Mobile Node on the foreign network) to route packets to the Mobile Node as it roams.

Agent Discovery

During the agent discovery phase, the Home Agent and Foreign Agent advertise their services on the network by using the ICMP Router Discovery Protocol (IRDP). The Mobile Node listens to these advertisements to determine if it is connected to its home network or foreign network.

The IRDP advertisements carry Mobile IP extensions that specify whether an agent is a Home Agent, Foreign Agent, or both; its care-of address; the types of services it will provide such as reverse tunneling and generic routing encapsulation (GRE); and the allowed registration lifetime or roaming period for visiting Mobile Nodes. Rather than waiting for agent advertisements, a Mobile Node can send out an agent solicitation.

This solicitation forces any agents on the link to immediately send an agent advertisement.

If a Mobile Node determines that it is connected to a foreign network, it acquires a care-of address. Two types of care-of addresses exist:

- Care-of address acquired from a Foreign Agent - an IP address of a Foreign Agent that has an interface on the foreign network being visited by a Mobile Node. A Mobile Node that acquires this type of care-of address can share the address with other Mobile Nodes.

- Collocated care-of address - an IP address temporarily assigned to the interface of the Mobile Node itself. A collocated care-of address represents the current position of the Mobile Node on the foreign network and can be used by only one Mobile Node at a time.

Registration

When the Mobile Node hears a Foreign Agent advertisement and detects that it has moved outside of its home network, it begins registration.

The Mobile Node is configured with the IP address and mobility security association (which includes the shared key) of its Home Agent. In addition, the Mobile Node is configured with either its home IP address, or another user identifier, such as a Network Access Identifier.

The Mobile Node uses this information along with the information that it learns from the Foreign Agent advertisements to form a Mobile IP registration request. It adds the registration request to its pending list and sends the registration request to its Home Agent either through the Foreign Agent or directly if it is using a collocated care-of address and is not required to register through the Foreign Agent. If the registration request is sent through the Foreign Agent, the Foreign Agent checks the validity of the registration request, which includes checking that the requested lifetime does not exceed its limitations, the requested tunnel encapsulation is available, and that reverse tunnel is supported. If the registration request is valid, the Foreign Agent adds the visiting Mobile Node to its pending list before relaying the request to the Home Agent. If the registration request is not valid, the Foreign Agent sends a registration reply with appropriate error code to the Mobile Node.

The Home Agent checks the validity of the registration request, which includes authentication of the Mobile Node. If the registration request is valid, the Home Agent creates a mobility binding (an association of the Mobile Node with its care-of address), a tunnel to the care-of address, and a routing entry for forwarding packets to the home address through the tunnel.

The Home Agent then sends a registration reply to the Mobile Node through the Foreign Agent (if the registration request was received via the Foreign Agent) or directly to the Mobile Node. If the registration request is not valid, the Home Agent rejects the request by sending a registration reply with an appropriate error code.

The Foreign Agent checks the validity of the registration reply, including ensuring that an associated registration request exists in its pending list. If the registration reply is valid, the Foreign Agent adds the Mobile Node to its visitor list, establishes a tunnel to the Home Agent if reverse tunnel is enabled, and creates a routing entry for forwarding packets to the home address. It then relays the registration reply to the Mobile Node.

Finally, the Mobile Node checks the validity of the registration reply, which includes ensuring an associated request is in its pending list as well as proper authentication of the Home Agent. If the registration reply is not valid, the Mobile Node discards the reply. If a valid registration reply specifies that the registration is accepted, the Mobile Node is confirmed that the mobility agents are aware of its roaming. In the collocated care-of address case, it adds a tunnel to the Home Agent. Subsequently, it sends all packets to the Foreign Agent.

The Mobile Node reregisters before its registration lifetime expires. The Home Agent and Foreign Agent update their mobility binding and visitor entry, respectively, during reregistration. In the case where the registration is denied, the Mobile Node makes the necessary adjustments and attempts to register again. For example, if the registration is denied because of time mismatch and the Home Agent sends back its time stamp for synchronization, the Mobile Node adjusts the time stamp in future registration requests.

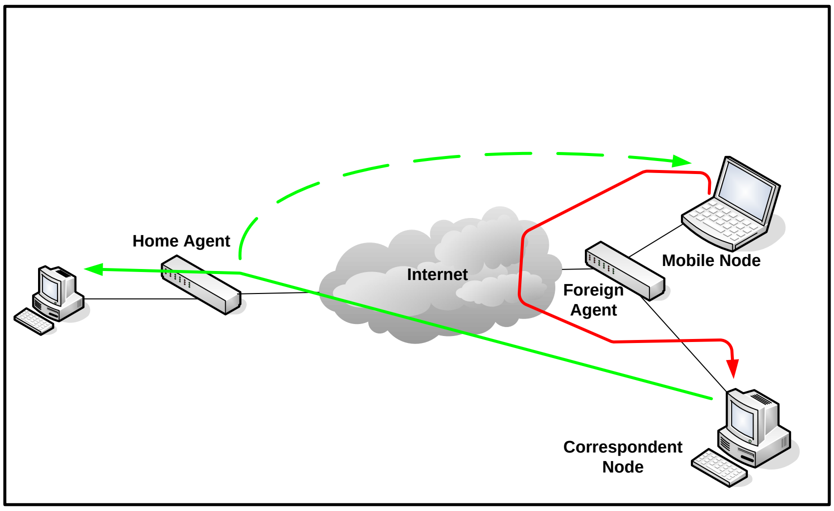
Thus, a successful Mobile IP registration sets up the routing mechanism for transporting packets to and from the Mobile Node as it roams.

Tunneling

The Mobile Node sends packets using its home IP address, effectively maintaining the appearance that it is always on its home network. Even while the Mobile Node is roaming on foreign networks, its movements are transparent to correspondent nodes.

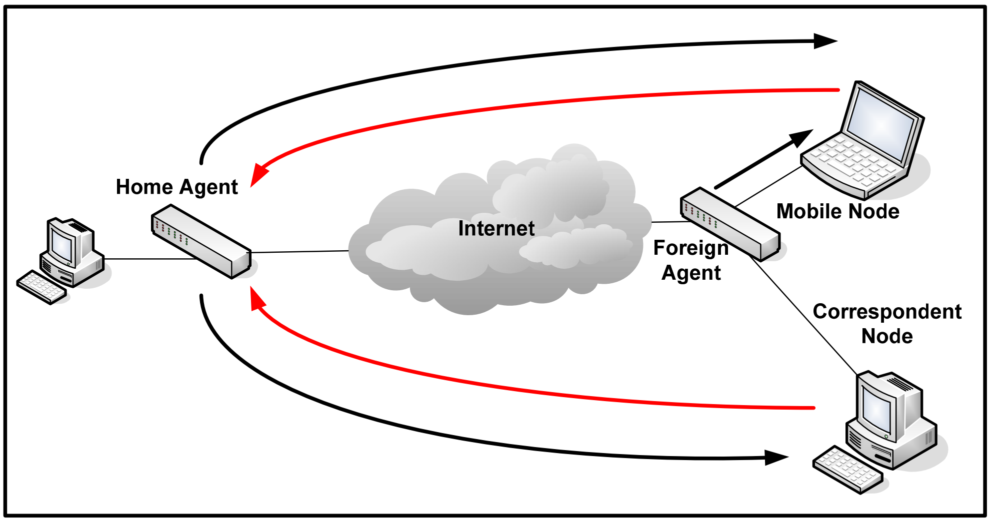
Data packets addressed to the Mobile Node are routed to its home network, where the Home Agent now intercepts and tunnels them to the care-of address toward the Mobile Node. Tunneling has two primary functions: encapsulation of the data packet to reach the tunnel endpoint, and decapsulation when the packet is delivered at that endpoint. The default tunnel mode is IP Encapsulation within IP Encapsulation. Optionally, GRE and minimal encapsulation within IP may be used. Typically, the Mobile Node sends packets to the Foreign Agent, which routes them to their final destination, the Correspondent Node (Figure 1).

Figure 1 – Packet Forwarding



However, this data path is topologically incorrect because it does not reflect the true IP network source for the data—rather, it reflects the home network of the Mobile Node. Because the packets show the home network as their source inside a foreign network, an access control list on routers in the network called ingress filtering drops the packets instead of forwarding them. A feature called reverse tunnelling solves this problem by having the Foreign Agent tunnel packets back to the Home Agent when it receives them from the Mobile Node (Figure 2).

Figure 2 – Reverse Tunnel



Tunnel MTU discovery is a mechanism for a tunnel encapsulator such as the Home Agent to participate in path MTU discovery to avoid any packet fragmentation in the routing path between a Correspondent Node and Mobile Node. For packets destined to the Mobile Node, the Home Agent maintains the MTU of the tunnel to the care-of address and informs the Correspondent Node of the reduced packet size. This improves routing efficiency by avoiding fragmentation and reassembly at the tunnel endpoints to ensure that packets reach the Mobile Node.

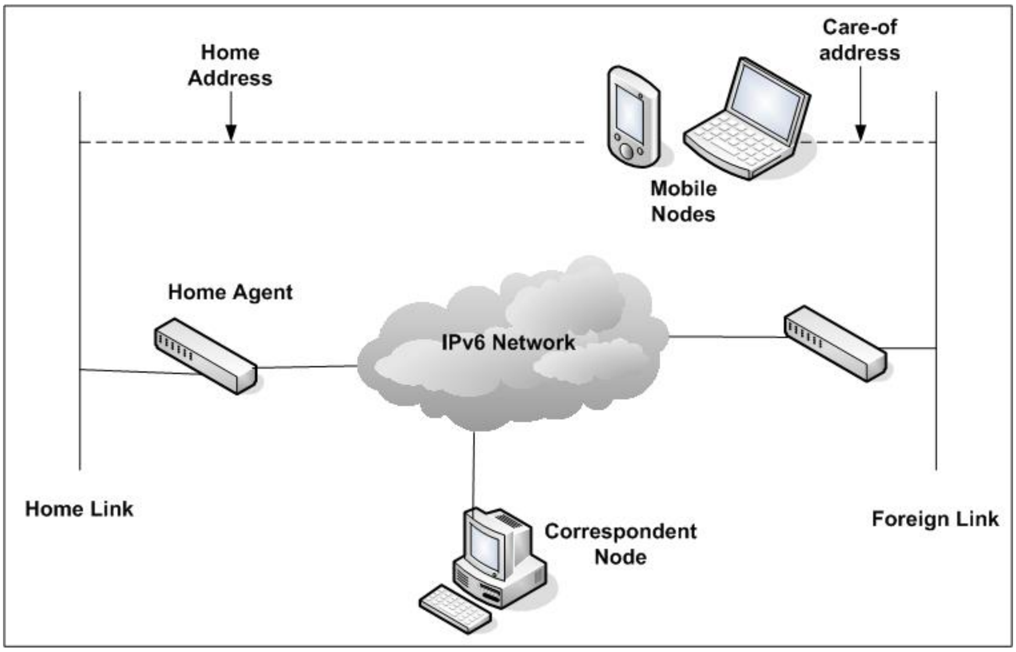
2.4 Mobile Internet Protocol version 6

2.4.1 MIPv6 Overview

Mobile Internet Protocol version 6 (MIPv6) is a new protocol that allows IPv6 nodes to be mobile, to arbitrarily change their location on an IPv6 network and remain reachable. Mobile IPv6 defines a new Mobility header, new mobility messages, new ICMPv6 messages, and new and updated options to perform mobility functions and processes. Mobile IPv6 defines the processes and message exchanges for mobile nodes, home agents, and correspondent nodes when a mobile node changes its location from its home link to a foreign link, to another foreign link, and returns home.

When an IPv6 node changes its location, it might also change its link. When an IPv6 node changes its link, its IPv6 address might also change in order to maintain connectivity. There are mechanisms to allow for the change in addresses when moving to a different link, such as stateful and stateless address autoconfiguration [30] for IPv6. These mechanisms are completely transparent for all layers above IP, e.g. for TCP [9], UDP and of course for all applications. Therefore DNS entries for a mobile node refer to its home address and don’t change if the mobile node changes its Internet access point. In fact IPv6 influences the routing of packets but it is independent of the routing protocol itself i.e RIP, OSPF. The solution given by MIPv6 consists of creating a so-called care-of-address whenever a node changes its point of attachment to the web. **Figure 3 –** Components of Mobile IPv6[24] shows the MIPv6 Components.

Figure 3 – Components of Mobile IPv6



2.4.2 MIPv6 Messages & Data Structures

The following data structures are needed to facilitate the processes of Mobile IPv6:

- Binding cache
- Binding update list
- Home agents list

Binding Cache

The binding cache is a table maintained by each correspondent node and home agent that contains the current bindings for mobile nodes. Each binding cache entry contains the following information:

- The home address for the mobile node
- The care-of address for the mobile node
- The lifetime of the binding cache entry

The lifetime is obtained from a Lifetime field of the last Binding Update [16] message that was received for this cache entry.

The information in the binding cache takes precedence over the information in the neighbour cache. For mobile destinations that are away from home, packets should be sent to the mobile node's home address by way of its care-of address. If packets are sent directly to the home address while the mobile node is away from home, the home agent must intercept the packets and tunnel them to the mobile node, lowering the efficiency and performance of the communication between the correspondent node and the mobile node.

Binding Update List

The binding update list is maintained by a mobile node to record the most recent binding updates sent for the home agent and correspondent nodes. A binding update list entry contains:

- The address of the node to which the binding update was sent
- The home address for the binding update
- The care-of address sent in the last binding update
- The value of the Lifetime field in the binding update
- The remaining lifetime of the binding

  The initial value is the value of the Lifetime field in the binding update. When the lifetime expires, the entry is deleted from the binding update list.
- The maximum value of the Sequence Number field sent in previous binding updates
- The time that the last binding update was sent
- An indication of whether a retransmission is needed for binding updates sent and when the retransmission is to be sent
- A flag indicating that no future binding updates need to be sent

Home Agents List

Home agents maintain the home agents list and record information about each router from which a Router Advertisement message was received on the home link. Home agents maintain the home agents list so that they can send the list of home agents to a requesting mobile node away from home during home agent address discovery. A home agent's list entry contains the following:

- The link-local address of the router on the link, obtained from the source address of the received Router Advertisement message
- The global address or addresses of the home agent, obtained from the Prefix field in the Prefix Information options in the Router Advertisement message
- The remaining lifetime of this entry

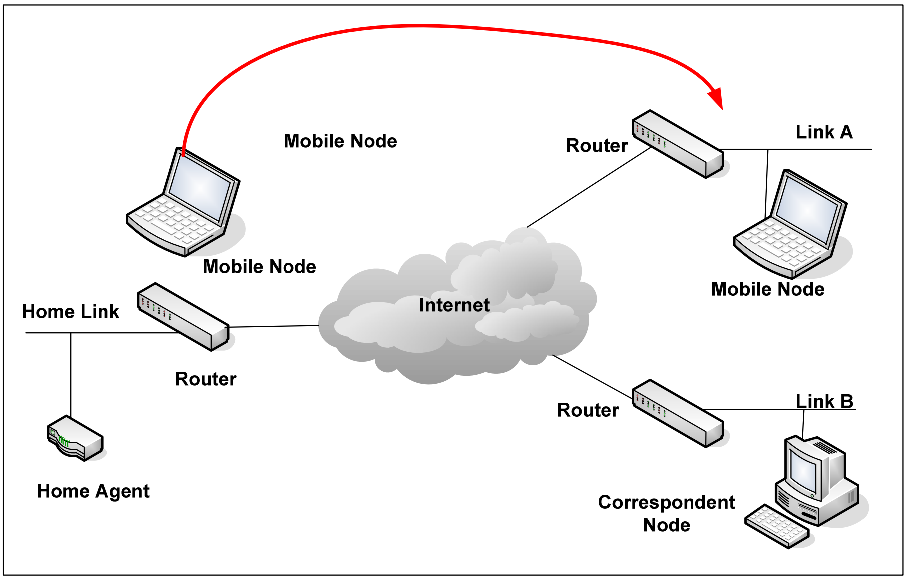
  The initial lifetime is obtained from either the Home Agent Lifetime field in the Home Agent Information option or the Router Lifetime field in the Router Advertisement message. When the lifetime expires, the entry is deleted from the home agents list.
- The preference for the home agent, obtained from the Home Agent Preference field in the Home Agent Information option

When the mobile node receives the list of home agents, it chooses the first home agent in the list.

2.4.3 MIPv6 Operation

The Figure 4 shows a MN moving from its home network to a foreign link. The procedures that will be described in this scenario are Home Agent Registration, Triangle Routing, Route Optimization and Home Agent Discovery.

Figure 4 – Mobile Node Movement



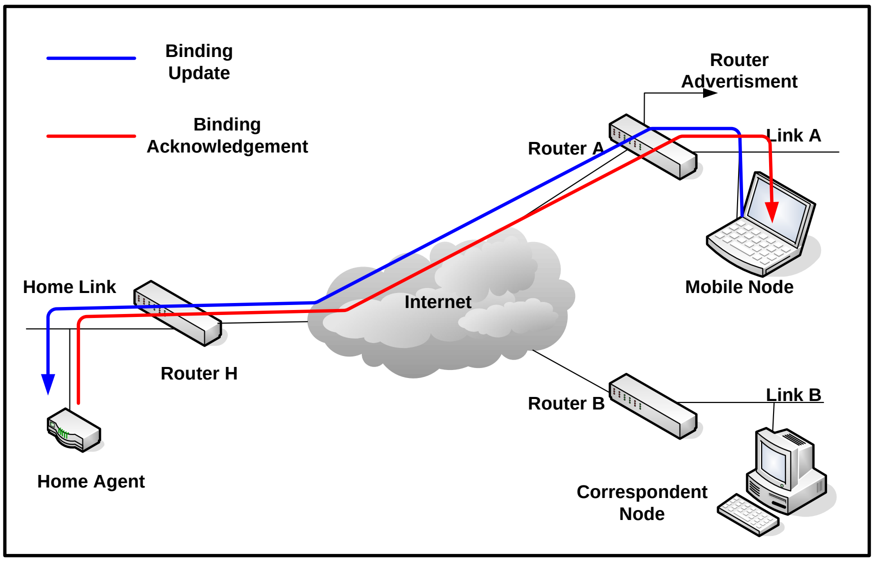
While the MN resides on the home network, the correspondent nodes use its regular home address and no CoA is needed.

Home Agent Registration

Figure 5 illustrates when the MN has moved from its home link to link A. Every router in an IPv6 network sends RA to the all-nodes multicast address periodically. The MN needs an RA in order to detect movement and add a new default router. The RA provides the MN with the correct network prefix so that it can start the address configuration procedure. If the delay between each RA is too long, the MN can request it by sending a RS. The RA message on this link specifies the prefix, and the default router will be router A.

Once the RA is received, the MN starts DAD [14] to guarantee the uniqueness of the generated address by sending a NS. If this procedure is successful, the MN has an address ready for use on the new link. This new address is referred to as the MNs CoA. When the MN has acquired its new CoA, the binding update procedures can begin by sending an IPv6 destination option packet with a BU to the HA. When the HA receives the BU it registers the new CoA and returns a BACK to the MN confirming that the binding is accepted. The MN also sends BUs to the nodes listed in its BUL. Authentication Header or Encapsulated Security Payload to avoid misuse by other nodes must protect these binding messages.

Figure 5– HA is provided with the new CoA using BU and replies with a BACK.



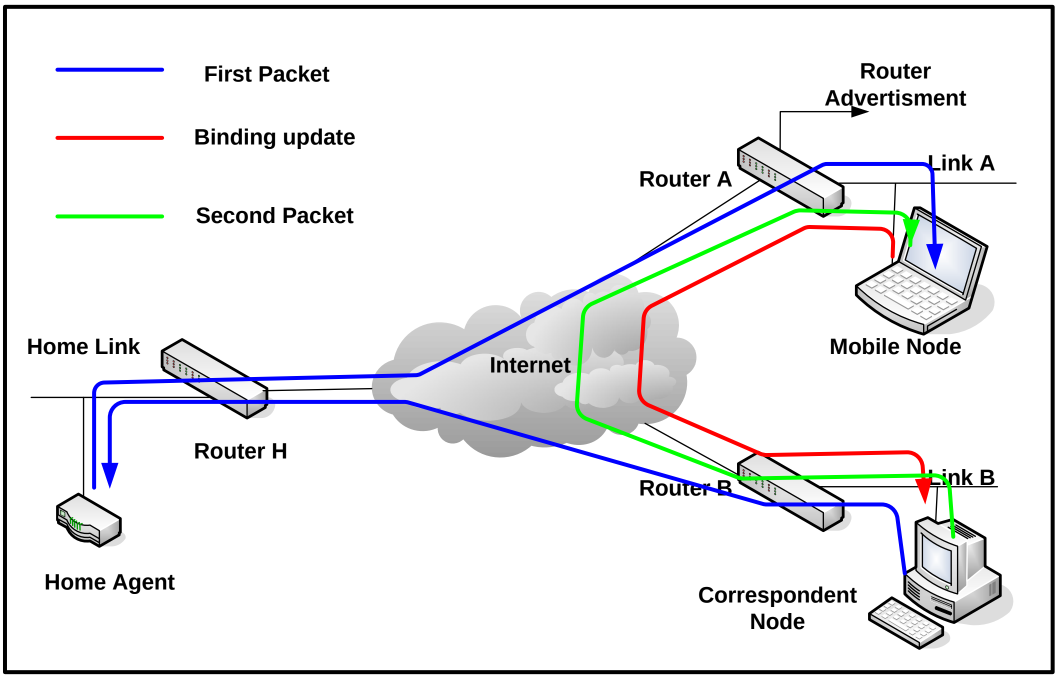
Triangle Routing and Route Optimization

When the MN has received its new CoA, the HA will intercept all packets addressed to the MNs home address. When the MN sends packets, it sets its CoA as the source address and includes a home address destination option. A MN is statically configured with a home address, opposed to the CoA that changes when moving between the network segments. Protocol layers above IP do not, however, see the changing CoAs – only the home address. The MN itself sends packets directly to the nodes it communicates with, known as correspondent nodes (CN). This scenario is known as triangle routing. The problem with this is that packets may need to traverse a longer path than necessary, thus causing longer delays. Consider a CN on the same subnet as the MN far away from the MN's HA. All packets from the CN must traverse through the HA although the MN and the CN resides on the same subnet.

A solution to triangle routing is Route Optimization. This provides means for nodes to cache the binding of a mobile node and tunnel their datagrams directly to its CoA. Route Optimization is illustrated in Figure 6. The MN has a CoA that is unknown for the CN. The CN delivers the packet to the MN's home address. The HA intercepts this packet and tunnels it on to the MN.

When the MN receives the tunneled packet, it is able to detect that this packet is originating from the CN, thus sending a BU to that address. The CN will register the new binding in its BC. The next packet addressed to the MN can then be sent directly, thus avoiding triangle routing.

Figure 6 – Route Optimization eliminates triangle routing



The BU sent to the MN can decide whether or not the receiver should generate a BACK. If it chooses to disable BACK, it will know if the binding was received by inspecting the next packet from this specific node. If that packet comes from the HA, the binding was not received and the MN should generate a new BU message.

Each binding in the BC is associated with a lifetime. There are two possibilities to renew the binding when the lifetime expires. The MN can send a new BU, or the CN can request a new binding by sending a BR.

Binding management

A mobile node, which configured a new care-of address as primary care-of address, has to register this new address as its home agent and at the corresponding nodes, which have been already informed about the mobile node's binding. For this purpose the mobile node sends a Binding Update containing its new binding. To make sure that the intended receiver receives the Binding Update, the mobile node can enforce the receiver to acknowledge the receipt of the Binding Update by responding with a Binding Acknowledgement. To trigger this acknowledgement, the mobile node sets the acknowledgement bit in the Binding Update. Until receipt of the acknowledgement the mobile node continues retransmitting the Binding Update periodically.

In case a mobile node receives a packet from a correspondent node it is able to detect, if the sending correspondent node has already a Binding Cache entry. If the correspondent node has a Binding Cache entry for that mobile node, it addresses the packet directly to the mobile node's care-of address. Otherwise the correspondent node sends that packet to the mobile node's home address. In this case the mobile node receives a tunneled packet. The mobile node may send a Binding Update to the correspondent node to enable it, to send future packets directly to the mobile node without tunneling by the home agent.

A mobile node must set the Acknowledgement bit in Binding Updates addressed to a home agent. The mobile node may also set the Acknowledgement bit in Binding Updates sent to a corresponding node. If the Binding Update was not received by the corresponding node, the mobile node would recognize this in receiving still tunneled packets from the home agent.

Before expiration of a Binding Cache entry for a mobile node the correspondent node can initiate a refreshing of the binding by sending a Binding Request towards the mobile node. Receiving this Binding Request the mobile node may reply with a Binding Update.

Movement Detection

An important aspect when considering mobility in IPv6 is how the MNs detect that they have moved from one link to another. This is critical in order to provide mobility, since delays in movement detection mechanisms will cause delays in obtaining a new CoA. This will again decrease the performance when moving between different networks. The specification of MIPv6 defines that a MN can use any combination of the mechanisms available to detect that it has moved from one network to another. These are router discovery, neighbor unreachability detection (NUD) and indications from the link-layer.

Router Discovery

When a MN moves between networks it can detect routers by waiting for the periodic router advertisement or it can send a router solicitation. The neighbor discovery protocol has limits for how often a MN can send solicitations, and these limitations can prevent the MN to receive router advertisements quickly, thus delaying the detection of a new router. Therefore, MIPv6 does not impose these strict limitations, meaning that a MN when away from home can send router solicitations more frequently. In addition, the interval between router advertisements can be reduced. This can lead to a reduced overall network performance due to the increased network traffic, but it will also increase handover performance for the MN. It is important to remember that the MNs will reside on wireless links with limited bandwidth, implying that the router solicitation interval will represent a compromise between handover performance and network load.

The main goal with movement detection mechanisms is that MNs should detect their new routers as quickly as possible and this implies that there is a balance between handover performance and the network load created. When considering solicitations, a maximum number that can be sent has been defined to prevent unnecessary network load. The only exception is MNs that are moving to another network. They can exceed this limit if they are currently without a CoA on their new link, thus helping the MNs to detect a new router more quickly.

There is however a problem with this approach. If a MN increases the RS rate without knowing that it has moved to a new link, this will cause extra traffic on the old link, where the MN already is registered with an existing CoA. To prevent this, the MN must know for sure that it has moved to a new link, e.g. by receiving a positive indication from lower protocol layers (see below). It is also important that MNs reduces their RS rate after they have received a CoA, to prevent unnecessary network load.

Neighbor Unreachability Detection

While a MN is away from home and is using some router as default, it is important for the MN to be able to quickly detect when that router becomes unreachable so that it can switch to a new default router and to a new care-of address. Since some links (e.g. wireless) do not necessarily work equally well in both directions, it is likewise important for the MN to detect when it becomes unreachable for packets sent from its default router. The MN can then take necessary precautions to ensure that any CN attempting to communicate with it can still reach it through some other route. This can be done through the NUD procedure, which is a movement detection mechanism that can tell the MN if it has moved to a new link.

It is, however, important to remember that the MN cannot efficiently rely on NUD alone. This is because the network load would be prohibitively high in many cases for a MN to continually probe its default router with NS messages even when it is not otherwise actively sending packets to it. To prevent this from happening it is recommended that the MN can use every received packet from its router as an indication that it is still reachable on its current care-of address. The router should send RA messages periodically and the MN will have frequent opportunity to check if the default router is reachable.

Lower Level Indications

Another possibility for movement detection is obtaining some type of indication about link-layer mobility from lower protocol layers, or device driver software, controlling the network interface on the MN. This is especially important when considering wireless access technologies such as WLAN. A MN can for instance use signal strength or signal quality information for its link with the available routers to decide when to switch to a new primary care-of address that could provide a better connection. It is, however, essential that the MN does not assume that all link-layer mobility indications from lower levels necessarily means a movement to a new network segment. Movement from one WLAN cell to another can be made transparent to the IP layer if all the WLAN access points are operating within the same network segment.

Evaluations of Movement Detection

Movement detection is essential in order to provide mobility in IPv6. Although the default procedure for this is router discovery, it would be preferable to provide additional mechanisms in order to prevent too much network load. The NUD can help the MNs in determining that their default routers are no longer available, thus indicating that they must change to another care-of address. NUD can also help to decide whether a MN can increase their RS rate or not, based on advertisements and indications that the MN really has moved to a new link. The efficiency of movement detection can also be increased if the MN could obtain indications about link layer mobility from lower protocol layers. This means that the MN can detect new routers while still receiving advertisements from its current default router and decide whether or not to switch based on for instance signal strength in a wireless access technology. The conclusion is that a MN should use any information possible in order to perform handover to another network, thus minimizing the delay when changing its primary care-of address.

Duplicate Address Discovery

A node must perform DAD (Duplicate Address Detection) when it boots up onto an IPv6 network to ensure that its configured addresses are likely to be unique on the link, a MN that moves onto a new network must perform DAD on the CoA that it obtains from the CoA configuration phase. This holds true regardless of whether the CoA address has been obtained by stateless, stateful or manual means.

In IPv6, the DAD procedure is defined in RFC 2462 “IPv6 Stateless Address Autoconfiguration”, [47] and uses the neighbour discovery procedures defined in RFC 2461. A MN cannot begin to use a new CoA until the DAD procedure has been successfully executed. Until DAD has succeeded, the MN’s new CoA is seen as tentative, in that it can only be used for neighbour discovery purposes (of which the DAD procedure is part of). If a MN was to use its new CoA before successful DAD and another node was using the same address on the link, the MN would erroneously process packets intended for the other node.

To perform DAD, the MN sends out a neighbour solicitation message with its own new CoA address as the target address of the solicitation message. The destination address in the IPv6 header of the neighbour solicitation is set to the solicited-node multicast address of the target address with the source address being the unspecified address. If there is another node on the link that is using the same address as the MN’s new CoA, one of two things will happen:

1. The duplicate node will receive the MN’s neighbour solicitation message and reply with a neighbour advertisement (sent to the all-nodes multicast address) thus exposing the duplicated address to the MN.
2. The MN will receive a neighbour solicitation with its new CoA as the target address from a duplicate node that is also in the process of performing DAD.

Thus, the DAD procedure will give an explicit indication to the MN should there be another node on the network that is using its new CoA. However, (and to the detriment of any node wishing to perform autoconfiguration at haste) the DAD procedure provides no explicit indication that a MN’s new CoA is *not* being used by another node on the network. Indeed, the point at which DAD can be considered to have succeeded is quite vague. According to RFC 2462 a node performing DAD under default conditions will take a minimum of 1 second plus additional delay for link transmissions and logic computation.

Note that in order to speed up the autoconfiguration process, a MN may choose to initiate DAD in parallel to router discovery. Since the value of the node’s link-layer identifier is known in advance, the MN can perform DAD on its link local address before receiving a router advertisement. If the router advertisement instructs the node to use stateless address configuration, the MN need not perform DAD on its resultant global unicast address if it has already verified the uniqueness of it’s link-local address.

As a router may delay responding to a router solicitation by a few seconds, a MN that performs DAD only after receiving a valid router advertisement may experience significantly longer autoconfiguration latency than performing the steps in parallel when stateless addressing is used. However, as noted above, a MN may only detect that it has moved onto a new network as a result of receiving a new router advertisement; in which case the potential speed up of performing DAD in parallel to router discovery is lost.

2.5 Mobile IPv4 or Mobile IPv6? – Comparison

As the new protocol is evolving it is a matter of time for the networks to support it. Nevertheless a network to support MIPv6 needs to be configured for IPv6. A question that needs to be answered is what are the benefits to move from IPv4 to IPv6 and respectively the same for moving from MIPv4 [43] to MIPv6 [42] .

This section provides an overview of the features that differ between Mobile IPv4 and Mobile IPv6. Mobile IPv6 shares many features with Mobile IPv4, but the protocol is now fully integrated into IP and provides many improvements over Mobile IPv4. This section summarizes the major differences between Mobile IPv4 and Mobile IPv6:

- Due to the shortage of IPv4 addresses there might be problems in assigning IPs for all mobile nodes. MIPv6 won’t have that problem since the number of IPv6 addresses space is huge.
- Avoid waste of bandwidth. Support for what is known in Mobile IPv4 as "Route Optimization" is now built in as a fundamental part of the protocol, rather than being added on as an optional set of extensions that may not be supported by all nodes as in Mobile IPv4.
- The use of the care-of address as the Source Address in each packet's IP header also simplifies routing of multicast packets sent by a mobile node. With Mobile IPv4, the mobile node had to tunnel multicast packets to its home agent in order to transparently use its home address as the source of the multicast packets [5]. With Mobile IPv6, the use of the Home Address option allows the home address to be

used but still be compatible with multicast routing that is based in part on the packet's Source Address.

- There is no longer any need to deploy special routers as "foreign agents" as are used in Mobile IPv4. In Mobile IPv6, mobile nodes make use of IPv6 features, such as Neighbor Discovery and Address Autoconfiguration, to operate in any location away from home without any special support required from its local router.
- Unlike Mobile IPv4, Mobile IPv6 utilizes IP Security for all security requirements for Binding Updates [27].
- The movement detection mechanism in Mobile IPv6 provides bi-directional confirmation of a mobile node's ability to communicate with its default router in its current location (packets that the router sends are reaching the mobile node, and packets that the mobile node sends are reaching the router).
- Most packets sent to a mobile node while away from home in Mobile IPv6 are sent using an IPv6 Routing header rather than IP encapsulation, whereas Mobile IPv4 must use encapsulation for all packets. The use of a Routing header requires less additional header bytes to be added to the packet, reducing the overhead of Mobile IP packet delivery [3].
- While a mobile node is away from home, its home agent intercepts any packets for the mobile node that arrive at the home network, using IPv6 Neighbor Discovery rather than ARP as is used in Mobile IPv4. The use of Neighbor Discovery improves the robustness of the protocol and simplifies implementation of Mobile IP due to the ability to not be concerned with any particular link layer as is required in ARP.
- The dynamic home agent address discovery mechanism in Mobile IPv6 uses IPv6 anycast and returns a single reply to the mobile node, rather than the corresponding Mobile IPv4 mechanism that used IPv4 directed broadcast and returned a separate reply from each home agent on the mobile node's home link. The Mobile IPv6 mechanism is more efficient and more reliable, since only one packet need be sent back to the mobile node.

- The use of IPv6 destination options allows all Mobile IPv6 control traffic to be piggybacked on any existing IPv6 packets, whereas in Mobile IPv4 and its Route Optimization extensions, separate UDP packets were required for each control message.
- Mobile IPv4 uses UDP for signaling, whereas Mobile IPv6 uses IPv6 extension headers. This allows for a cleaner implementation, since the code can fully integrated with the IP-processing where it belongs, and no transport protocol port numbers need to be bound for special use.

2.6 Mobility and Wireless Local Area Networks (WLANs)

Having in mind that mobility is the movement of the users it means there is a media to support this movement apart from the mobile protocol. That media can be fixed media like cabling or the most common used media is the wireless infrastructure. For the needs of this thesis the media used was the wireless technology.

Although wireless technology is not the most secure communication method since “all information is in the air”, it is the most practical. Users traveling with vehicles are changing networks subnets rabidly and the wireless LAN technology offers the best media to support that movement. Wireless technology is mostly known as Wi-Fi (Wireless Fidelity) and the supported protocol is the standard 802.11 [10]. A typical WLAN contains at least one Access Point and on or more clients. An access point can be integrated to a wireless router which also includes an Ethernet switch, and internal Router firmware application that provides IP Routing, NAT, and DNS forwarding through an integrated Wide Area Network (WAN) interface. A wireless router allows all three devices (mainly the access point and router) to be configured through one central utility. In this thesis the wireless routers were used during the simulation.

2.7 Handover

As explained earlier a very important process during roaming is the handover. Handover (or handoff) refers to the event when an MN changes its point of attachment from one access network to another. Handovers is said to be seamless if the handover is transparent to the user of the MN. Handovers can be categorized as a hard or soft handover [RFC2461] [46] . In hard handover the terminal has connectivity to a single access point, either the old or the new one in any point of time. Typically, wireless technologies, such as IEEE 802.11 employ hard handover. The control of hard handover is simpler since there is no ambiguity over which access point the mobile terminal shall communicate. In soft handover the terminal has connectivity to more than one access point simultaneously. It requires that wireless cells overlap. Also handover is distinguished in horizontal and vertical [22] [17].

The performance metric of handover is the handover latency which is the time where the mobile host experiences certain duration without being able to send and receive data packets. It is commonly described as the time it takes a mobile host to resume data traffic after the handover event has occurred.

Chapter 3

Performance Evaluation

3.1 Introduction

As stated earlier during this thesis OPNET simulator tool was used to investigate mobility and roaming issues in mobile IPv6. In this chapter the basic scenarios which were designed are described as well as all the different sub-scenarios (named tests) that were used to extract the various results. The expected results from each scenario are described in this chapter and the actual results are presented and analysis is given in the next chapter. All the parameters that were tested for each scenario are tabulated in Table 21 in **Appendix 1**.

3.2 Problem statement

The main features that are going to be evaluated during the simulation scenarios are mainly delay, overhead, packet loss and binding update. Although there are other parameters that can influence mobility like security those are out of the scope of this thesis.

The network applications that were selected during the various scenarios are videoconferencing, Voice Over IP (VoIP) and FTP, so as to have a mixture of real time and elastic applications. The videoconferencing though is the main application that is used for all the scenarios whereas the FTP and VoIP were used just for comparison reasons.

The IP assignment to the Mobile Nodes was stateless taking advantage of the IPv6 protocol mechanisms. The stateless auto configuration mechanism is used to configure the MNs with their IPv6 addresses without the need to set up a DHCP server. All is needed is to configure the IPv6 enable router with the prefix information for the link to which it is attached.

During simulations the following performance issues were considered:

- Delays: Packet round trip time, End to end delay
- Packet loss
- Bandwidth/Overhead usage (due to triangle)
- Handover latency (the time spent during the handover)
- Layer 2 Handover vs. Layer 3 handover
- The impact of QoS and some applications on roaming services
- Tailoring the MIPv6 protocol to provide adequate QoS without wasting resources
- Enable and disable cases for route optimization are evaluated
- Binding update issues, early binding updates (binding table)
- Transmission Power. MNs are likely to be battery powered, and minimizing power consumption is important. Therefore, the number of administrative messages sent over the link by which a MN is directly attached to the Internet should be minimized, and the size of these messages should be kept as small as is reasonably possible.

It is worth noting that there is no similar work as in my knowledge where so many parameters are tested. Some of these parameters are studied in other work but not the same way as in this thesis. This approach allows one to understand better MIPv6 and better tune the values of these parameters to a real environment.

The motivation of choosing the specific parameters was to best tune a MIPv6 environment using wireless technology. It will help in setting up a mIPv6 wireless LAN in an optimised way.

3.4 Scenarios

In this thesis a total of 75 simulated scenarios are designed and run in order to investigate the setting of the various parameters influencing MIPv6, as discussed above. Many other scenarios were implemented but are not presented here although their outcomes were useful and used during the results presentation. For better reference all the scenarios are tabulated in Table 21 in Appendix 1: Table of scenarios.

All the simulation scenarios were carried out using OPNET tool [34], Version OPNET 12.0.A PL1 (Build 4162). Similar works working with OPNET can be found in [20] and [21].

To demonstrate the effects of Mobile IPv6 (MIPv6) mechanisms while two mobile nodes communicate with each other a MIPv6 environment was set-up. The Mobile IPv6 network environment is composed of four Wireless Local Area Network (WLAN) access points (APs) connected through an IP cloud which denotes the internet (Figure 7 - Scenario 1). All four access points are capable of performing Layer 2 (L2) switching as well as Layer 3 (L3) routing. The core of the network, represented by the IP cloud, has a constant latency normally of 0.1 seconds. This value makes it easier to note the effects of the different MIPv6 mechanisms over the application delay. The latency variation during simulation is a parameter that is used to note the effects on MIPv6.

Mobile Node A (MN_A) and Mobile Node B (MN_B) communicate to each other by running different applications but mostly a very light video application is used (Low Resolution Video of 128X120 pixels, 9 bits/pixel, 10 frames/sec) as a source of constant UDP traffic. Mobile Node A is the calling party and Mobile Node B is the called party.

A total of ten different scenarios have been designed in order to investigate the MIPv6 roaming and mobility issues. Each one scenario out of the ten is further used for creating other scenarios (sub-scenarios which are named Tests) for examining the behaviour of the MIPv6 mechanisms. Initially (Scenario 1) the MNs are placed at their corresponding home networks. Then MN_A and MN_B move in fixed or random trajectories around the four access points which are Home Agent A (HA_A), Home Agent B (HA_B), Foreign Router 0 (FR_0) and Foreign Router 1 (FR_1). Both MNs use MIPv6 to roam among the various access points in the network.

Other features and parameters that are used during the scenarios simulation to investigate mobility and roaming issues are given below:

1. Route optimization enabled /disabled

Route optimization is a process in which the MIPv6 is handling the communication between the various nodes. It eliminates overheads as well as decrease delays. It is worth examining this to better understand the effects on the MIPv6 environment and what is the influence in the various scenarios.

2. Core Network latency

Network Latency is a very important parameter since it creates an important delay in the transmission of packets. Its value depends on the quality of the network and always desirable to have as low latency as possible. This thesis investigated the effects of different values of latency on MIPv6 environment.

3. Beacon Interval

Bacons include the necessary information between the communication of nodes and access points. Beacon Interval specifies the TBTT (Target Beacon Transmission Time) in seconds. In other words, the AP will try to transmit Beacon frames with a period specified by the value of this attribute. The actual time when the Beacon is transmitted by the AP can be slightly off since it may need to wait for the shared medium to become available for this transmission. Tuning for the best value of this parameter will help in minimizing the end to end delay.

4. Wireless LAN data rate

The data rate in a WLAN is the actual bandwidth of the media which is the wireless network. Altering this parameter has direct effect in the communication between the nodes and access points. Data rate is an essential parameter to tune on access points while setting up a wireless network so this thesis investigates the best tuned value.

5. Mobile Node velocity

Velocity is an important parameter which it is believed to influence the MIPv6 environment. This thesis investigated a node while changing its ground speed and examines the effects on MIPv6 environment. This parameter is worth going under test since mobility has the meaning of moving IP devices and it worth examining the effects of the velocity on the MIPv6 environment.

6. Access Point transmit power

Although changing transmit power of a device like access point or mobile node has other effects on the device ie on battery life, it is an important parameter to be tested since altering the access point transmit power has direct effects on handover process.

7. TCP Buffer size

This is the size of the buffer holding received data before it is forwarded to the higher layers (e.g. applications). In this thesis the size of this buffer is examined to investigate the effects of its alteration on the MIPv6 environment.

8. Mobility Detection Factor

Mobility Detection Factor, Represents the maximum number of routing advertisement periods this node will wait without receiving a router advertisement from its default router, before it consider the default router as not reachable. It is an important parameter and it worth examining the influence on the MIPv6 environment while altering its value.

9. Random Roaming

It is true that devices trajectories most of the time are random and not fixed. The purpose of the examination of this parameter is to compare the results between the fixed and random trajectories in a simulated environment.

10. Network application (VoIP, VC, FTP)

Mobility is necessary for the IP devices to help them maintain the communication between the network application. Examining some of the most common network applications like VoIP and Video Conferencing will give good indication how network applications get influenced in a wireless MIPv6 environment.

11. Binding update interval

Binding update interval is a very important parameter in the MIPv6 technology which is used to update the MIPv6 devices about the status of the network topology. The period of this interval is going under test in this thesis to examine the effects on the MIPv6 results like end to end delay and MIPv6 overheads.

All the above parameters are examined either alone or as a combination during simulation of the ten scenarios. The specific parameters are part of the various procedures that take place in the MIPv6 mechanism like handover. Further discussion on the effect of these parameters on the MIPv6 performance is made in the next Chapter.

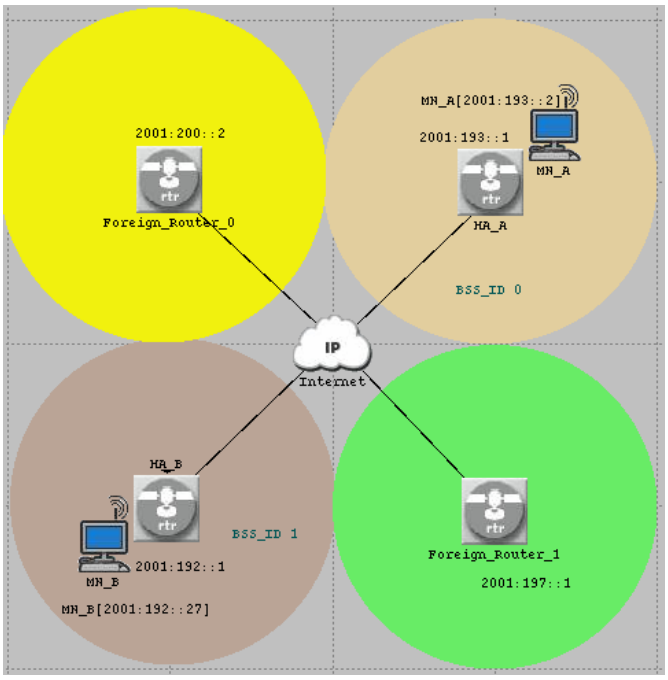
It is worth noting that the method used for simulating the scenarios didn't follow any strict rules or any trial and errors effort but it was more something extracted from my personal experience. The method used was to examine first very simple scenarios even static environments and end up with a quite complex scenario where both MNs are moving. This method is helpful to better understand the behaviour of the parameters under test in the MIPv6 environment.

The simulation times were chosen arbitrarily and didn't follow any pattern selection. During the tests where the velocity was under investigation the simulation time was changing according to velocity increment or decrement.

3.4.1 Simulation Scenario 1 – Both Mobile Nodes situated in their Home Agent

Figure 7 shows the position of the MNs in the MIPv6 environment during scenario 1.

Figure 7 - Scenario 1



Scenario 1 Description:

Scenario number 1 is the basic scenario where both MNs are situated by their HAs. There is no movement during the simulation and during the alteration of the various parameters. It is a static environment and it is used to examine the set up without the MIPv6 mechanisms. Totally five different tests were run for this scenario.

Opnet Models used:

During the scenario 1 the following Opnet models were used,

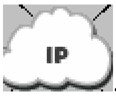
1. Two Mobile Nodes,
    a. MN_A with IPv6 address 2001:193::2
    b. MN_B with IPv6 address 2001:192::27

Each MN is presented by the symbol, 

2. Four Access Points with routing capabilities,
   a. HA_A with IPv6 address 2001:193::1,
   b. HA_B with IPv6 address 2001:192::1,
   c. FR_0 with IPv6 address 2001:200::2,
   d. FR_1 with IPv6 address 2001:197::1

Each AP is presented by the symbol, 

3. Four links with T1 speed each one connecting the four access points with the internet in a star topology

4. An IP cloud denoting the internet which is represented by the symbol, 

.

5. Four coloured ellipse shapes representing the area around the four AP, but note that it does not represent the exact covered area.

6. An Application Model where the used network applications were configured and used as a reference for the Profile Model. The Application model is represented by the symbol, 

7. A Profile Model where the network applications that were configured in Application Model are assigned to a name creating a specific profile. This profile is then assigned to any Mobile Node. The profile name is presented by the symbol, 

Parameters to examine:

In this static environment the parameters that are altered are the ‘Core Network Latency’ and the network application running on MNs. Three different values of network latency are examined which are, 0.1, 0.05 and 0.001 seconds. Also the network applications that were used are Video Conferencing (VC) and Voice Over IP (VoIP).

Simulations Purpose:

The results after changing the core network latency in this static environment are expected to have analogous effects on the delay and overall performance on the network applications. Despite that I believe it is necessary to perform these tests for future reference and comparison when MIPv6 mechanisms will be examined. It is expected that as the latency is decreased both delay and overhead will also be decreased. Packet loss is not expected to be influenced since the environment is not changing dynamically.

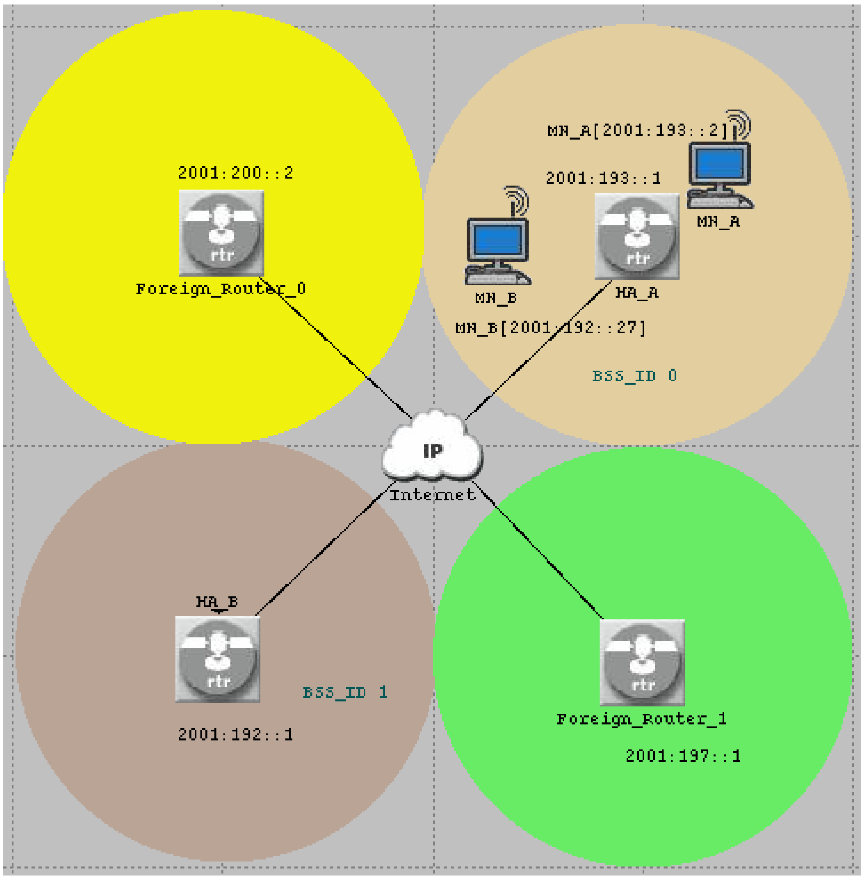
Simulation time:

18 minutes

3.4.2 Simulation Scenario 2 – Both MNs situated in the same area of HA_A

The figure 8 shows the position of the MNs in the MIPv6 environment during scenario 2.

Figure 8 – Scenario 2



Scenario 2 Description:

During scenario number 2 both MNs are situated in the area of HA_A. There is no movement during the simulation and during the alteration of the various parameters. It is a static environment and it is used to examine the MIPv6 behaviour the specific time when a MN is at the corresponding node HA_A. At this scenario MN_B is away from its HA and MN_A behaves as a Corresponding Node (CN).

Totally six different tests were run for this scenario.

Opnet Models used:

Scenario 2 uses all the Opnet models as in scenario 1.

Parameters to examine:

In this static environment the parameter that is altered is the ‘Core Network Latency’ in combination with the ‘Route Optimisation’ (RO) feature enabled and RO feature disabled. Three different values of network latency are defined which are, 0.1, 0.05 and 0.001 seconds. Also during scenario 2 the ‘MN Network Applications’ VC and VoIP are tested while RO is enabled.

Simulations Purpose:

The MN_B is situated in a CN area and MIPv6 protocol is used. It is expected that network latency will have the same influence on the overall performance as in scenario 1. The difference here is that RO disable feature is used which is expected to increase the overhead and delay during simulation.

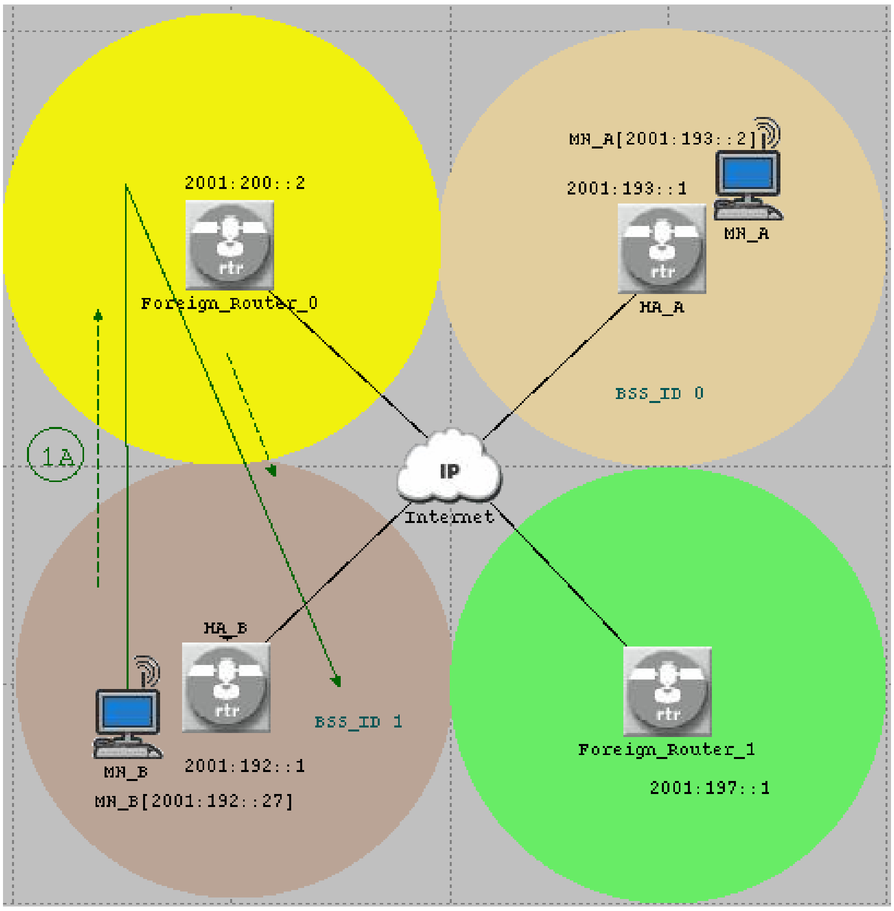
Simulation time:

18 minutes

3.4.3 Simulation Scenario 3 – MNB movement to FR0

The **Figure 9** shows the position of the MNs in the MIPv6 environment during scenario 3.

Figure 9 – Scenario 3



Scenario 3 Description:

During scenario number 3 MN_A is situated in the area of its Home Agent, HA_A. For the first time movement of a MN is introduced. The movement is performed by the MN_B and it can be described as follows:

<u>Movement of MN_B:</u>

(Trajectory 1A) - MN_B moves in a trajectory roaming from HA_B to FR_0 and returning to HA_B.

MN_A is behaving as a CN. In this scenario we can observe that the movement of MN_B is between two different subnet networks where is necessary to use L3 routing.

MN_B trajectory parameters are as follows,

	Traverse Time	Ground Speed	Wait Time	Accum Time
1	n/a	n/a	1m00.00s	1m00.00s
2	14m24.54s	6.214	2m00.00s	17m24.54s
3	15m02.96s	6.214	00.00s	32m27.50s

Traverse time - is the exact time that the MN has travelled for each part of the trajectory (between the previous and next point).
Ground speed - is the speed (velocity) that the MN is travelling with.
Wait Time - is the time where the MN stops and waits before it starts moving again.
Accumulative time - is the total time that is accumulated form the starting point.

Number 1 is the starting point where MN_B waits for 1 minute before start.
Number 2 is the point where MN_B stops and waits for 2 minutes in the area of FR_0
Number 3 is the returning point for MN_B to its HA (HA_B).

Totally six different tests were run for this scenario.

Opnet Models used:

Further to Opnet models used in Scenario 1, in the Scenario 3 a trajectory model is introduced. *Trajectory* is represented by an arrow indicating the direction of the MN's movement.

Parameters to examine:

In this mobile environment the parameter that is altered is the core network latency in combination with the 'Route Optimisation' (RO) feature enabled and RO feature disabled. Two different values of network latency are examined which are, 0.1 and 0.05 seconds. Also apart from VC the VoIP 'MN Network Application' is tested for RO enabled and RO disabled.

Simulations Purpose:

MN_B is on the move roaming from its HA to a FR. It is expected that network latency will have the same influence on the overall performance as in scenario 1 and 2. This scenario is used to examine mobility effect when a MN is moving in a foreign subnet from its home subnet.

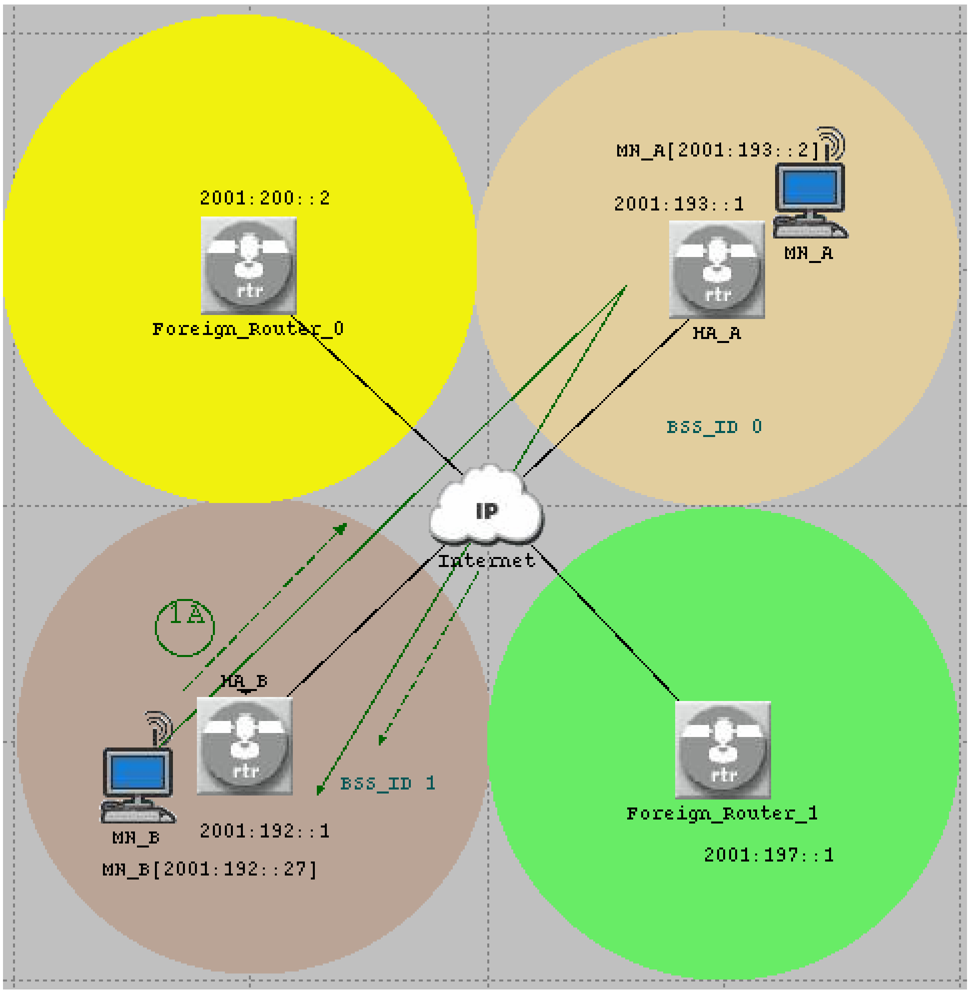
Simulation time:

33 minutes

3.4.4 Simulation Scenario 4 – MNB is travelling through IP cloud (Internet)

The **Figure 10** shows the position of the MNs in the MIPv6 environment during scenario 4.

Figure 10 – Scenario 4



Scenario 4 Description:

During scenario number 4 MN_A is situated in the area of its Home Agent, HA_A. MN_B is moving through IP cloud (internet). The movement that is performed can be described as follows:

Movement of MN_B:

(Trajectory 1A) - MN_B moves in a trajectory roaming from HA_B to HA_A and returning to HA_B.

MN_A is behaving as a CN. In this scenario we can observe that the movement of MN_B is between two different subnet networks where is necessary to use L3 routing. While MN_B is in the area of HA_A then the communication is done using the same AP which means that is done with L2 switching.

Also MN_B while travelling through internet looses connection with its HA as well as with its CN which is HA_A and it re-establish connection as soon as it enters the border of the HA_A covered area.

MN_B trajectory parameters are as follows,

	Traverse Time	Ground Speed	Wait Time	Accum Time
1	n/a	n/a	1m00.00s	1m00.00s
2	17m23.99s	6.214	2m00.00s	20m23.99s
3	15m11.01s	6.214	00.00s	35m35.00s

Number 1 is the starting point where MN_B waits for 1 minute before start.

Number 2 is the point where MN_B stops and waits for 2 minutes in the area of HA_A

Number 3 is the returning point for MN_B to its HA (HA_B).

Totally four different tests were run for this scenario.

Opnet Models used:

As in scenario 3

Parameters to examine:

In scenario 4 the parameter that is altered is the core network latency in combination with the ‘Route Optimisation’ (RO) feature enabled and RO feature disabled. Two different values of network latency are examined which are, 0.1 and 0.05 seconds.

Simulations Purpose:

MN_B is on the move roaming from its HA to the area of HA_A. It is expected that network latency will have the same influence on the overall performance as in scenario 1 to 4. An extra interest here is that the MN_B loses connection and re-establish connection with its CN (HA_A) which is expected to add some more delay, overhead and possible increase in the packet loss.

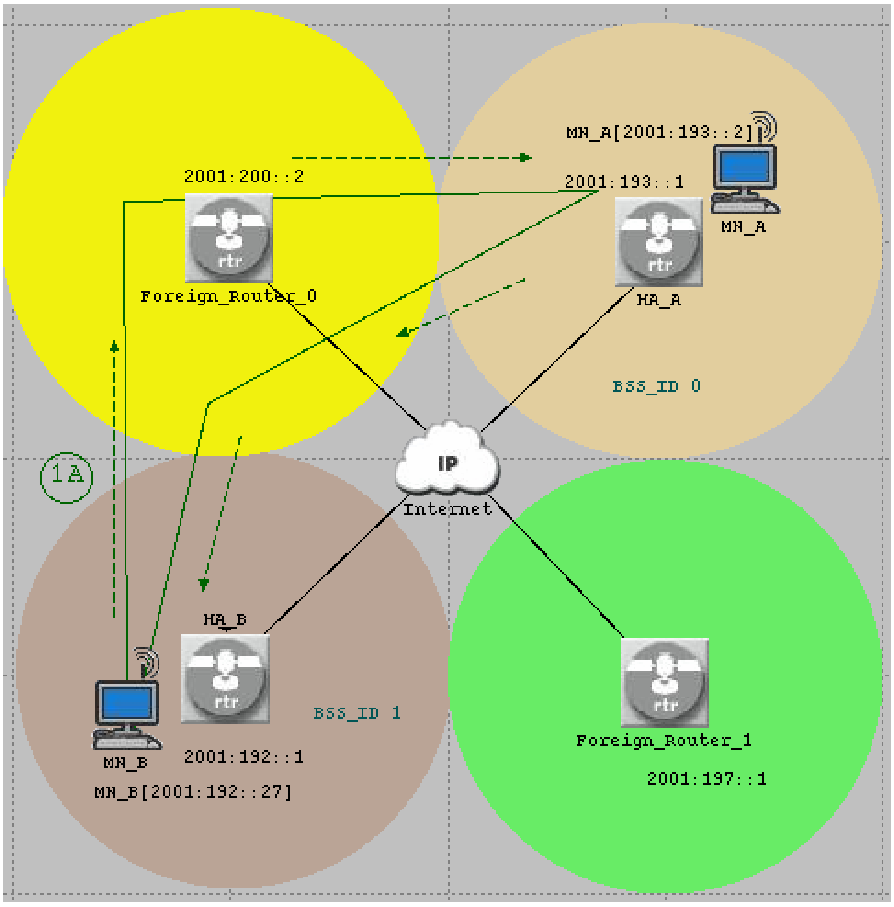
Simulation time:

36 minutes

3.4.5 Simulation Scenario 5 – MNB travels to HAA through FR0

The **Figure 11** shows the position of the MNs in the MIPv6 environment during scenario 5.

Figure 11 – Scenario 5



Scenario 5 Description:

During scenario number 5 MN_A is situated in the area of its Home Agent, HA_A. MN_B is moving towards HA_A through FR_0. The movement that is performed can be described as follows:

<u>Movement of MN_B:</u>

(Trajectory 1A) - MN_B moves in a trajectory roaming from HA_B to FR_0, then to HA_A and returning from the same route back to HA_B. MN_A is behaving as a CN. In this scenario we can observe that the movement of MN_B is between three different subnet networks where is necessary to use L3 routing. Also at the time when MN_B in the area of HA_A L2 switching is established between MN_A and MN_B.

MN_B trajectory parameters are as follows,

	Traverse Time	Ground Speed	Wait Time	Accum Time
1	n/a	n/a	1m00.00s	1m00.00s
2	13m44.98s	6.214	00.00s	14m44.98s
3	13m05.60s	6.214	00.00s	27m50.58s
4	12m15.65s	6.214	00.00s	40m06.23s
5	9m19.01s	6.214	00.00s	49m25.24s

Number 1 is the starting point where MN_B waits for 1 minute in the area of HA_B before it starts roaming.
Number 2 is the point where MN_B is in the area of FR_0 and turns right towards HA_A.
Number 3 is the returning point for MN_B from area HA_A back to FR_0.
Number 4 is the point where MN_B is in the area of FR_0 heading towards HA_B.
Number 5 is the point when MN_A returns and stops to HA_B.

Totally four different tests were run for this scenario.

Opnet Models used:

As in scenario 3

Parameters to examine:

In scenario 5 the parameter that are examined are the different APs ‘Data Rate’ and the APs ‘Transmit Power’. Note that the core network latency in this scenario is kept constant at 0.1sec and the Route Optimisation (RO) feature is enabled. Two different values of data rate are examined which are, 1Mbps and 11Mbps. Also the transmit power of HA_A and FR_0 is altered to 0.05W while data rate is at 1Mbps. The value of 0.05W is ten times bigger than the default/normal one that is used in the various scenarios.

Simulations Purpose:

MN_B is on the move roaming from its HA to a HA_A. It is expected that data rate will not have much influence on the packet loss or the delay. The increase of the transmit power is expected to force for faster handover of the MN_B roaming.

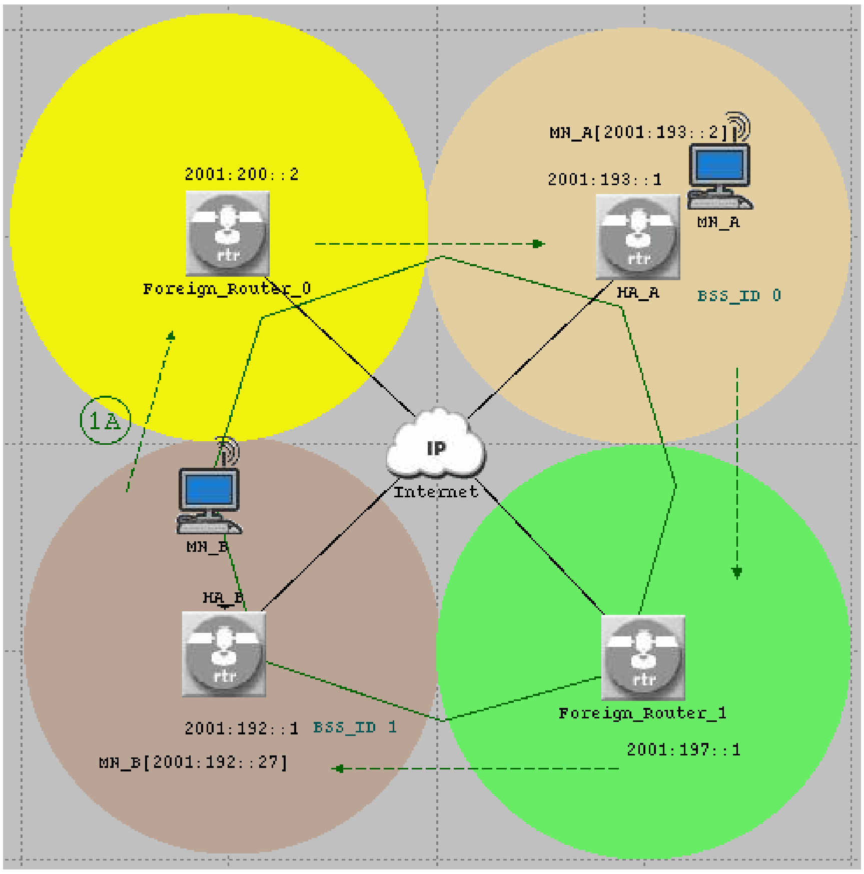
Simulation time:

50 minutes

3.4.6 Simulation Scenario 6 – MNB circle movement travelling through the areas of all routers

The **Figure 12** shows the position of the MNs in the MIPv6 environment during scenario 6.

Figure 12 – Scenario 6



Scenario 6 Description:

During scenario number 6 MN_A is situated in the area of its Home Agent, HA_A. MN_B is moving through the areas of all access points in a clockwise trajectory. The movement that is performed can be described as follows:

<u>Movement of MN_B:</u>

(Trajectory 1A) - MN_B moves in a trajectory roaming continuously through areas of HA_B, FR_0, HA_A, FR_1 and stops at HA_B. MN_A is behaving as a CN. In this scenario we can observe that the movement of MN_B is between the four different subnet networks where is necessary to use L3 routing. While travelling in the area of HA_A, L2 switching is established between MN_A and MN_B.

MN_B trajectory parameters are as follows,

i. For the scenario where ground speed is approximately 60-70mph

	Traverse Time	Ground Speed	Wait Time	Accum Time
1	n/a	n/a	2m00.00s	2m00.00s
2	30.00s	63.195	2m00.00s	4m30.00s
3	30.00s	68.897	2m00.00s	7m00.00s
4	30.00s	66.654	2m00.00s	9m30.00s
5	30.00s	67.263	2m00.00s	12m00.00s
6	30.00s	68.576	2m00.00s	14m30.00s
7	30.00s	67.295	2m00.00s	17m00.00s
8	30.00s	69.267	2m00.00s	19m30.00s
9	30.00s	65.535	00.00s	20m00.00s

ii. For the scenario where ground speed is approximately 30mph

	Traverse Time	Ground Speed	Wait Time	Accum Time
1	n/a	n/a	2m00.00s	2m00.00s
2	1m03.20s	29.998	2m00.00s	5m03.20s
3	1m08.90s	29.999	2m00.00s	8m12.10s
4	1m06.65s	30.002	2m00.00s	11m18.75s
5	1m07.26s	30.001	2m00.00s	14m26.01s
6	1m08.58s	29.998	2m00.00s	17m34.59s
7	1m07.30s	29.998	2m00.00s	20m41.89s
8	1m09.27s	29.999	2m00.00s	23m51.16s
9	1m05.54s	29.998	00.00s	24m56.70s

iii. For the scenario where ground speed is approximately 120mph

	Traverse Time	Ground Speed	Wait Time	Accum Time
1	n/a	n/a	2m00.00s	2m00.00s
2	15.80s	119.991	2m00.00s	4m15.80s
3	17.22s	120.030	2m00.00s	6m33.02s
4	16.66s	120.026	2m00.00s	8m49.68s
5	16.82s	119.970	2m00.00s	11m06.50s
6	17.14s	120.028	2m00.00s	13m23.64s
7	16.82s	120.027	2m00.00s	15m40.46s
8	17.32s	119.977	2m00.00s	17m57.78s
9	16.38s	120.028	00.00s	18m14.16s

Points 1 to 9 represent each angle of the polygon trajectory and are explained as in previous scenarios. Totally 11 different tests were run for this scenario.

Opnet Models used:

As in scenario 3

Parameters to examine:

In scenario 6 the parameters that are altered are the 'Beacon Interval', the 'Ground Speed', the 'MN Network Application' and the 'MN Mobility Detection Factor'. Some of these parameters are altered in combination. For further details regarding combinations of the parameters alteration the reader can refer to table **Table 21** in Appendix 1. Note that the core network latency in this scenario is kept constant at 0.1sec and the Route Optimisation (RO) feature is enabled.

Simulations Purpose:

MN_B is on the move roaming from its HA to a HA_A. It is expected that while beacon interval becomes smaller the delay will be decreased but the overhead should be increased.

Simulation time:

20 minutes with ground speed is approximately 60-70mph

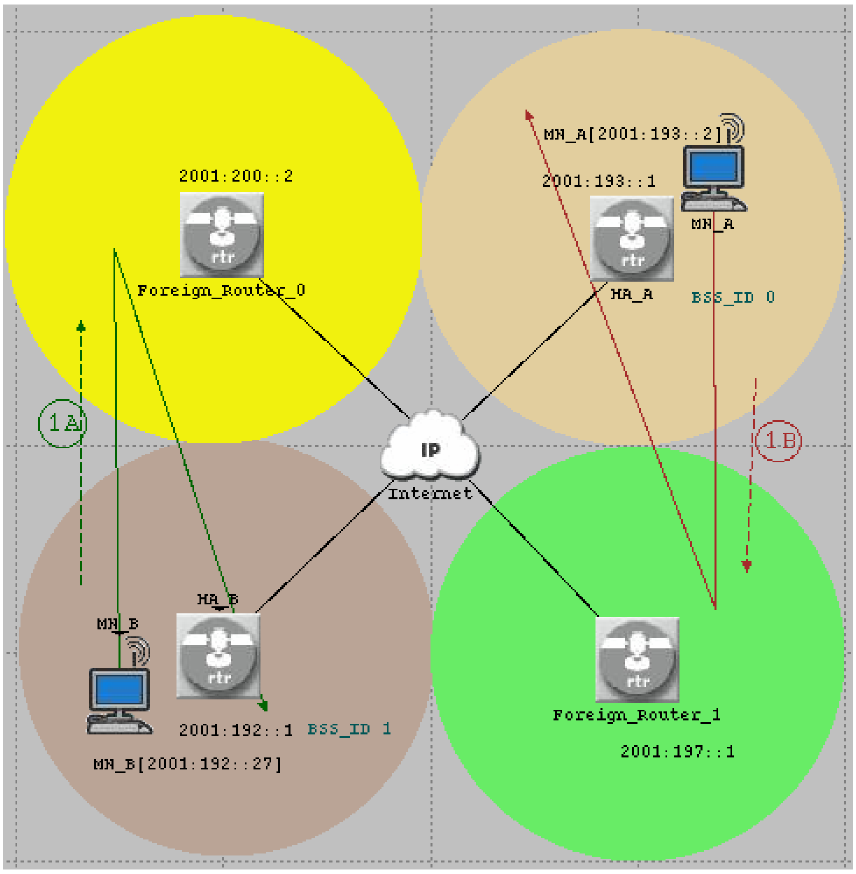
25 minutes with ground speed is approximately 30mph

19 minutes with ground speed is approximately 120mph

3.4.7 Simulation Scenario 7 – MN_A and MN_B travelling to FR1 and FR0 respectively

The **Figure 13** shows the position of the MNs in the MIPv6 environment during scenario 7.

Figure 13 – Scenario 7



Scenario 7 Description:

During scenario number 7 MN_A is situated in the area of its Home Agent, HA_A and MN_B in its Home Agent, HA_B. MN_A is moving from HA_B to FR_0 while at the same time MN_A roams from HA_A to FR_1. The movement that is performed can be described as follows:

Movement of MN_A:

(Trajectory 1B)- MN_A moves in a trajectory roaming from HA_A to FR_1 and returning to HA_A.

Movement of MN_B:

(Trajectory 1A)- MN_B moves in a trajectory roaming from HA_B to FR_0 and returning to HA_B.

This is the first scenario where both MNs move away from their HA at the same time. In this scenario we can observe that both MNs are roaming into different subnet networks.

MN_A trajectory parameters are as follows,

	Traverse Time	Ground Speed	Wait Time	Accum Time
1	n/a	n/a	1m00.00s	1m00.00s
2	12m53.21s	6.214	2m00.00s	15m53.21s
3	15m27.78s	6.214	00.00s	31m20.99s

MN_B trajectory parameters are as follows,

	Traverse Time	Ground Speed	Wait Time	Accum Time
1	n/a	n/a	1m00.00s	1m00.00s
2	12m38.04s	6.214	2m00.00s	15m38.04s
3	14m06.16s	6.214	00.00s	29m44.20s

Points 1 to 3 represent each point of the trajectory of the movement of the MNs.

Totally four different tests were run for this scenario.

Opnet Models used:

As in scenario 3

Parameters to examine:

In scenario 7 the parameters that are altered are the 'TCP Buffer Size' in combination with the 'MN Network Application'. TCP Buffer size is changed from 8760 to 32768 for both VC and VoIP Network Applications.

Simulations Purpose:

Both MNs move to a different FR area. These tests are examining the effect of TCP buffer size while both MNs are performing Layer 3 handover while running network applications.

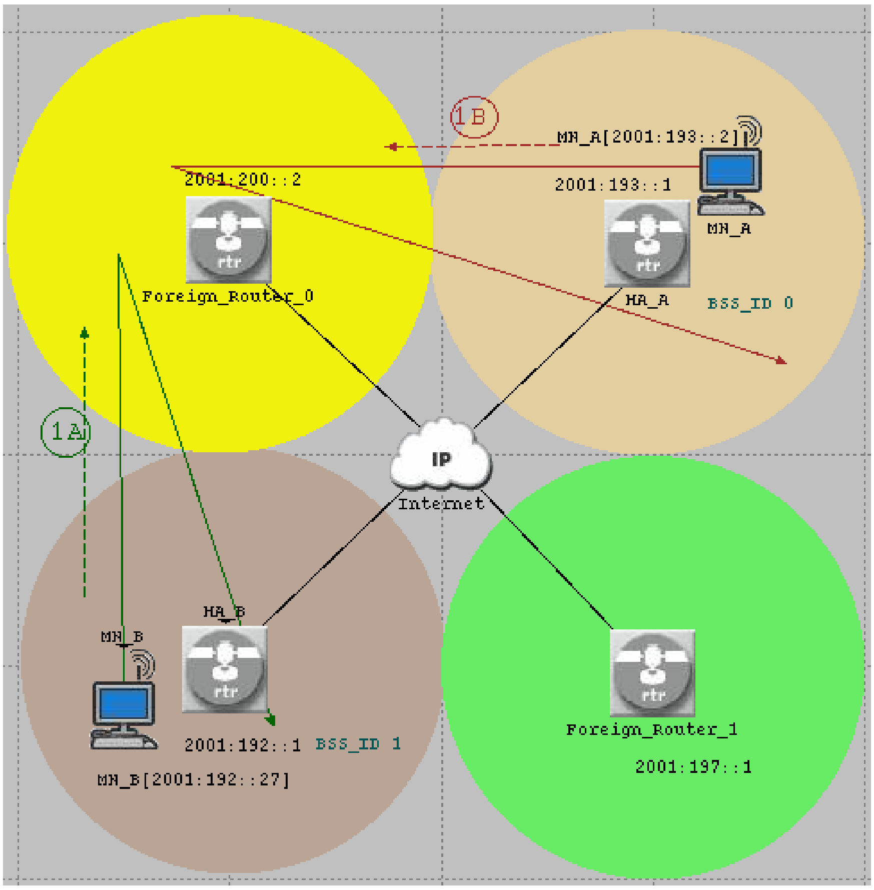
Simulation time:

32 minutes

3.4.8 Simulation Scenario 8 – Both MNs travel to FR_0

The **Figure 14** shows the position of the MNs in the MIPv6 environment during scenario 8.

Figure 14 – Scenario 8



Scenario 8 Description:

During scenario number 8 MN_A is situated in the area of its Home Agent, HA_A and roams to FR_0. MN_B is moving from HA_B to FR_0. The movement that is performed can be described as follows:

<u>Movement of MN_A:</u>

(Trajectory 1B)- MN_A moves in a trajectory roaming from HA_A to FR_0 and returning to HA_A.

Movement of MN_B:

(Trajectory 1A)- MN_B moves in a trajectory roaming from HA_B to FR_0 and returning to HA_B.

In this scenario we can observe that both MNs are roaming into different subnet networks and meet at FR_0 area.

MN_A trajectory parameters are as follows,

	Traverse Time	Ground Speed	Wait Time	Accum Time
1	n/a	n/a	00.00s	00.00s
2	15m49.77s	6.214	1m00.00s	16m49.77s
3	18m19.41s	6.214	00.00s	35m09.18s

MN_B trajectory parameters are as follows,

	Traverse Time	Ground Speed	Wait Time	Accum Time
1	n/a	n/a	1m00.00s	1m00.00s
2	12m38.04s	6.214	2m00.00s	15m38.04s
3	14m06.16s	6.214	00.00s	29m44.20s

Points 1 to 3 represent each point of the trajectory of the movement of the MNs.

Totally four different tests were run for this scenario.

Opnet Models used:

As in scenario 3

Parameters to examine:

In scenario 8 the parameter that is altered is the transmit power of FR_0, HA_A and HA_B.

Simulations Purpose:

Both MNs roam to area of FR_0 and then return to their HAs. Scenario 8 examines the effect of transmit power alteration on handover process.

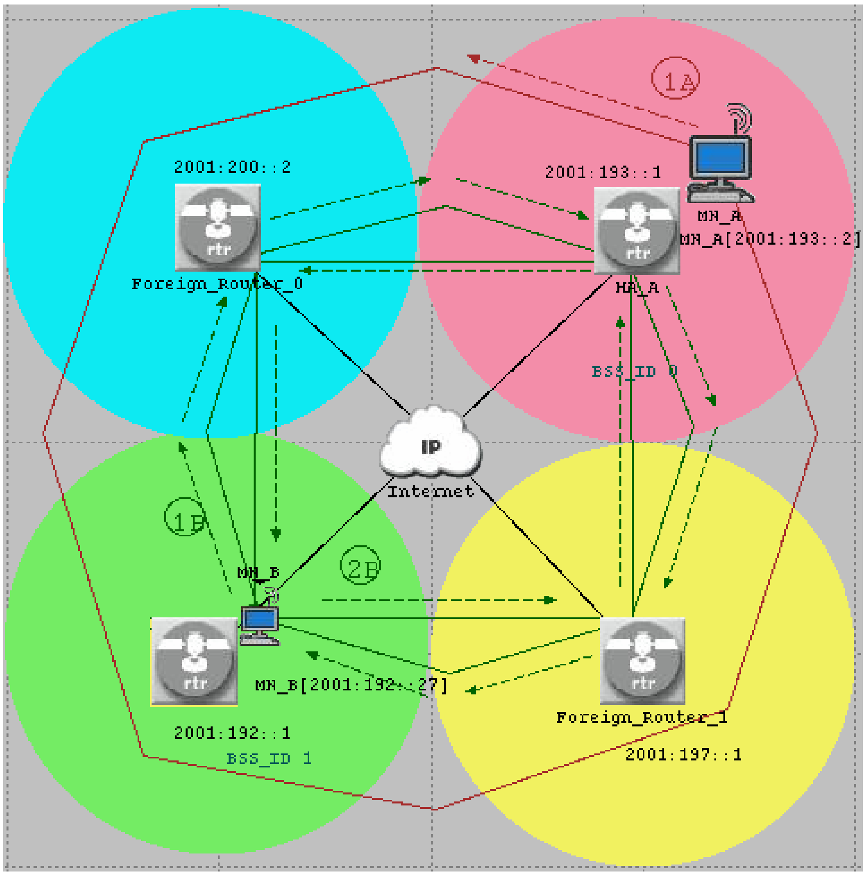
Simulation time:

36 minutes

3.4.9 Simulation Scenario 9 – MN_A follows anticlockwise trajectory and MN_B perform two continues different trajectories

The **Figure 15** shows the position of the MNs in the MIPv6 environment during scenario 9.

Figure 15 – Scenario 9



Scenario 9 Description:

During scenario number 9 both MNs roam away from their HAs performing specific trajectories and returning after some time back to the initial position. The movement that is performed can be described as follows:

Movement of MN_A:

(Trajectory 1A)- MN_A moves in a counterclockwise trajectory roaming through all four access points in the network.

Movement of MN_B:

(Trajectory 1B) - MN_B moves, first in a clockwise trajectory roaming through all four access points in the network.

(Trajectory 2B) - Then it moves counterclockwise re-visiting all access points again.

MN_B trajectory parameters are as follows,

For MN_A when ground speed is approximately 62mph

	Traverse Time	Ground Speed	Wait Time	Accum Time
1	n/a	n/a	1m30.00s	1m30.00s
2	50.27s	62.134	00.00s	2m20.27s
3	51.47s	62.125	1m00.00s	4m11.74s
4	52.47s	62.132	00.00s	5m04.21s
5	57.39s	62.131	1m00.00s	7m01.60s
6	50.46s	62.128	00.00s	7m52.06s
7	52.47s	62.132	1m00.00s	9m44.53s
8	49.29s	62.135	00.00s	10m33.82s
9	49.68s	62.135	00.00s	11m23.50s

For MN_B when ground speed is approximately 62mph

	Traverse Time	Ground Speed	Wait Time	Accum Time
1	n/a	n/a	1m30.00s	1m30.00s
2	32.66s	62.132	00.00s	2m02.66s
3	31.87s	62.138	1m00.00s	3m34.53s
4	32.34s	62.133	00.00s	4m06.87s
5	32.45s	62.142	1m00.00s	5m39.32s
6	30.07s	62.145	00.00s	6m09.39s
7	34.56s	62.137	1m00.00s	7m43.95s
8	32.07s	62.143	00.00s	8m16.02s
9	34.20s	62.145	1m00.00s	9m50.22s
10	1m03.93s	62.134	1m00.00s	11m54.15s
11	1m00.58s	62.136	1m00.00s	13m54.73s
12	1m03.62s	62.139	1m00.00s	15m58.35s
13	1m00.58s	62.136	1m00.00s	17m58.93s

For MN_B when ground speed is approximately 30mph

	Traverse Time	Ground Speed	Wait Time	Accum Time
1	n/a	n/a	1m30.00s	1m30.00s
2	1m07.64s	30.001	00.00s	2m37.64s
3	1m06.01s	30.001	1m00.00s	4m43.65s
4	1m06.98s	30.000	00.00s	5m50.63s
5	1m07.22s	29.999	1m00.00s	7m57.85s
6	1m02.29s	30.000	00.00s	9m00.14s
7	1m11.58s	30.001	1m00.00s	11m11.72s
8	1m06.43s	30.001	00.00s	12m18.15s
9	1m10.84s	30.002	1m00.00s	14m28.99s
10	2m12.41s	29.999	1m00.00s	17m41.40s
11	2m05.47s	30.001	1m00.00s	20m46.87s
12	2m11.78s	29.999	1m00.00s	23m58.65s
13	2m05.47s	30.001	1m00.00s	27m04.12s

For MN_B when ground speed is approximately 120mph

	Traverse Time	Ground Speed	Wait Time	Accum Time
1	n/a	n/a	1m30.00s	1m30.00s
2	16.91s	120.002	00.00s	1m46.91s
3	16.50s	120.021	1m00.00s	3m03.41s
4	16.74s	120.035	00.00s	3m20.15s
5	16.80s	120.030	1m00.00s	4m36.95s
6	15.57s	120.019	00.00s	4m52.52s
7	17.90s	119.969	1m00.00s	6m10.42s
8	16.61s	119.984	00.00s	6m27.03s
9	17.71s	120.008	1m00.00s	7m44.74s
10	33.10s	120.007	1m00.00s	9m17.84s
11	31.37s	119.994	1m00.00s	10m49.21s
12	32.94s	120.015	1m00.00s	12m22.15s
13	31.37s	119.994	1m00.00s	13m53.52s

Points 1 to 9 for MN_A and points 1 to 13 for MN_B represent each point of the trajectories of the movement for MNs.

Totally seventeen different tests were run for this scenario.

Opnet Models used:

As in scenario 3.

Parameters to examine:

In scenario 9 the parameters that are altered are *all* the parameters that have been tested in the previous scenarios which are,

- Route optimization enabled
- Route optimization disabled
- Core Network latency
- Beacon Interval
- Wireless LAN data rate
- Mobile Node velocity
- Access Point transmit power
- TCP Buffer size
- MN Mobility Detection Factor

The above parameters are altered and tested either alone or in combination between them.

Simulations Purpose:

Both MNs are visiting all APs and during their movement they communicate either establishing L2 or L3 connection. Scenario 9 examines the effect of all parameters tested in the previous scenario in order to compare the results as well as to find the best parameters combination for better MIPv6 performance.

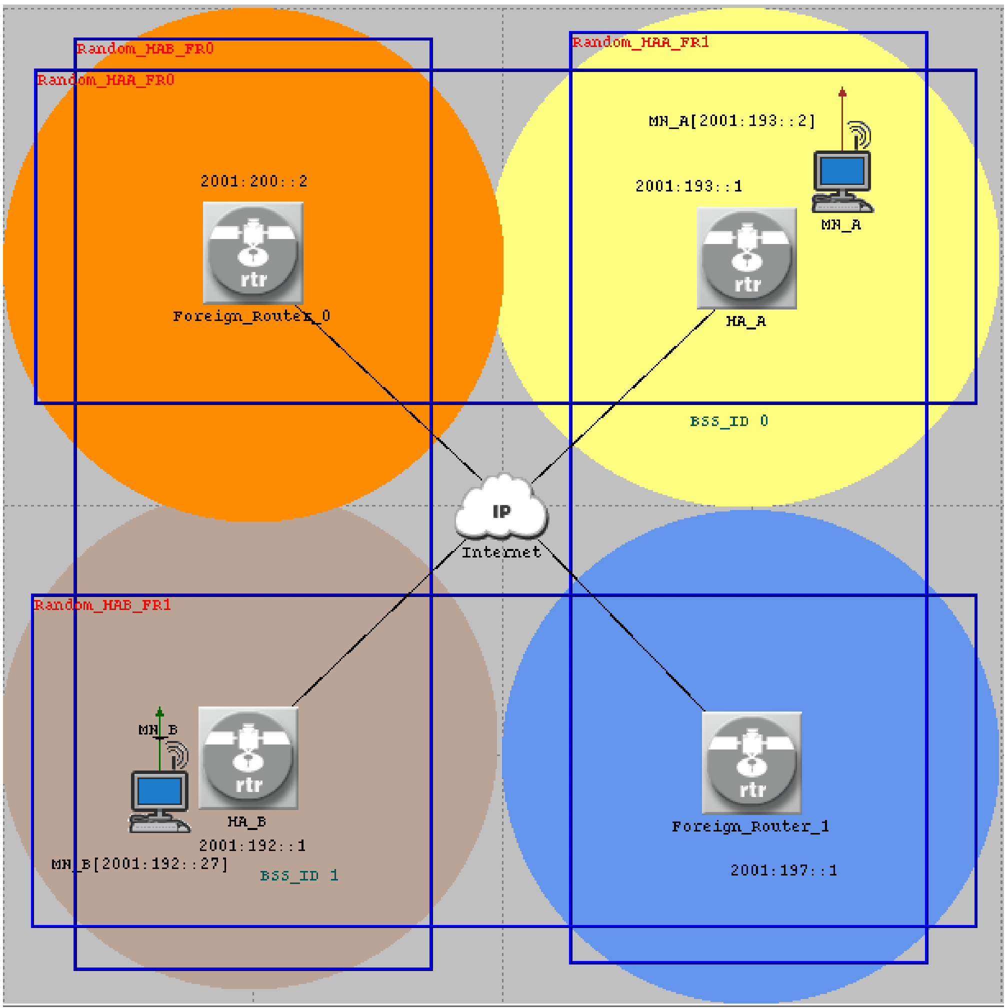
Simulation time:

18 minutes when velocity

3.4.10 Simulation Scenario 10 – Random Mobility

The **Figure 16** shows the position of the MNs in the MIPv6 environment during scenario 10.

Figure 16 – Scenario 10



Scenario 10 Description:

Both MNs move randomly in the predefined area. Four different areas were created named,

- Random_HAA_FR0, where MN_A moves
- Random_HAA_FR1, where MN_A moves
- Random_HAB_FR0, where MN_B moves
- Random_HAB_FR1, where MN_B moves

Totally six different tests were run for this scenario.

Opnet Models used:

Further to models as in scenario 3 here it is used a model with a name "Mobility Config" where the mobility domains are specified. A Mobile Node can randomly move in any point inside the Mobility Domain during the simulation. A mobility configuration object holds random mobility parameters as profiles, making it easy to reuse them. The Mobility Config model is represented with the symbol 

Parameters to examine:

In scenario 10 the parameter that is tested is the random mobility of both MNs in combination with the alteration of 'MN Mobility Factor', 'WLAN Data Rate' and 'Beacon Interval'.

Simulations Purpose:

Both MNs move in the Mobility Domains as per the various tests. The purpose is to study the effect of the random roaming and compare the results with the previous scenarios where the trajectories of the MNs were fixed.

Simulation time:
25 minutes

Chapter 4

Results and Analysis

4.1 Introduction

This Chapter presents the results of the ten simulation scenarios from the previous Chapter. Each scenario results are presented in tables and graphs followed by analysis.

The results/statistics from the ten scenarios show three main aspects of the dynamics for the communication between the two MNs which are

- Application traffic,
- Mobile IPv6 measurements and
- Visited access points.

The results can be used to compare the behaviour of MIPv6 environment while altering the various parameters. All the results that are tabulated in the tables have been extracted from the OPNET simulation tool output.

It is worth discussing a bit the three main aspects for the two MNs as referred above.

1) Application traffic.

Some gaps in the communication (observe videoconferencing and VoIP traffic received statistics) can be observed. Each gap is produced every time a mobile changes its current access point triggering MIPv6 binding procedures to inform its home agent about its new Care-of Address (CoA). When route optimization is used the mobile will also inform all its correspondent nodes about its new CoA. While the binding procedure updates home agent and correspondent nodes all traffic directed to the mobile will be lost.

The application response time will be directly affected by the MIPv6 mechanism used by the mobile in order to communicate with correspondent nodes. There are two possible mechanisms used by MIPv6 which are Route Optimization and Tunnel/reverse tunnel (Route Optimization disabled).

Notice that when RO is enabled the application delay is reduced compared to the case when route optimization is disabled.

2) Mobile IPv6 measurements

In all scenarios two mobile nodes communicating with each other. This means that at some point in the simulation the mobile nodes will be acting as both a mobile node and/or a correspondent node. This cause interesting MIPv6 effects that can be observed at the "Mobile IPv6 Traffic" statistic tables:

A) When both mobiles are away from their corresponding home networks a double MIPv6 overhead will occur, either:
   - Two MIPv6 tunnels will be needed for the mobiles to communicate. In this case the application response time delay will be mainly produced by the three times the data packet must pass through the IP cloud (Internet). Given the initial latency values for the IP cloud is 0.1 sec, the total application delay will be approximately 0.3 seconds.
   - Two IPv6 extension headers (routing extension header and destination extension header) will be used (at the same time) to transport the data traffic when using route optimization mechanism. In this case the application response time will be mainly produced by only one time the data packet must pass through the IP cloud (approximately 0.1 sec.). This is when both mobiles are away from home but located in different networks. Now, when both mobiles are located at the same access point, the data packets will just go through the access point, reducing the application response time even more. For example in scenario 9 in test 9.1

this can be observed starting approximately at time 2 min. 20 sec., until time 8 min. 30 sec.

B) When only one mobile is away from its home network, it will act as a mobile while the other one will perform correspondent node operations. In this case:

- One MIPv6 tunnel will be needed to communicate.
- Just one MIPv6 extension header (at a given time) will be used to transport the data traffic when using route optimization mechanism. For example in scenario 9, test 9.2, an example of this can be observed starting approximately at time 8 min. 30 sec. until time 16 min. 32 sec.

3) Visited access points

Under this statistic tables it is possible to observe all access points that were visited by both mobiles. Each bar in the graph represents an access point visited by the mobiles, and the bar width represents the time the mobile used the access point until it moved to a different one. The colours of the bars have been set so each one identifies one of the four access points. By these graphs we can observe the handover times. Measures are sometimes given as variation which is an instance of change or the rate or magnitude of change. During this Chapter we note the changes that take place after the alteration of the various parameters. Further results are tabulated in Appendix 2.

4.2 Results and Analysis for Scenario 1

As stated earlier in scenario 1 the only parameter that is changed is the ‘Core Network Latency’. In simulation applications, 'Core Network Latency' refers to the time delay, normally measured in milliseconds, between initial input and an output. Latency is sometimes also called transport delay.

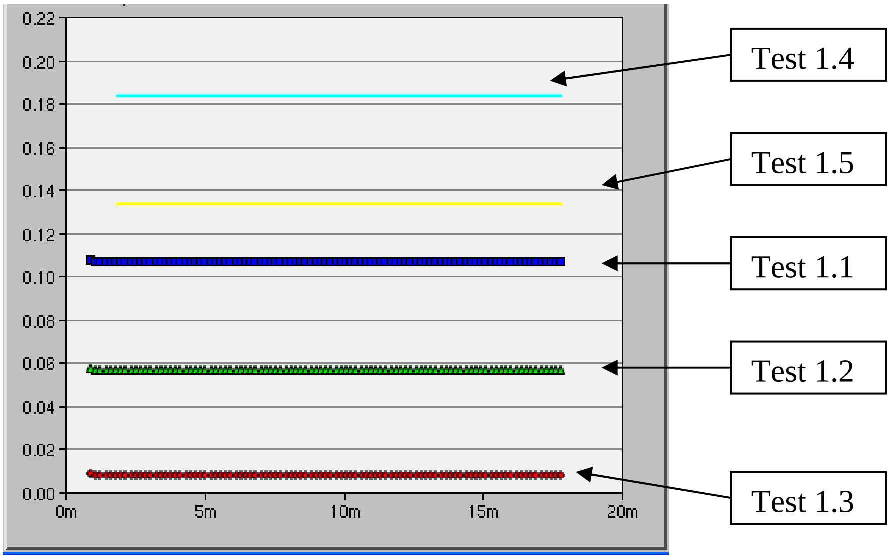
The **Table 2** shows the End-to-End Delay in seconds for the two types of Network Applications that are tested while changing the ‘Core Network Latency’. This delay is also presented in the **Graph 1** below.

Refer to **Table 21** for the exact values of the parameters that have been changed during the Tests.

Table 2 – Scenario 1, Video Conferencing and Voice End-to-End Packet Delay

Statistic	**Video Conferencing Packet End-to-End Delay (sec)**		
	Average	**Maximum**	**Minimum**
Test 1.1	0.10677	0.10710	0.10676
Test 1.2	0.056765	0.057083	0.056757
Test 1.3	0.0077702	0.0085166	0.0077570
Test 1.5	0.056766	0.057112	0.056757
Statistic	**Voice Packet End-to-End Delay (sec)**		
Test 1.4	0.18341	0.18342	0.18341
Test 1.5	0.13347	0.13348	0.13346

Graph 1 – Video Conferencing and Voice End-to-End Delay



As it can be seen from the **Graph 1** as the Core Network Delay decreases the Video Conference and Voice End-to-End Delay also decreases. In both cases as it can be seen from the tables in Appendix 1 for this scenario when running VoIP there are almost no packet loss in traffic according to results where traffic received is 2,956.78 and traffic sent 2,956.96 in bytes/sec. Also the same stands for VC where traffic sent is 324.95 and traffic received is 324.89 in bytes/sec. While running both applications VC and VoIP it seems that there is no influence on the output for VC when the results are compared with the test 1.2 when only VC was running.

Simulation scenario 1 was the basic scenario that was used to present the steady state conditions where there was no movement of the MNs. These results will be used to compare with other scenarios and indicate the differences of the results when MNs are on the move.

4.3 Results and Analysis for Scenario 2

In scenario 2 there is no movement from the MNs. The tests in this scenario are performed in order to get the statistics from the use of MIPv6 and compare them with the next scenarios the time when both MNs while are on the move meet in the same AP area.

During this scenario the 'Core Network Latency', 'Network Applications' and Route Optimization are altered either alone or in combination. Although there is no movement of the MNs, MN_B needs to communicate with its HA since its away from home. This creates MIPv6 tunneled traffic and this is tabulated in the **Table 3**.

Refer to **Table 21** in **Appendix 1** for the exact values of the parameters that have been changed during the Tests.

Table 3 – Scenario 2, MIPv6 Results

Value	Test 2.1	Test 2.2	Test 2.3	Test 2.4	Test 2.5	Test 2.6
Mobile IPv6 Overhead (bits/sec)	724.98	723.73	0	0	17,898	0
Mobile IPv6 Traffic Received (pkts/sec)	3.7759	3.7694	0	0	93.22	0
Mobile IPv6 Traffic Sent (pkts/sec)	3.7759	3.7694	0	0	93.22	0
Mobile IPv6 Tunnelled Traffic Overhead (bits/sec)	0.889	1.78	604.59	604.74	0.889	14,304
Mobile IPv6 Tunnelled Traffic Received (pkts/sec)	0.00556	0.0111	3.7787	3.7796	0.00556	89.39
Mobile IPv6 Tunnelled Traffic Sent (pkts/sec)	0.00556	0.0111	3.7787	3.7796	0.00556	89.40

It can be seen from the results that application VoIP generates much more overhead than VC application. This can be observed by comparing Test 2.1 with Test 2.5. Also it worth noting that during Tests 2.3, 2.4 and 2.6 there are no results for Overhead since the Route Optimization (RO) parameter is disabled. Moreover during the Tests 2.3, 2.4 and 2.6 the MIPv6 tunnelled traffic overhead has been dramatically increased when compared to the Tests 2.1, 2.2 and 2.5 while RO parameter is enabled. The higher value of MIPv6 tunnelled traffic Overhead in Test 2.6 when running simultaneously VC and VoIP network applications is caused by the application VoIP. Comparing now Test 2.1 with Test 2.5 where the only difference is the running network application it can be seen that the MIPv6 tunnelled traffic Overhead and traffic are the same.

The End-to-End Delay of network applications of scenario 2 is presented in the next table.

Table 4 – Scenario 2, Video Conferencing and Voice Packet End-to-End Delay

Statistic	**Video Conferencing Packet End-to-End Delay (sec)**		
	Average	**Maximum**	**Minimum**
Test 2.1	0.005644	0.027321	0.005333
Test 2.2	0.005717	0.17181	0.00534
Test 2.3	0.21011	0.21037	0.21004
Test 2.4	0.11019	0.11042	0.11015
Test 2.5	0.006971	0.027317	0.005397
Statistic	**Voice Packet End-to-End Delay (sec)**		
Test 2.5	0.083527	0.083548	0.083509
Test 2.6	0.28486	0.28487	0.28485

Comparing Test 2.1 and Test 2.2 where the only difference is the network latency it can be seen that the average End-to-End delay is almost the same. This happens because the Internet is only used once from MN_B at the beginning of the communication since MN_B is static and in the area of MN_A's HA.

An important difference in values can be seen between Test 2.1 (RO enabled) and Test 2.3 (RO Disabled). This is because in Test 2.3 the application response time delay will be mainly produced by the two times the data packet must pass through the

IP cloud (Internet) whereas in Test 2.1 the MN does not need to contact its HA more than once.

It can also be extracted when comparing Test 2.1 and Test 2.6 that the Voice Packet End-to-End Delay is bigger for the Voice Application than the VC application as it was seens earlier that there is much more overhead from the VoIP application.

Analysing results for this scenario in Appendix 2 it can be seen that when running VoIP in test 2.4 there is no packet loss in traffic. According to results traffic received is 2,951.67 and traffic sent is 2,951.67 in bytes/sec.

4.4 Results and Analysis for Scenario 3

In the scenario 3 movement on MN_B is introduced for the first time. The MN_B is moving from its HA to FR_0 attaching itself to a different subnet network. The tests that are performed here are for 'Core Network Latency', Route Optimisation and Network Application.

Refer to **Table 21** in **Appendix 1** for the exact values of the parameters that have been changed during the Tests.

Table 5 shows the MIPv6 traffic and overhead for the various tests of scenario 3.

Table 5 Scenario 3, MIPv6 Results

Value Name	Test 3.1	Test 3.2	Test 3.3	Test 3.4	Test 3.5	Test 3.6
Mobile IPv6 Overhead (bits/sec)	424.15	424.34	0	0	10,596	0
Mobile IPv6 Traffic Received (pkts/sec)	2.0995	2.1035	0	0	52.93	0
Mobile IPv6 Traffic Sent (pkts/sec)	2.2091	2.2101	0	0	55.19	0
Mobile IPv6 Tunnelled Traffic Overhead (bits/sec)	0.889	0.646	353.70	353.78	16.73	8,844
Mobile IPv6 Tunnelled Traffic Received (pkts/sec)	0.00556	0.00404	2.1040	2.1061	0.105	52.82
Mobile IPv6 Tunnelled Traffic Sent (pkts/sec)	0.00556	0.00404	2.2106	2.2111	0.105	55.28

Comparing Test 3.1 with Test 2.1 it can be seen that for both Tests the MIPv6 Tunnelled traffic is the same value. This is mainly because the necessary tunnelled traffic is the same despite the fact that in scenario 3 there is movement.

Comparing Test 3.1 and 3.3 where the only difference is the RO enabled for 3.1 and disabled for 3.3, it can be seen that the MIPv6 tunnelled traffic is much higher in Test 3.3 due to triangle routing. For once again the network application VoIP compared with VC application is proved to have more overheads (Tests 3.5 and 4.6) for both cases either RO is enabled or disabled.

Table 6 below shows the results for the End-to-End packet delay for both applications VoIP and VC.

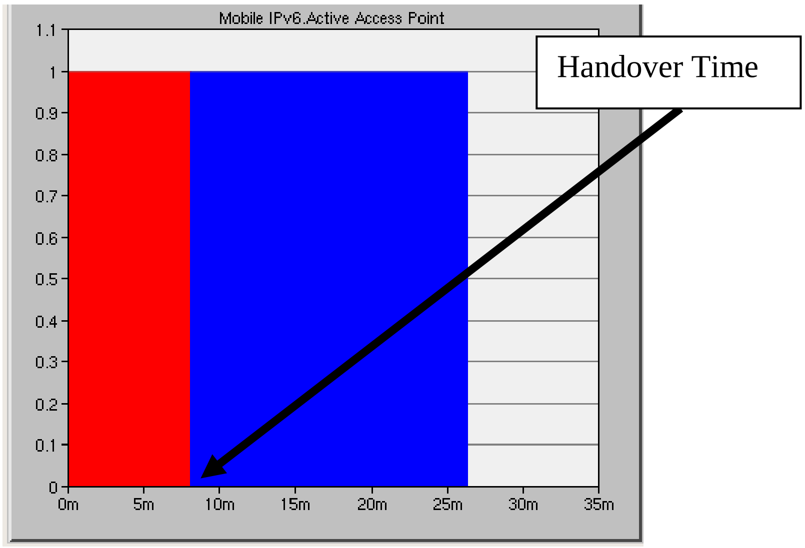
Table 6 - Scenario 3, Video Conferencing and Voice Packet End-to-End Delay

Statistic	Video Conferencing Packet End-to-End Delay (sec)		
	Average	**Maximum**	**Minimum**
Test 3.1	0.342	22.646	0.107
Test 3.2	0.1155	5.58	0.0568
Test 3.3	0.2204	5.4793	0.1068
Test 3.4	0.308	21.350	0.057
	Voice Packet End-to-End Delay (sec)		
Test 3.5	0.504	15.926	0.183
Test 3.6	0.511	16.394	0.183

As far it concerns the variation of 'Network Core Latency' the same outcome as in scenarios 1 and 2 is true that is as the Latency of the network decreases the End-to-End delay also decreases. Also once again the VoIP delay is higher than VC as in the previous scenarios.

Graph 3 shows the visited access points where each bar in the graph represents an access point visited by the MN_B in Test 3.1 and the bar width represents the time the mobile used the access point until it move to the next one. The handover times can be monitored.

Graph 2 – Scenario 3, Visited Access Points by MN_B

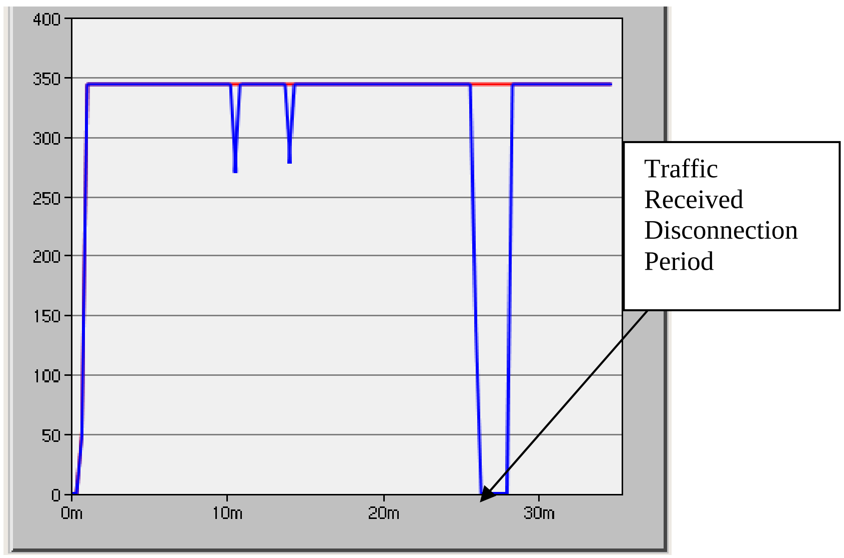


From the above graph it can be seen that MN_B was attached on HA_B for approximately 8minutes before the handover process occurs to FR_0. The handover process is examined later in this thesis.

4.5 Results and Analysis for Scenario 4

The difference between scenario 3 and scenario 4 is that the movement of MN_B in scenario 4 is through the IP cloud (Internet) meaning that there is an interruption of the connection while travelling through the IP cloud. MN_B is moving from its HA_B to HA_A. The **Graph 3** shows the period of disconnection of the communication at approximately 26 minutes from the start point. This graph represents the traffic send and received for MN_B.

Graph 3 – Scenario 3, MN_B traffic send/receive



Because of the above interruption the average End-to-End delay for VC application is approximately three times bigger in Test 4.1 than Test 3.1.

Refer to **Table 21** for the exact values of the parameters that have been changed during the Tests.

Table 7 Scenario 4, MIPv6 Results

	Test 4.1	Test 4.2	Test 4.3	Test 4.4
Mobile IPv6 Overhead (bits/sec)	386.19	375.82	0	0
Mobile IPv6 Traffic Received (pkts/sec)	1.7495	1.7032	0	0
Mobile IPv6 Traffic Sent (pkts/sec)	2.0114	1.9574	0	0
Mobile IPv6 Tunnelled Traffic Overhead (bits/sec)	0.990	0.741	313.41	313.33
Mobile IPv6 Tunnelled Traffic Received (pkts/sec)	0.00714	0.00463	1.7069	1.7079
Mobile IPv6 Tunnelled Traffic Sent (pkts/sec)	0.00714	0.00463	1.9588	1.9583

The **Table 8** shows the VC packet End-to-End delay where it is clear for once again that the decrease of 'Network Core Latency' has the same effect on the VC delay as in the previous scenarios.

Table 8 – Scenario 4, Video Conferencing Packet End-to-End Delay

Statistic	Video Conferencing Packet End-to-End Delay (sec)		
	Average	Maximum	Minimum
Test 4.1	0.784	66.568	0.005
Test 4.2	0.284	22.852	0.006
Test 4.3	0.348	18.103	0.107
Test 4.4	0.301	20.514	0.057

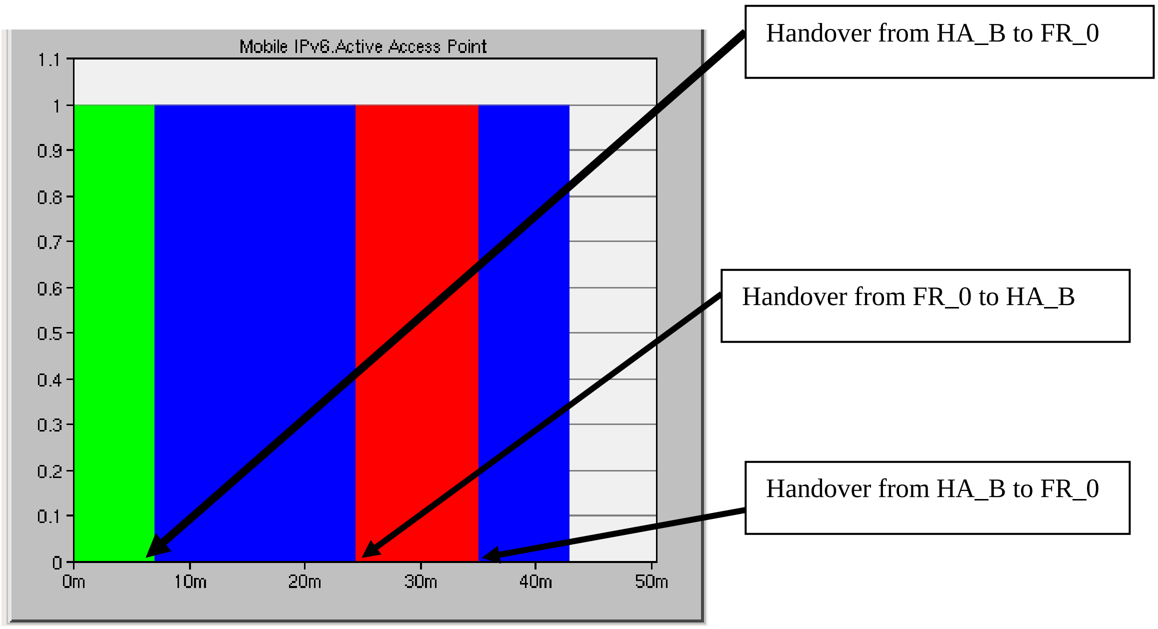
Also it is true for scenario 4 that the triangle routing when RO is disabled creates MIPv6 tunneled traffic overhead and this is clear when comparing Tests 4.1 and 4.2 with Tests 4.3 and 4.4 respectively.

4.6 Results and Analysis for Scenario 5

In Scenario 5 the MN_B is moving from its HA to HA_B travelling through the area of FR_0. In this scenario same new parameters are tested which are the APs 'Transmit Power' and the 'WLAN Data Rate'. Refer to **Table 21** in **Appendix 1**for the exact values of the parameters that have been changed during the Tests.

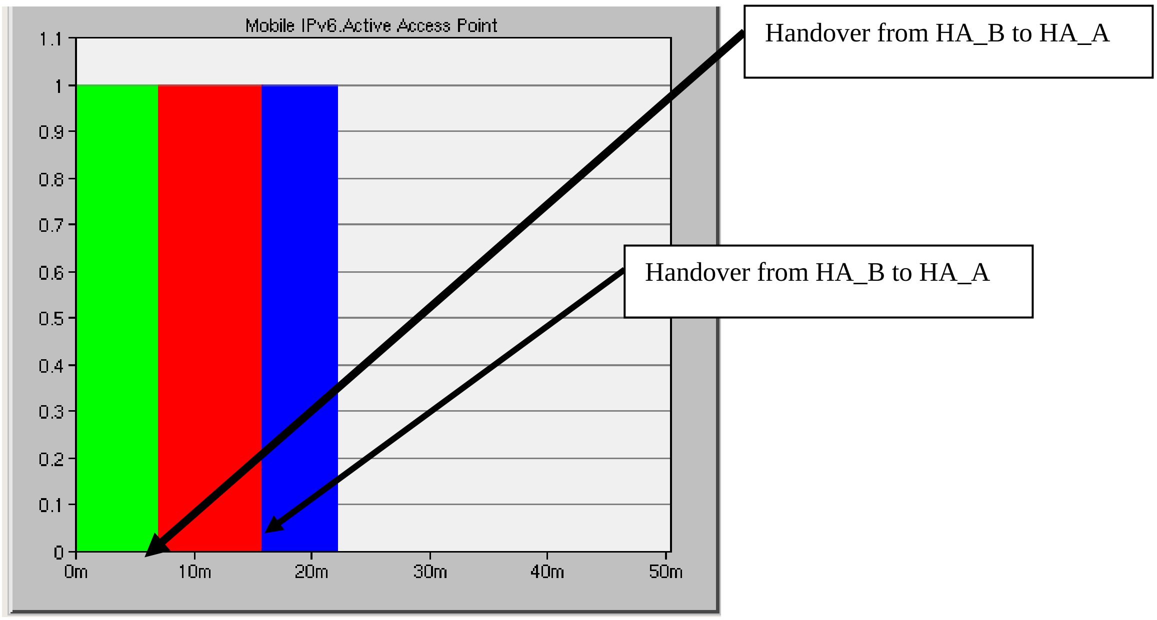
Graph 4 below shows the Handover process when all the parameters are set to initial/default values

Graph 4 – Scenario 5, Test 5.1, Handover Process for MN_B



Graph 5 shows the handover process when the Transmit Power of AP HA_A is set to a value of ten times bigger (0.05W) than the initial value which was 0.005W.

Graph 5 – Test 5.3, Handover Process for MN_B



From the above graph from Test 5.3 it can be seen that increasing the transmit power of AP can force the MN to associate itself on the next AP much faster than the Test 5.1 with initial values. In this case in Test 5.3 the MN_B is never associated eith AP FR_0 as in Test 5.1 because the HA_A signal is too strong that force the MN_B to communicate with itself as soon as the MN_B leaves its HA area.

In **Table 9** below the MIPv6 results are presented for the Tests in scenario 5.

Table 9 - Scenario 5, MIPV6 Results

	Test 5.1	**Test 5.2**	**Test 5.3**	**Test 5.4**
Mobile IPv6 Overhead (bits/sec)	550.46	417.15	521.79	-
Mobile IPv6 Traffic Received (pkts/sec)	2.7950	1.9883	2.1113	-
Mobile IPv6 Traffic Sent (pkts/sec)	2.8670	2.1727	2.7177	-

Mobile IPv6 Tunnelled Traffic Overhead (bits/sec)	0.960	111.31	59.47	-
Mobile IPv6 Tunnelled Traffic Received (pkts/sec)	0.00600	0.6590	0.01333	-
Mobile IPv6 Tunnelled Traffic Sent (pkts/sec)	0.00600	0.6957	0.3717	-

The WLAN Data Rate value is 11MB in Test 5.2 instead of the default 1MB that is in Test 5.1. In the above table it can be observed that there is a huge increase in the MIPv6 tunneled traffic overhead. In contrast the average VC packet End-to-End delay of Test 5.2 has a slight difference from that of 5.1 as shown in **Table 10**.

Table 10 – Scenario 5, Video Conferencing Packet End-to-End Delay

Statistic	Video Conferencing Packet End-to-End Delay (sec)		
	Average	**Maximum**	**Minimum**
Test 5.1	0.1386	5.3023	0.0054
Test 5.2	0.1411	4.0665	0.0014
Test 5.3	0.03880	0.21181	0.00537
Test 5.4	-	-	-

From **Table 10** it is obvious that the faster handover process for MN_B from HA_A is made much faster so both MN_A and MN_B are attached on the same AP which is HA_A for longer leading to minimization of the VC End-to-End delay.

4.7 Results and Analysis for Scenario 6

In Scenario 6 the MN_B is moving in a clockwise trajectory visiting all APs. The parameters that are tested are Beacon Interval, MN velocity, Mobility Detection Factor and network applications VC or VoIP. All parameters are tested either alone or in combination between them.

From the results in **Table 11** below for once again it can be seen that when the network application under test is VoIP as in Tests 6.9 and 6.11 the MIPv6 overhead is much bigger in value than those Test where VC application is running. The difference between Test 6.9 and Test 6.11 is that in 6.11 the Mobility Detection Factor has the value of one instead of three as in Test 6.9 which is the default value. This alteration of value minimises the MIPv6 Tunnelled Traffic Overhead as well as the average VoIP packet End-to-End delay as it can be seen in **Table 12**.

Graph 6 – Tests 6.9 and 6.11 Voice Packet End-to-End Delay

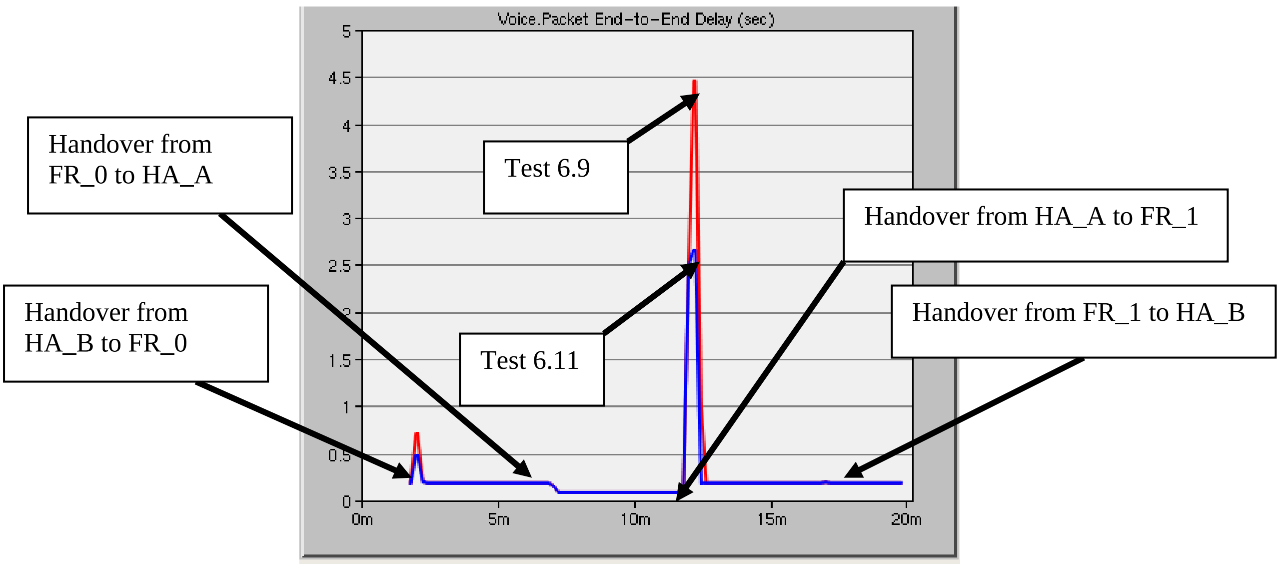


Table 11 – Scenario 6, MIPv6 Results

	Test 6.1	Test 6.2	Test 6.3	Test 6.4	Test 6.5	Test 6.6	Test 6.7
Mobile IPv6 Overhead (bits/sec)	571.68	574.56	571.52	575.04	575.32	572.16	520.74
Mobile IPv6 Traffic Received (pkts/sec)	2.9550	2.9692	2.9550	2.9708	2.9550	2.9583	2.9507
Mobile IPv6 Traffic Sent (pkts/sec)	2.9775	2.9925	2.9767	2.9950	2.9808	2.9800	2.9700
Mobile IPv6 Tunnelled Traffic Overhead (bits/sec)	2.40	2.40	2.00	2.7	2.4	2.00	1.81
Mobile IPv6 Tunnelled Traffic Received (pkts/sec)	0.01500	0.01500	0.01250	0.015	0.01500	0.01250	0.01133
Mobile IPv6 Tunnelled Traffic Sent (pkts/sec)	0.01500	0.01500	0.01250	0.015	0.01500	0.01250	0.01133

	Test 6.8	Test 6.9	Test 6.10	Test 6.11
Mobile IPv6 Overhead (bits/sec)	551.58	14,240	572.32	14,258
Mobile IPv6 Traffic Received (pkts/sec)	2.8465	72.79	2.9592	73.130
Mobile IPv6 Traffic Sent (pkts/sec)	2.8728	74.167	2.9808	74.264
Mobile IPv6 Tunnelled Traffic Overhead (bits/sec)	2.11	79.6	2.27	63.73
Mobile IPv6 Tunnelled Traffic Received (pkts/sec)	0.01316	0.497	0.01417	0.398
Mobile IPv6 Tunnelled Traffic Sent (pkts/sec)	0.01316	0.497	0.01417	0.398

According to the above results in **Table 11** the alteration of the parameter Beacon Interval as in Test 6.4 by making the value half of the default value leads to an increase of the MIPv6 Tunnelled Overhead traffic. This happens because the APs with smaller Beacon Interval value create more traffic since more often they send beacon messages to the MN_B.

Also an interesting result is from Test 6.7 where after decreasing in half (30mph) the velocity (ground speed) of the MN_B the MIPv6 Tunnelled traffic overhead is decreased. At the same time the average VC packet End-to-End delay is slightly increased.

In Test 6.8 when doubling (120mph) the velocity of MN_B there is almost no change in the MIPv6 packet End-to-End delay. It can be seen though a slight decrease of the value for the MIPv6 Overhead Traffic.

Table 12 – Scenario 6, Video Conferencing and Voice Packet End-to-End Delay

Statistic	Video Conferencing Packet End-to-End Delay (sec)		
	Average	**Maximum**	**Minimum**
6.1	0.08909	0.80123	0.00538
6.2	0.08226	0.18119	0.00537
6.3	0.08929	0.83877	0.00572
6.4	0.08322	0.26124	0.00533
6.5	0.08904	0.80097	0.00536
6.6	0.08892	0.80099	0.00559
6.7	0.1069	2.4843	0.0054
6.8	0.08345	0.20036	0.00537
6.10	0.08380	0.31613	0.00533
Statistic	**VoIP Packet End-to-End Delay (sec)**		
6.9	0.2452	4.4759	0.0837
6.11	0.2138	2.6811	0.0834

4.8 Results and Analysis for Scenario 7

In scenario 7 it is the first time that mobility of MN_A is introduced while the TCP Buffer size is tested. According to the results in **Table 13** and **Table 14** it can be clearly stated that the alteration of the TCP Buffer size value from 8760 to 32768 of the APs and MNs has no effect on the MIPv6 results neither for VC application nor for VoIP application.

Table 13 – Scenario 7, MIPv6 Results

	Test 7.1	Test 7.2	Test 7.3	Test 7.4
Mobile IPv6 Overhead (bits/sec)	608.20	608.20	15,190	15,190
Mobile IPv6 Traffic Received (pkts/sec)	1.6276	1.6276	40.831	40.831
Mobile IPv6 Traffic Sent (pkts/sec)	1.7182	1.7182	42.911	42.911
Mobile IPv6 Tunnelled Traffic Overhead (bits/sec)	2.250	2.250	26.9	26.9
Mobile IPv6 Tunnelled Traffic Received (pkts/sec)	0.01406	0.01406	0.168	0.168
Mobile IPv6 Tunnelled Traffic Sent (pkts/sec)	0.01406	0.01406	0.168	0.168

Table 14 – Scenario 7, Conferencing and Voice Packet End-to-End Delay

Statistic	Video Conferencing Packet End-to-End Delay (sec)		
	Average	**Maximum**	**Minimum**
Test 7.1	0.338	22.420	0.107
Test 7.2	0.338	22.420	0.107
Statistic	**VoIP Packet End-to-End Delay (sec)**		
Test 7.3	0.387	13.216	0.183
Test 7.4	0.387	13.216	0.183

4.9 Results and Analysis for Scenario 8

In scenario 8 both MNs move from their HAs to FR_0. During the tests in this scenario we monitor the influence of the alteration of APs Transmit Power.

Table 15 – Scenario 8, MIPV6 Results

Value	Test 8.1	Test 8.2	Test 8.3	Test 8.4
Mobile IPv6 Overhead (bits/sec)	645.60	0	936.62	0
Mobile IPv6 Traffic Received (pkts/sec)	1.9079	0	1.2069	0
Mobile IPv6 Traffic Sent (pkts/sec)	1.9861	0	3.0611	0
Mobile IPv6 Tunnelled Traffic Overhead (bits/sec)	2.074	0	2.00	0
Mobile IPv6 Tunnelled Traffic Received (pkts/sec)	0.01296	0	0.01157	0
Mobile IPv6 Tunnelled Traffic Sent (pkts/sec)	0.01296	0	0.01250	0

Table 16 – Scenario 8, Videoconferencing Packet End-to-End Delay

Statistic	Video Conferencing Packet End-to-End Delay (sec)		
	Average	**Maximum**	**Minimum**
Test 8.1	0.1245	5.0981	0.0058
Test 8.2	0	0	0
Test 8.3	0.06744	0.12086	0.00574
Test 8.4	1.471	79.240	0.107

4.10 Results and Analysis for Scenario 9

Scenario 9 comprises tests with all the parameters that were tested in the previous scenarios. Also during the tests in this scenario both MNs are moving.

Table 17 – Scenario 9, MIPV6 Results

Value	Test 9.1	Test 9.2	Test 9.3	Test 9.4	Test 9.5	Test 9.6	Test 9.7	Test 9.8	Test 9.9
Mobile IPv6 Overhead (bits/sec)	872	0	23,270.40	22.04	779.02	914.74	486.8	501.87	0
Mobile IPv6 Traffic Received (pkts/sec)	3.0565	0	32.660	0.1074	2.7654	2.7286	0.4463	0.5694	0
Mobile IPv6 Traffic Sent (pkts/sec)	3.1972	0	87.94	0.1148	2.8969	3.0976	2.1981	2.6139	0
Mobile IPv6 Tunnelled Traffic Overhead (bits/sec)	11.41	729.48	54.81	1.481	6.91	14.10	263.11	127.85	454.81
Mobile IPv6 Tunnelled Traffic Received (pkts/sec)	0.0694	4.4620	0.336	0.00926	0.04321	0.0833	1.5907	0.3250	0.7713
Mobile IPv6 Tunnelled Traffic Sent (pkts/sec)	0.0713	4.5593	0.343	0.00926	0.04321	0.0881	1.6444	0.7991	2.8426

Value	Test 9.10	Test 9.11	Test 9.12	Test 9.13	Test 9.14	Test 9.15	Test 9.16	Test 9.17
Mobile IPv6 Overhead (bits/sec)	0	868.09	864.36	864.36	1,475.91	871.47	791.1	670.40
Mobile IPv6 Traffic Received (pkts/sec)	0	2.7639	3.0361	3.0361	5.340	2.9528	2.6231	2.3250
Mobile IPv6 Traffic Sent (pkts/sec)	0	3.2065	3.1648	3.1648	5.502	3.2056	2.7815	2.80
Mobile IPv6 Tunnelled Traffic Overhead (bits/sec)	0	11.11	11.70	11.70	11.70	12.15	78.96	119.56
Mobile IPv6 Tunnelled Traffic Received (pkts/sec)	0	0.0676	0.0713	0.0713	0.0713	0.0713	0.3898	0.6731
Mobile IPv6 Tunnelled Traffic Sent (pkts/sec)	0	0.0694	0.0731	0.0731	0.0731	0.0759	0.4935	0.7472

Table 18 – Scenario 9, Video Conferencing and Voice End-to-End Delay

Statistic	Video Conferencing Packet End-to-End Delay (sec)		
Scenario 9	**Average**	**Maximum**	**Minimum**
Test 9.1	0.1399	1.9568	0.0054
Test 9.2	0.2816	1.8558	0.1068
Test 9.3	2.709	14.347	0.084
Test 9.4	-	-	-
Test 9.5	0.1292	2.8436	0.0054
Test 9.6	0.1045	2.3144	0.0054
Test 9.7	0.17252	0.22182	0.10676
Test 9.8	2.125	80.152	0.005
Test 9.9	0.19027	0.20954	0.10676
Test 9.10	-	-	-
Test 9.11	0.0921	1.0243	0.0014
Test 9.12	0.1199	1.9859	0.0057
Test 9.13	Same as 9.12		
Test 9.14	0.1299	1.7806	0.0054
Test 9.15	0.1181	1.7767	0.0054
Test 9.16	0.1054	1.0098	0.0054
Test 9.17	0.10586	0.63557	0.00151

From the tables above it can be seen that the best results are from Test 9.17 where both MIPv6 Overhead and End-to-End delay are decreased. This is because beacon interval is smaller forcing the MNs and APs to communicate faster and in that way noticing any state condition changed as change of subnet area. Also during this scenario Mobility detection factor is smaller.

4.11 Results and Analysis for Scenario 10

In scenario 10 a different parameter from all the previous scenarios is tested. This parameter is the Random Roaming of the MNs. Some Mobility Domains are specified and the MNs move randomly inside them. Also a test is made comprising all the parameters that had the best results in the previous scenarios.

Table 19 – Scenario 10, MIPv6 Results

Value	Test 10.1	Test 10.2	Test 10.3	Test 10.4	Test 10.5	Test 10.6
Mobile IPv6 Overhead (bits/sec)	390.66	238.46	115.84	540.16	238.46	408.19
Mobile IPv6 Traffic Received (pkts/sec)	2.0253	1.2313	0.5427	2.1860	1.2313	2.1207
Mobile IPv6 Traffic Sent (pkts/sec)	2.0347	1.2420	0.6033	2.8133	1.2420	2.1260
Mobile IPv6 Tunnelled Traffic Overhead (bits/sec)	3.63	2.35	1.067	61.76	2.35	2.45
Mobile IPv6 Tunnelled Traffic Received (pkts/sec)	0.02267	0.01467	0.00667	0.3440	0.01467	0.01533
Mobile IPv6 Tunnelled Traffic Sent (pkts/sec)	0.02267	0.01467	0.00667	0.3860	0.01467	0.01533

Table 20 – Video Conferencing Packet End-to-End Delay

Statistic	Video Conferencing Packet End-to-End Delay (sec)		
	Average	**Maximum**	**Minimum**
Test 10.1	0.237	11.978	0.107
Test 10.2	0.10799	0.18465	0.10676
Test 10.3	0.321	20.573	0.107
Test 10.4	0.2160	9.3133	0.1032
Test 10.5	0.10799	0.18465	0.10676
Test 10.6	0.10797	0.12728	0.10676

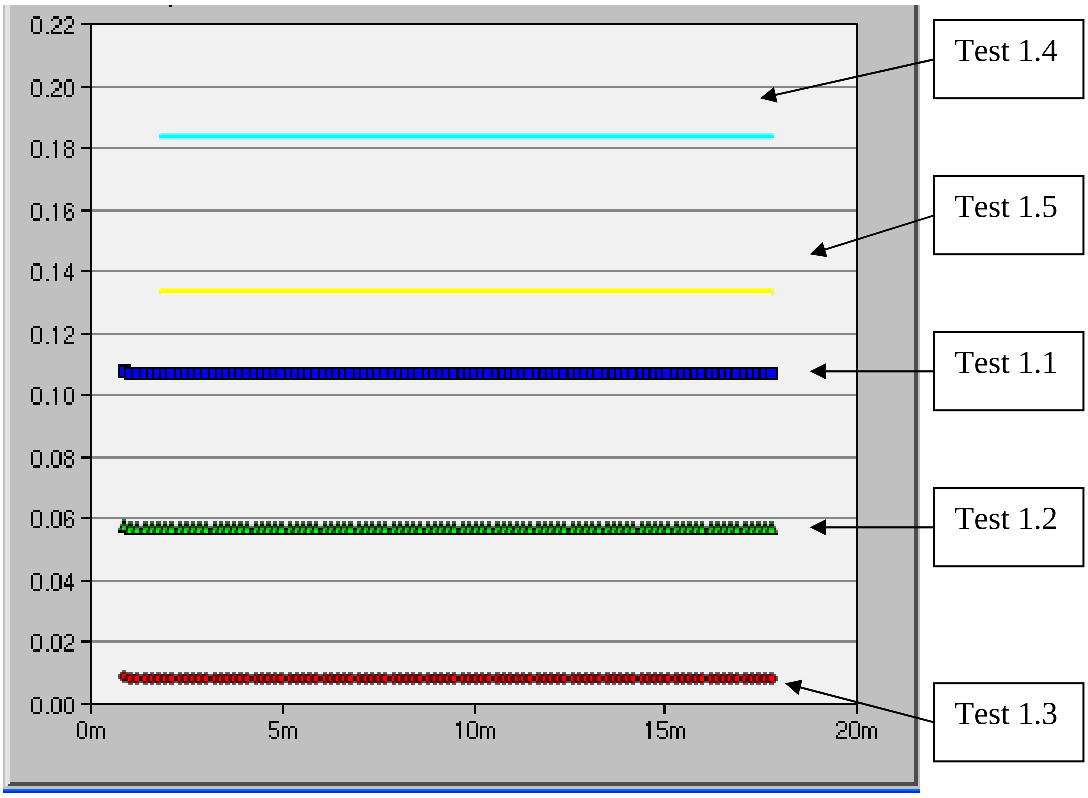
4.12 *Discussion of results and comparison with related work*

The main aspect of this thesis was the alteration of some parameters that I believe could influence the behavior of the components of a MIPv6 environment. Running ten different scenarios with various sub-scenarios helped in understanding MIPv6 characteristics as well as how these characteristics could influence the final outcome but also how they can be influenced by the changing of other parameters.

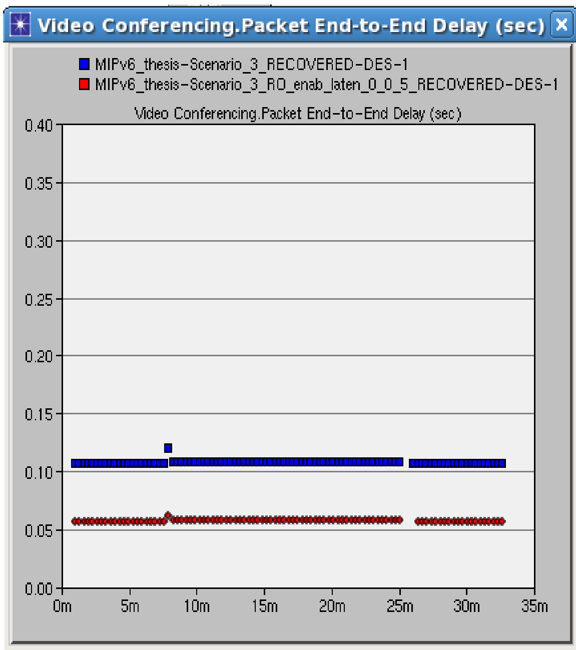
Core Network Latency

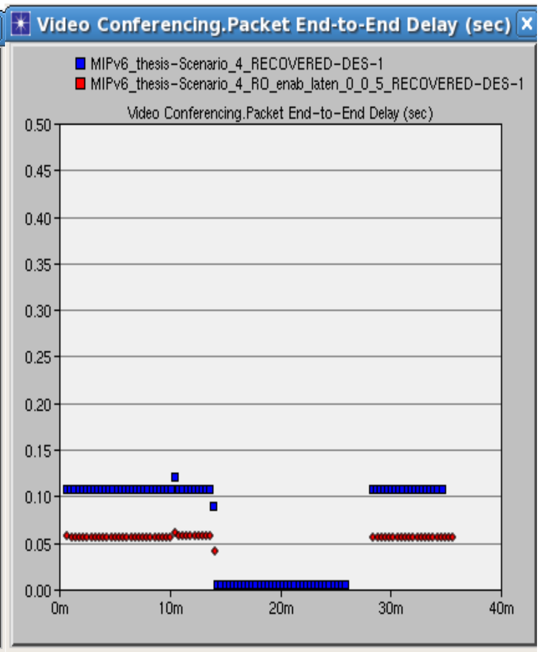
Analyzing the results it can be said that Core Network Latency which was a parameter under study can influence the performance of the MIPv6 environment. While latency decreases the application delay decreases too, leading to a better communication between the Mobile Nodes. This can be observed in all simulated scenarios with steady or moving conditions. The extracted information was after the correlation of results from nine different Tests (1.2, 1.3, 1.5, 2.2, 2.4, 3.2, 3.4, 4.2, 4.4).

The following graphs are an indication of the effect of Core network Latency.



Scenario 3.1 and 3.2 **Scenario 4.1 and 4.2**





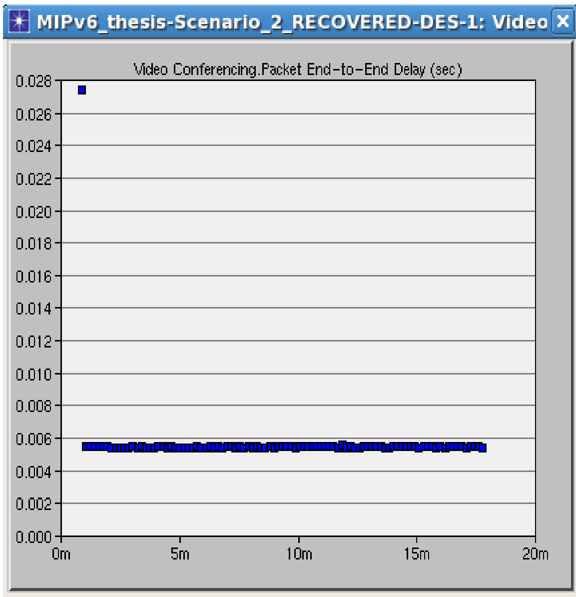
Route Optimization (RO)

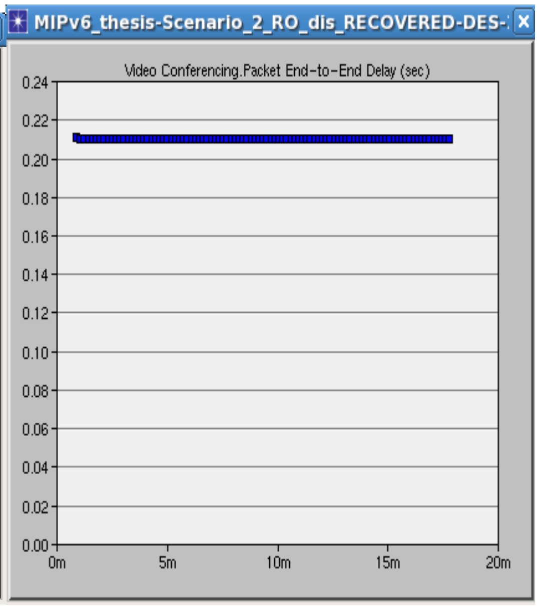
An important parameter that is highly influencing the performance of the MIPv6 protocol is the solution to the triangle routing and that is Route Optimization (RO). It allows direct routing from any correspondent node to any mobile node, without needing to pass through the mobile node's home network and be forwarded by its home agent, and thus eliminates the problem of "triangle routing". Route optimization eliminates the transmission delays associated with bidirectional tunneling and is needed to provide sufficient performance for time-sensitive traffic, such as Voice over IP (VoIP) [26]. It also ensures that the shortest communications path will be taken. The route optimization technique eliminates congestion at the mobile node's home agent and home link. It can be seen that during the performed scenarios where RO was disabled both delays and overhead were dramatically increased. Enabling the RO parameter while maintaining all the other parameters with the same value it can be seen that both delays and overhead decreased.

During the simulation for Route Optimisation a correlation of results from nine different Tests (2.3,2.4,2.6,3.3,3.4,3.6,4.3,4.4,9.2) was made.

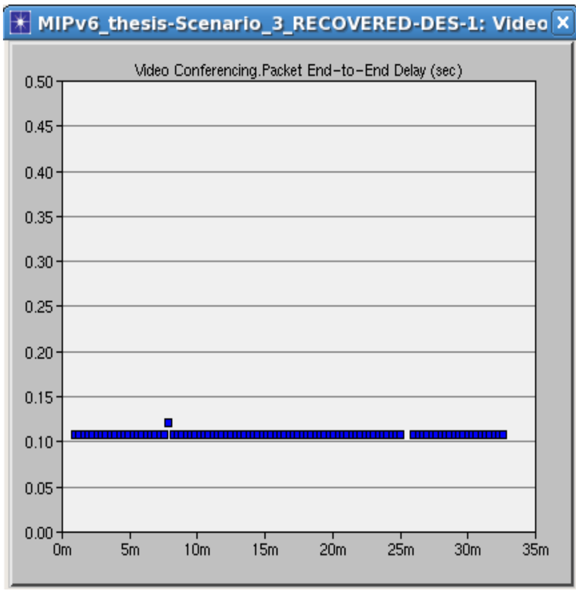
The following graphs are an indication of the effect of the route optimization.

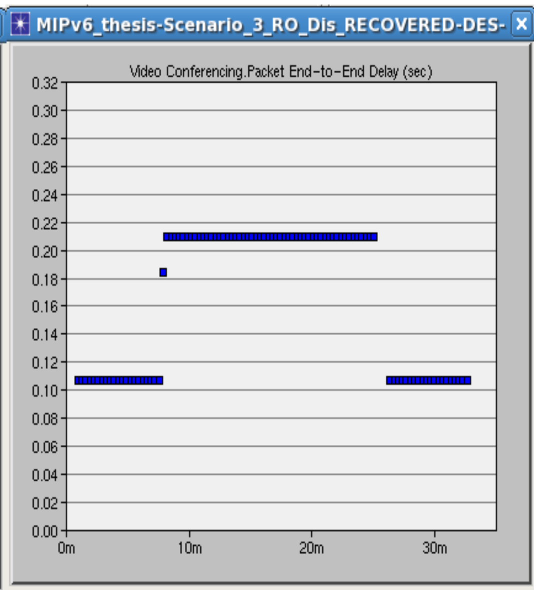
Test 2.1 – RO enabled **Test 2.3 – RO Disabled**



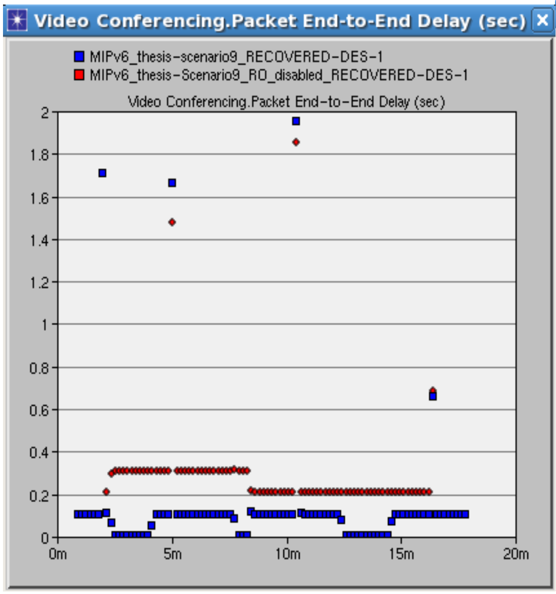


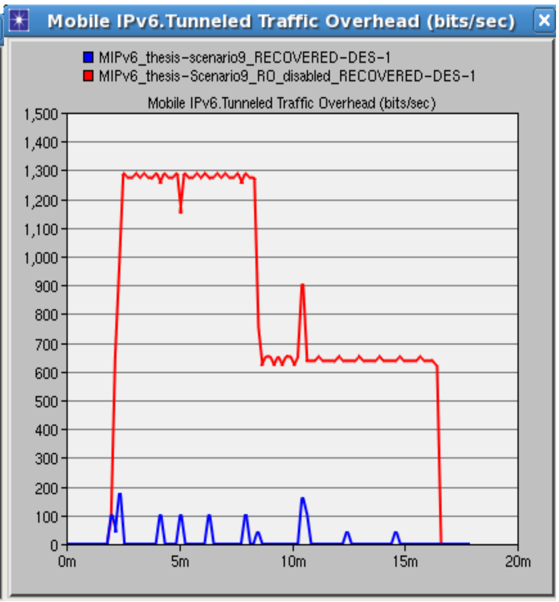
Test 3.1 – RO enabled **Test 3.3 – RO disabled**





Tests 9.1 and 9.2



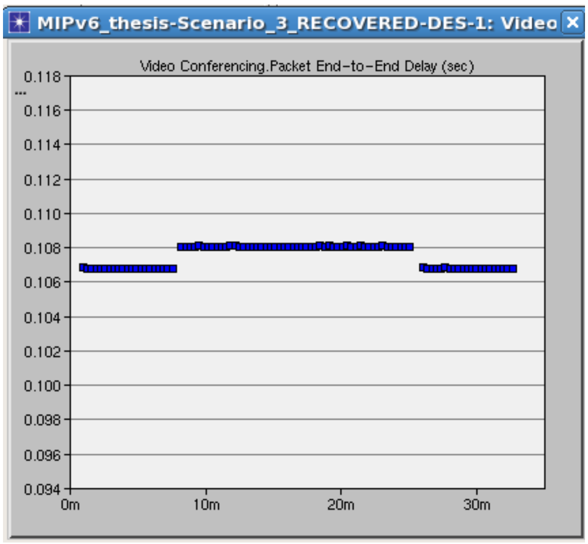


Network Applications

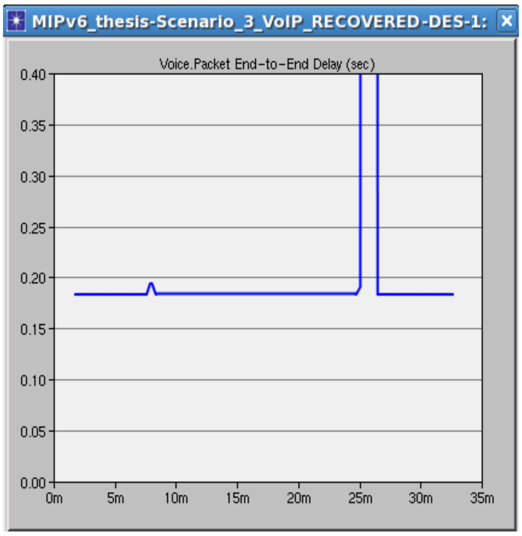
During the scenarios mainly two network applications were used for simulation purposes and those were the Voice Over IP (VoIP) and the Video Conferencing (VC). A third application which is File Transfer Protocol (FTP) was also tested but only in the scenario 9. From the results it can be concluded that VoIP has more overheads than the VC application. In all scenarios while keeping all the other parameters the same value while changing the VC to VoIP it can be seen that overhead and delays increased. This is also referred in [18].

The results for network applications were extracted from correlation of results from 13 different Tests (1.4,1.5,2.5,2.6,3.5,3.6,6.9,6.11,7.3,7.4,9.3,9.4,9.14). The following graphs are indicative for their behavior during simulation where VoIP has more overheads than the VC and application delay increases whenever the VoIP was included in the tests.

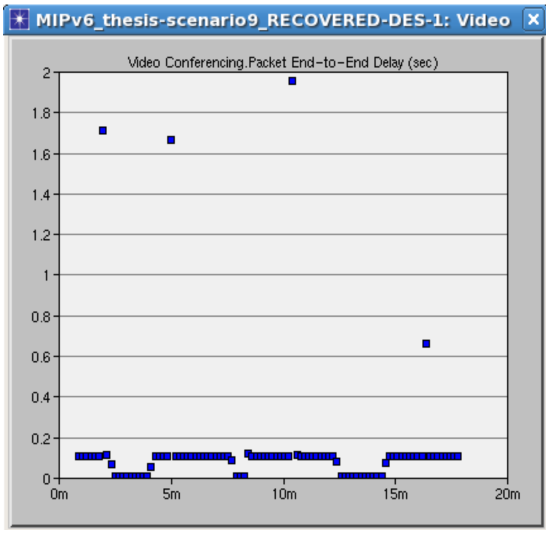
Test 3.1



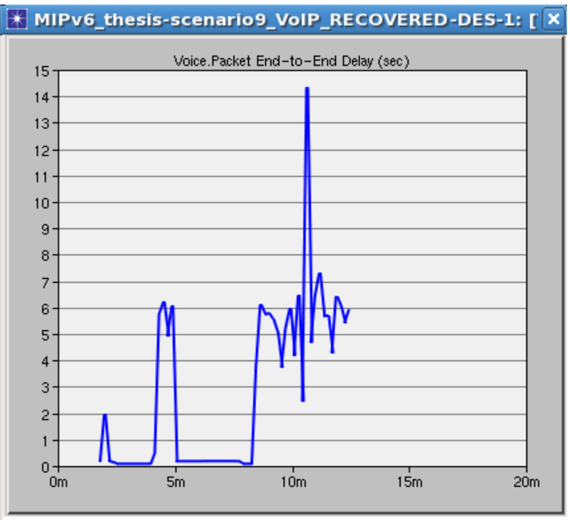
Test 3.5



Test 9.1



Test 9.3

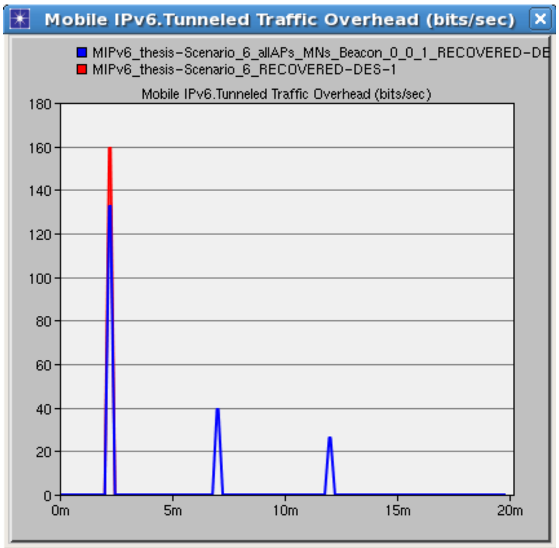


Beacon Interval

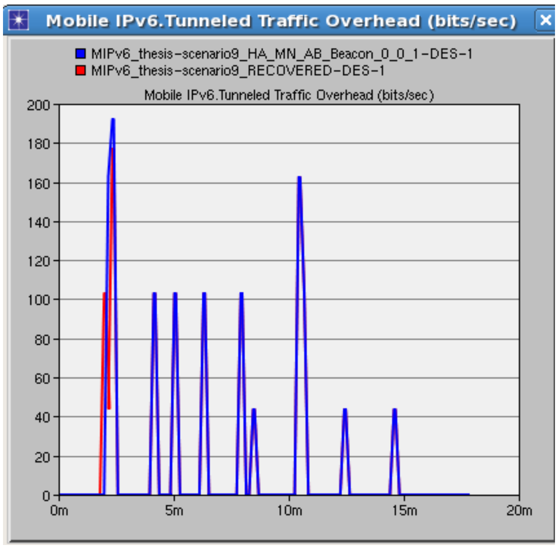
Beacon Interval which represents the amount of time between beacon transmissions is set to 0.02 as the default value. It can be seen from the results that minimising the beacon interval time to half minimises slightly application delay but at the same time increases slightly the MIPv6 overhead. Beacon is a method to perform Faster MIPv6 handovers as stated in [23] and [25]. It is also worth noting though that despite the improvement on MIPv6 performance due to beacon interval alteration as it stated in [4] MN will need more battery power.

The results about the beacon interval was the correlation from nine different Tests (6.2,6.3,6.4,6.5,6.6,9.12,9.13,9.17,10.4). The following graphs are indicating the effect of beacon interval in MIPv6 environment.

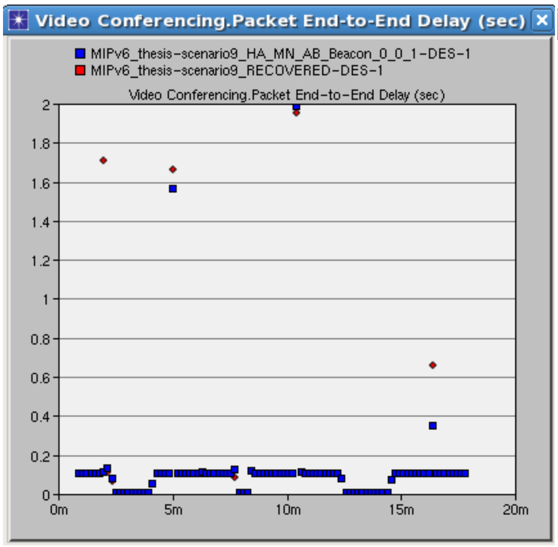
Tests 6.1 and 6.3



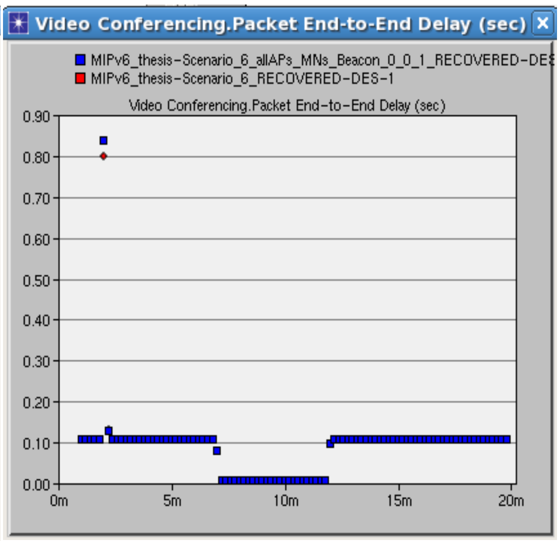
Tests 9.1 and 9.13



Test 9.1 and 9.13



Tests 6.1 and 6.3



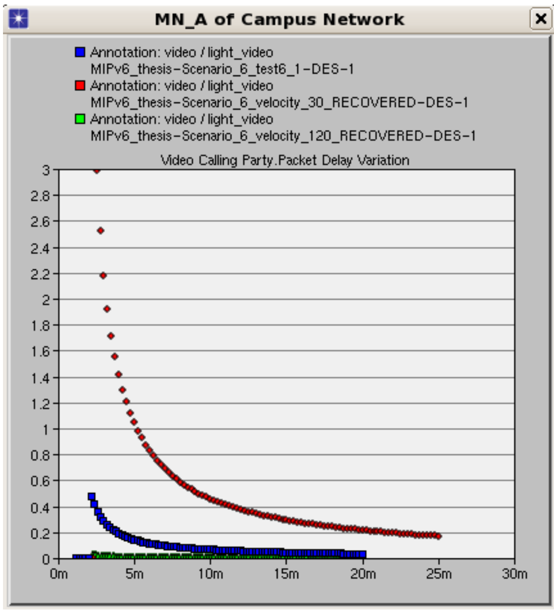
Ground Speed (velocity)

Ground speed (velocity) of MN was a parameter under investigation as in [21]. In the scenario 6 where only one MN was on the move it can be seen that when the ground speed of the MN was half of the default value we could monitor a decrease in MIPv6 overhead and in MIPv6 tunneled traffic. During the test where the ground speed of the

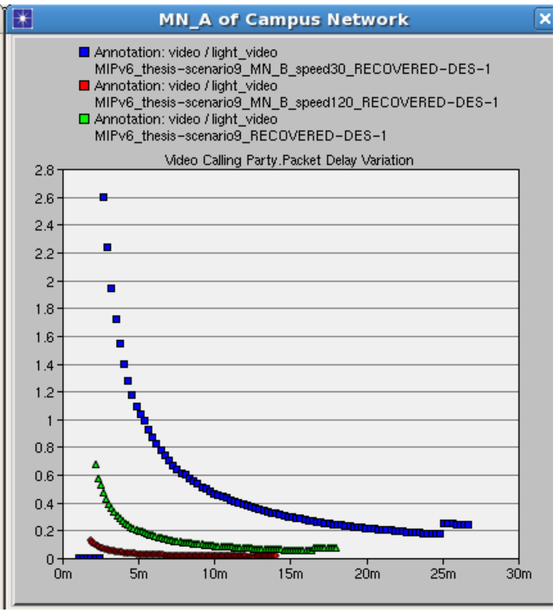
MN was twice the default value we can monitor the same results but now the decrement is less. At the same time in this test it can be observed that the MIPv6 traffic sent and received has been slightly deceased. It can also be seen that while ground speed of the MN is twice the default the application delay is slightly decreased. Analogous effects can be monitored when running the same tests in scenario 9 although there we have both MNs moving and an extra parameter is introduced which is the position of the MN_A which was stationary in scenario 6.

The following graph is an indication of the effects of the velocity alteration.

Scenario 6



Scenario 9



TCP Buffer Size

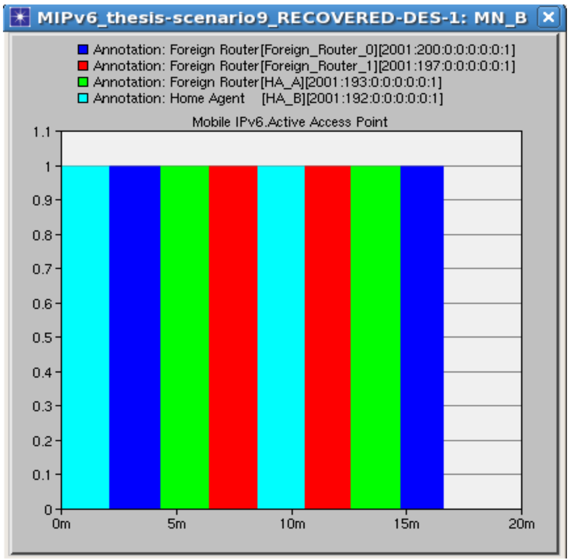
A parameter that did not have any effect on the results was the TCP Buffer Size no matter of what kind of application was running. The results in tables 13 and 14 are indicative of the above statement.

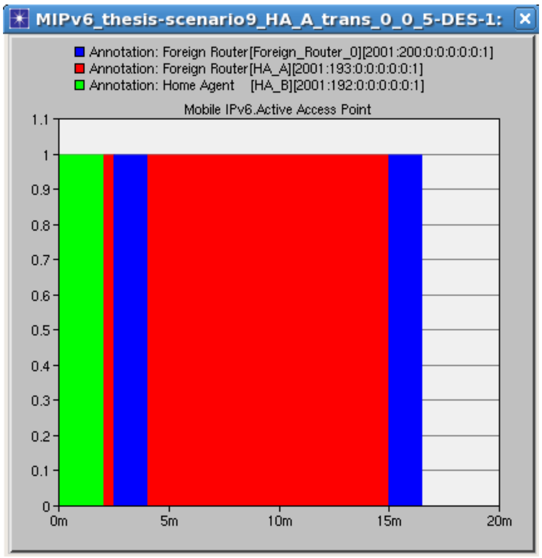
Transmit power

Wireless LAN transmit power was a parameter under test. When this parameter was increased for a specific Access Point (AP) then it could avoid the MN from performing an extra L3 handover leading to minimizing the application delay. This happens because after the increment in value the AP area becomes bigger. Increasing transmit power can lead to a faster association of the MN with the AP forcing for an earlier handover.

To get the results for this parameter it was necessary to correlate the results from nine different Tests (5.3,5.4,8.2,8.3,8.4,9.7,9.8,9.9,9.10). The graphs below is an indication of the transmit power behavior.

Test 9.1 **Test 9.7**



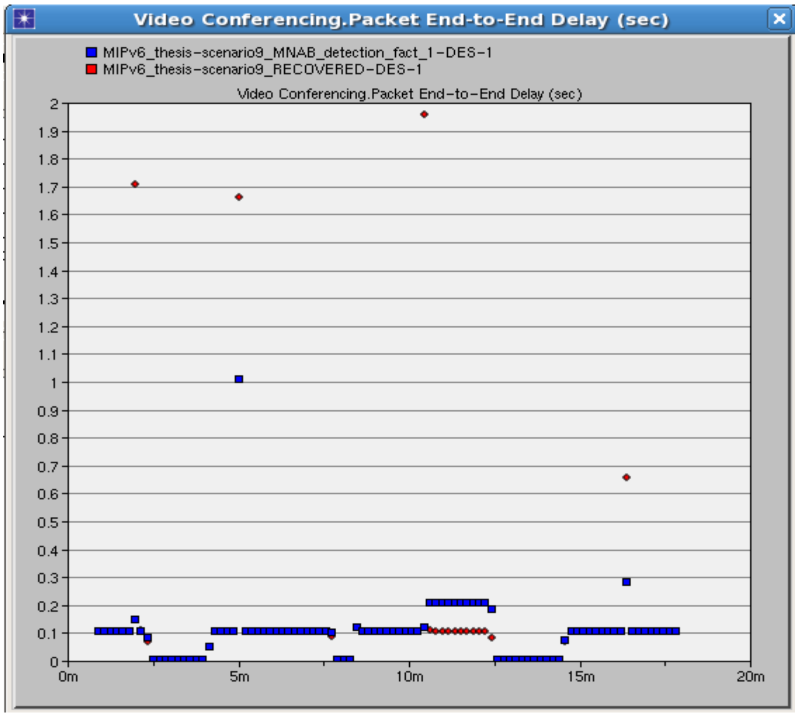


Mobility Detection Factor

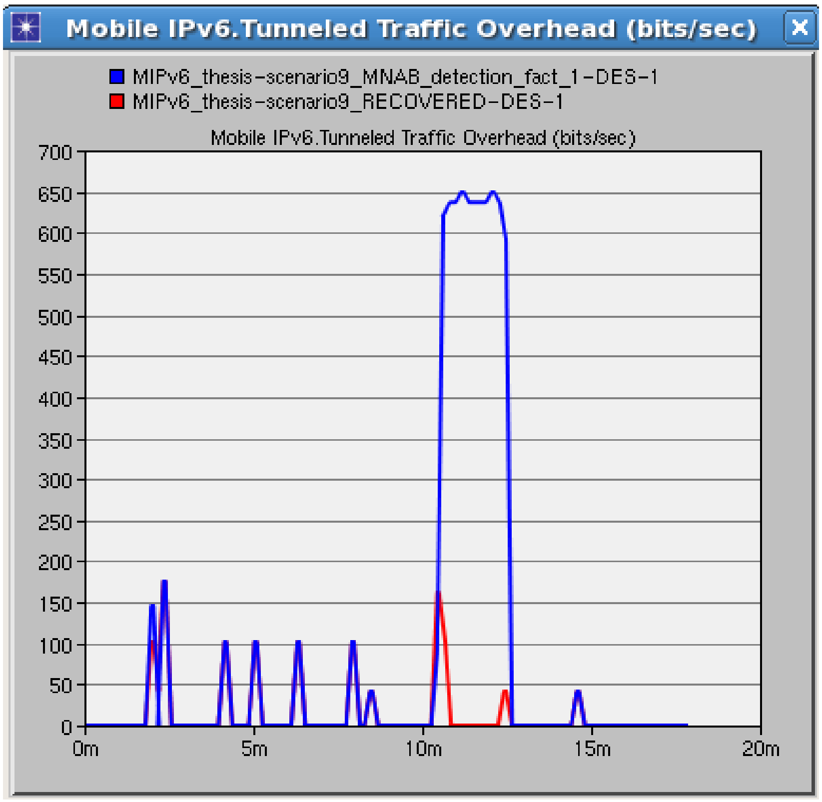
A parameter that is important for L3 handover is Mobility Detection Factor on MNs. Alteration of this to a smaller value has an effect on network application delay which becomes less but at the same time we can monitor a slight increase at the MIPv6 overhead traffic.

For the results from this parameter a correlation of results from ten different Tests (6.1,6.10,6.11,9.1,9.15,9.16,9.17,10.1, 10.3,10.4) was made. The graphs below are an indication of the results regarding the mobility detection factor parameter.

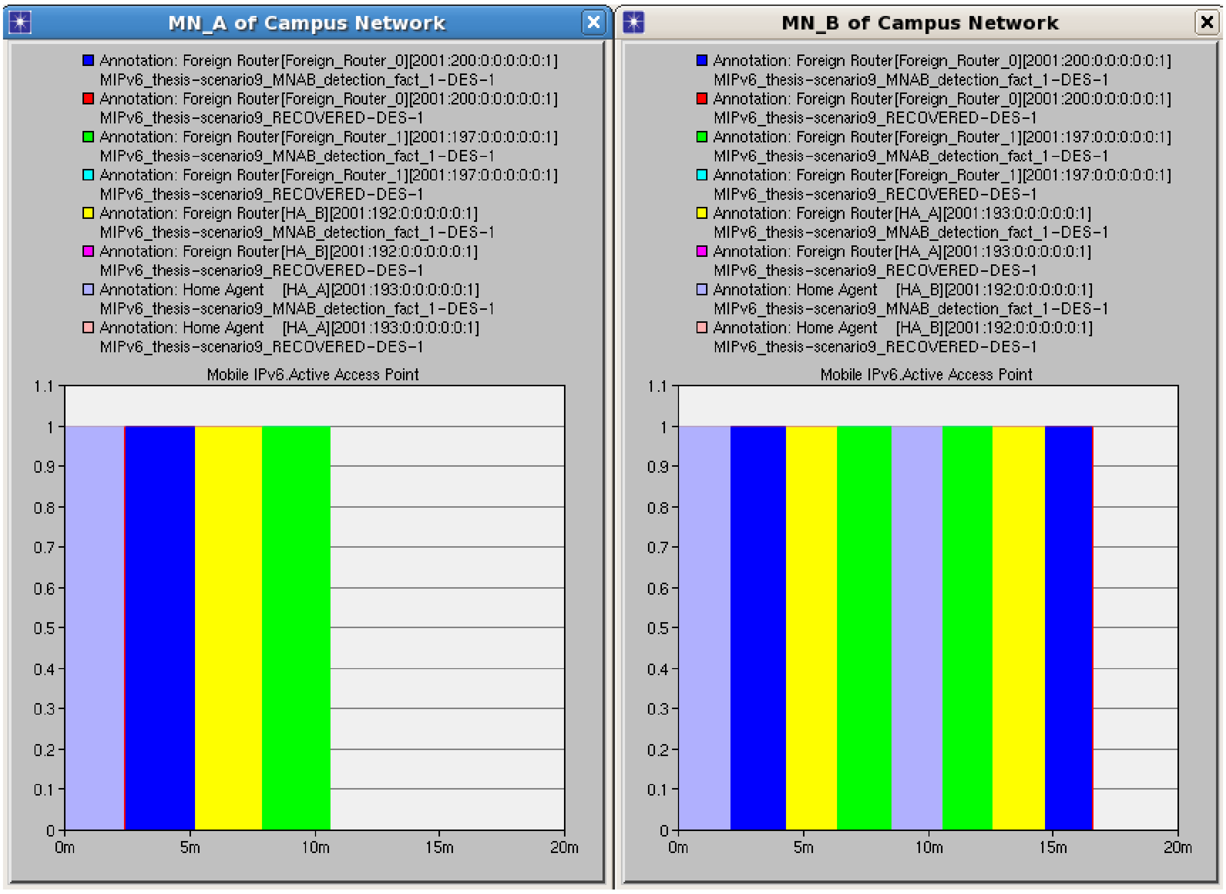
Tests 9.1 and 9.16



Tests 9.1 and 9.16



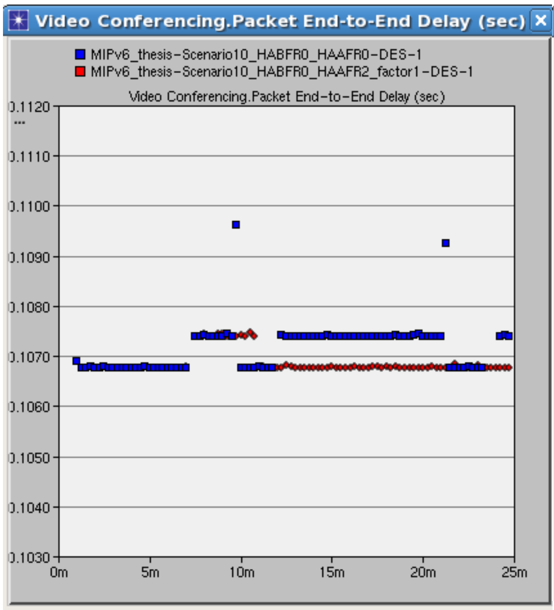
Tests 9.1 and 9.16

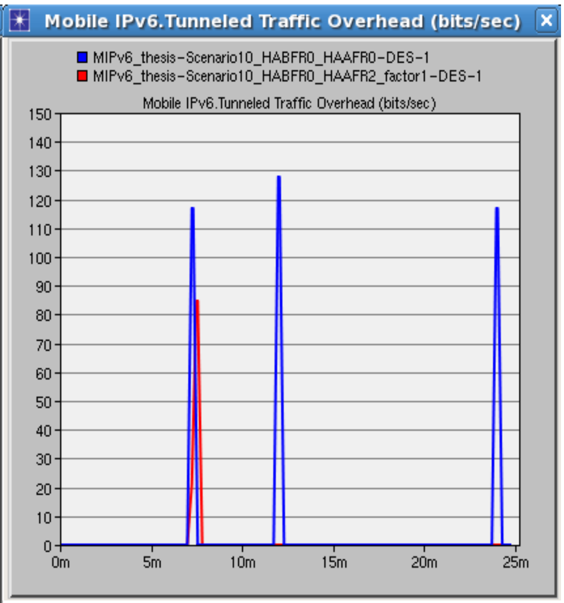


Random roaming

A situation is examined where MNs are not moving in a fixed trajectory but in random roaming. Comparison can be observed between scenarios 10.1 and 8.1 and between 10.2 and 7.1. In both cases it can be seen that MIPv6 Overhead is less when the scenarios are running in random roaming. On the other hand the MIPv6 Tunneled traffic is bigger in random roaming.

The graph below shows the results for overhead and delay from the random roaming scenario while mobility detection factor is 1sec and 10 sec.

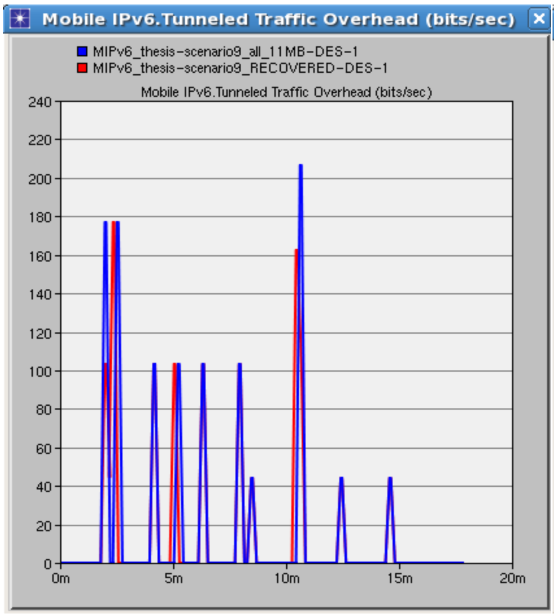


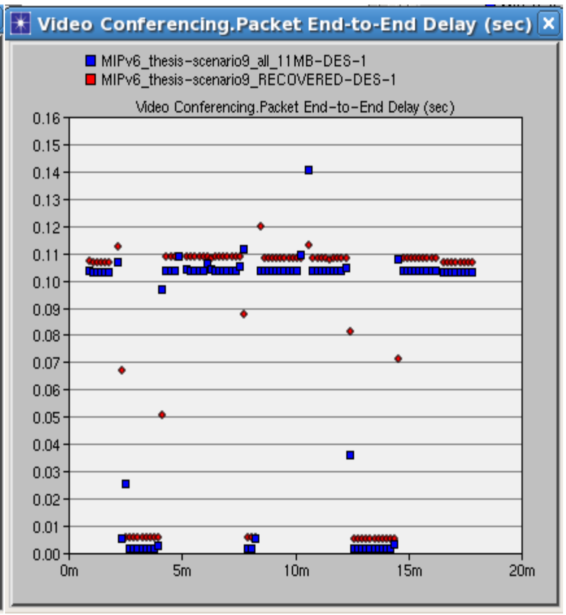


Data Rate

The results for the data rate was the Correlation of results from eight different Tests (5.1,5.2,5.4,9.1,9.11,9.17,10.1,10.4). It can be concluded that increasing the data rate the MIPv6 overheads (bits/sec) are minimized which can be seen in the graph below.

Scenario 9



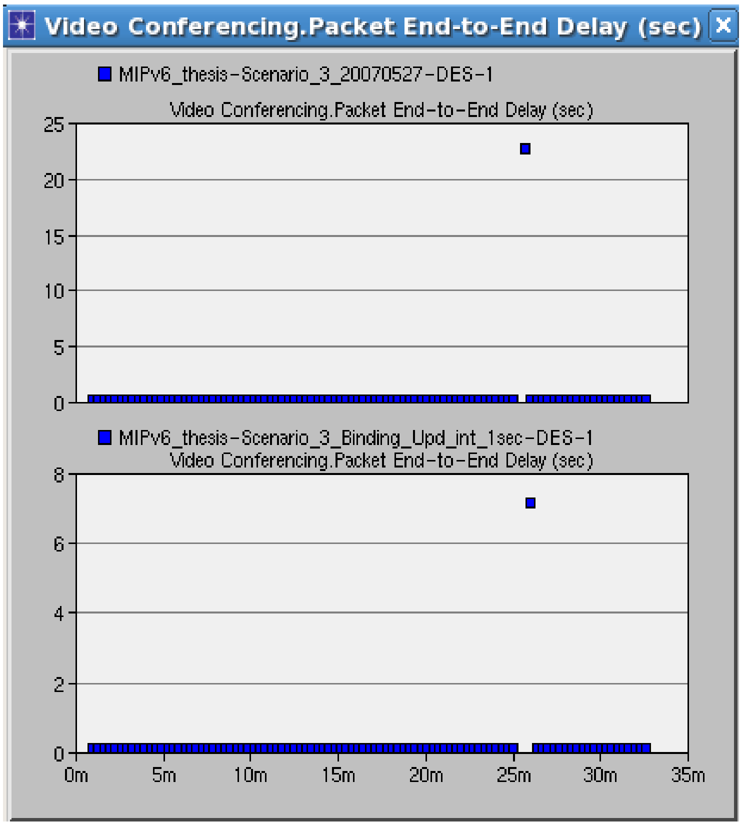


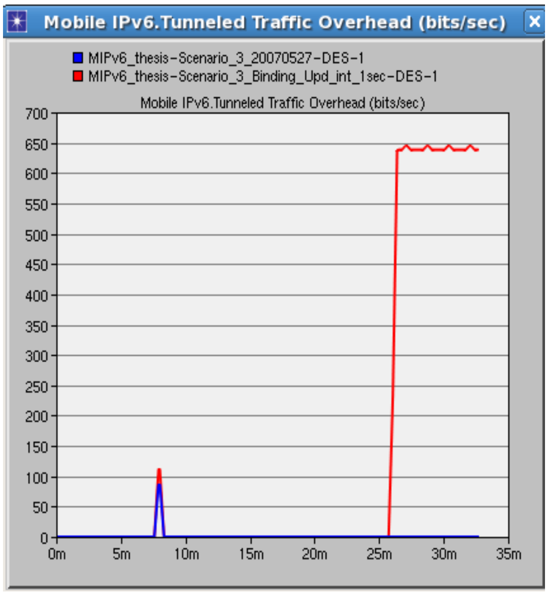
Binding Update Interval

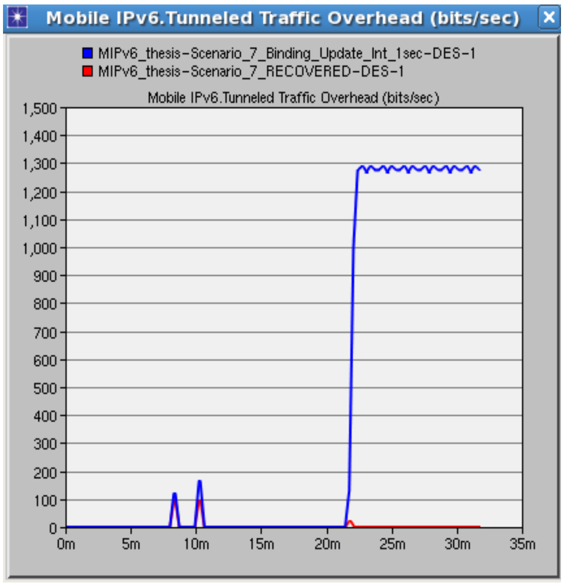
This is an important parameter for the MIPv6 performance. Correlating the results from eight different tests in scenarios 3,7,8 and 9 and altering the value of Binding Update interval on MNs to 1sec instead of the default which was 10sec it can be concluded that,

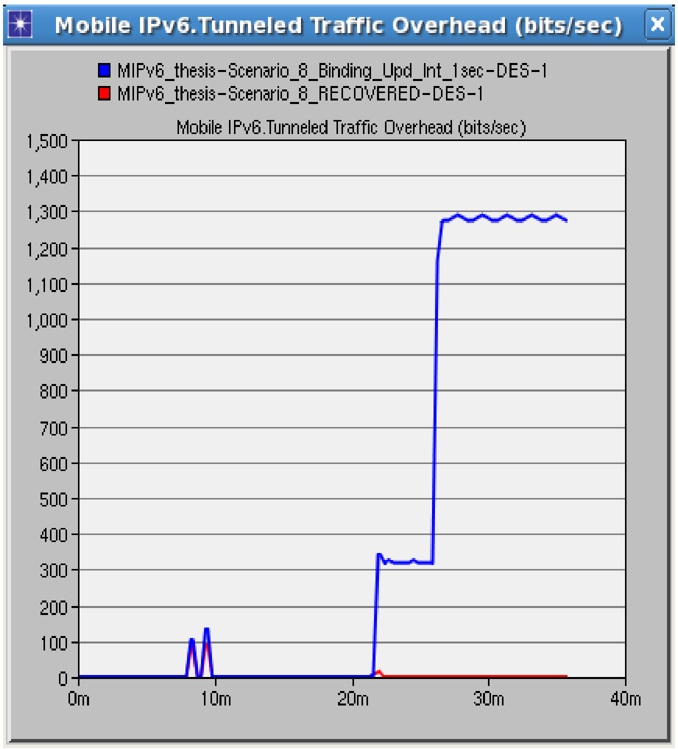
- There is a huge increase in MIPv6 tunneled overhead
- The Visited Access point graphs remain the same
- MN_B binding update list remain the same
- Decrease in application delay

The above can be seen in the graphs below,









Definitely what are influenced most during the movement of a mobile node are the network applications and especially multimedia services. During Mobility processes the Quality of Service of the network is decreasing leading to packet loss and packet delays. Real-time multimedia applications are sensitive to delays while bulk file transfer is sensitive to packet loss. The need to minimize the delays and losses is a critical task to be achieved. Some parameters combination in this thesis achieved the improvement of Quality of Service.

The packet loss [21] is the number of packets that are lost during the handover process. In general, in wireless and mobile networks packet loss is mostly caused by bit errors in an error-prone wireless channel, congestion in the network, or due to handover. The main reason for packet loss caused by handover is the fact that packets are routed to the old access point while the link to the old access point is already broken. These packets might be dropped by the old access point. The number of lost packets is an indicator for the service quality seen by the application. Real-time applications that realize a two-way communication require a small end-to-end delay, and therefore, can not retransmit lost packets. Other applications that require a certain degree of reliability retransmit packets. Retransmissions, in turn, increase the delay and jitter, and consume bandwidth. Additionally, flow control mechanisms triggered by loss reduce the transmission rate of the sender.

The duplication of packets has less impact on the application than packet loss. Usually, duplicated packets are dropped at the application layer. However, the number of duplication packets per handover is a measure for the amount of unnecessary usage of bandwidth, in particular of the wireless link.

After all these tests in this thesis it can be concluded that the best values to be used while setting up a wireless MIPv6 environment are the following,

1. Route optimization enabled /disabled = enabled
2. Core Network latency = as less as possible
3. Beacon Interval = 0.01secs
4. Wireless LAN data rate = 11Mbps if using 802.11b protocol
5. Mobile Node velocity = according to needs
6. Access Point transmit power = according to needs
7. TCP Buffer size = no influence
8. Mobility Detection Factor = 1
9. Random Roaming = according to needs
10. Network application (VoIP, VC, FTP) = according to needs
11. Binding update interval = 1sec

Chapter 5

5.1 Conclusion

The objective of this thesis was to investigate IPv6 roaming and mobility issues using the OPNET simulation tool. The Mobile IPv6 protocol is a proposed standard by the IETF to provide transparent host mobility within IPv6. The protocol enables a Mobile Node to move from one network to another without the need to change its IPv6 address. A Mobile Node is always addressable by its home address, which is the IPv6 address that is assigned to the node within its home network. When a Mobile Node is away from its home network, packets can still be routed to it using the node's home address. In this way, the movement of a node between networks is completely invisible to transport and other higher layer protocols. Mobile Nodes participating in the MIPv6 protocol each have a persistent home address, which can be used to address the Mobile Node irrespective of its current point of attachment to the IPv6 network.

For the purpose of this thesis I designed and evaluated the MIPv6 protocol and its mechanisms using simulation of ten different MIPv6 scenarios. For each scenario various tests were run in order to examine the behaviour of the protocol while altering various parameters. The results guide us in determining values of the various parameters, which can improve the performance of the MIPv6.

All the scenarios were carried out in a simulated wireless environment. During the simulations several IPv6 existing mechanisms were used in order to perform mobility operations like IPv6 neighbor discovery, IPv6 extension headers (mobility, routing and destination extension headers) and IPv6 address auto-configuration. Also the effects of triangle routing was examined by using Route Optimization since the communication between a mobile node and a correspondent node can be either Bi-directional tunneling or Route optimization.

According to the results from this thesis contribution can be claimed in the following way:

- OPNET is an accurate and helpful tool to be used for MIPv6 for WLAN networks. Future releases will include other protocols like HMIPv6 and FMIPv6.
- The only simulation effort I know that implemented and evaluated all these parameters alone or in combination.
- MIPv6 compliance to [42] especially with reverse tunneling and route optimization.
- The effects of Mobile Node movement in various MIPv6 environments were taken into account.
- L3 handover which was examined in different scenarios is an important process in MIPv6.
- Adjusting the values of the investigated parameters can improve the performance of the MIPv6 under specific situations.
- When two MNs are in the same subnet then the delay is less when compared to the case where the MNs are in different subnet.
- Every time that a MN is moving away from a subnet it has to perform handover process which increases MIPv6 overhead
- Specific parameter values like ground speed of MNs, APs date rate, Binding Update Interval and Mobility detection factor can improve the performance of the MIPv6.
- I have suggested the best values for the parameters under test in this thesis to be used while setting a wireless MIPv6 environment.

5.2 *Future work*

This thesis is only a very small contribution in the field of MIPv6 which is in my opinion one of the well promised near future popular topics that the research and commercial communities will have to experiment and work with. For that reason some recommendations for future work about MIPv6 are given below.

MIPv6 in Ad-Hoc Wireless Network (MANET)

The Ad-Hoc networks sometimes can be characterised as the future networks. Definitely is a challenge to work with the future protocol MIPv6 in a future network environment that is Ad-Hoc network. MANET is an improved IP-based networking technology for dynamic autonomous wireless networks which consist of mobile platforms and nodes. A future work could examine the characteristics of MIPV6 in MANET networks like autoconfiguration, Duplicate Address Detection, Neighbour and Router Discovery and security. OPNET tool support MANET.

Compare MIPv6 with other protocols like FMIPv6 and HMIPv6 [1]

Although MIPv6 is an improved protocol when compared to MIPv4 there are still many open issues that other proposed protocols try to solve. It will be a good thesis objective to compare the results between these three protocols and try to distinguish the differences among them identifying the advantages and disadvantages. For the moment OPNET does not support these protocols but I have placed a suggestion to OPNET support team and someone can follow it by using the number of suggestion SUG-82299.

Compare other proposed processes like ODAD process with the results from MIPv6 operation

ODAD which stands for Optimistic Duplicate Address Detection is a process which is used to improve the performance of MIPv6. Other processes have been also proposed and a future work could compare those and why not get to conclusions by proposing some new.

Practical Implementation and comparison with the simulated results.

The results from a simulated environment can always be helpful before the implementation phase. OPNET tool is a very reliable tool but implementing the MIPv6 protocol in real life is a challenge. A network set up with the necessary MIPv6 configuration is a future proposal where among others the simulated results can be verified.

Examine the effect on the MIPv6 performance when security is implemented using various methods of Mobile Node authentication.

Security is always an issue when dealing with networks. Especially when the discussion is about mobility where a user is away from its home network the security is a necessity for the mobile user but also for the visited network. For that reason a good thesis objective would be to investigate the authentication methods when using MIPv6 and the implications on performance. Early binding update process could be studied in combination to security.

Mobility in UMTS

As the next generation mobile networks are based on UMTS technology and as the next generation IP protocol is the IPv6 it is a must to examine the effects of MIPv6 on UMTS technology.

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APPENDICES

Appendix 1: Table of scenarios

The following table (**Table 21**) presents all the scenarios that were described earlier in Chapter 3. This table is useful and it should be used while reading the Chapters 3-6. Each column of the table has a specific value of the parameters that were under testing and were used in the different scenarios. Every scenario has the Default/Initial values unless it is stated differently in the column of the parameter that was altered.

For example in scenario 1 test 1.2 all the values are the default except the parameter 'Core Network Latency' that has the value of 0.05 secs.

Also the referred value for the parameter 'Random Roaming' indicates the area where the MNs move.

Table 21 –Values of Parameters Tested per scenario

Scenarios	**Parameters tested**									
	Core Network Packet Latency (secs)	**Beacon Interval (secs)**	**Route Optimization**	**Network Application Running on MNs**	**WLAN Transmit Power for APs & MNs (W)**	**MNs Ground Speed**	**WLAN Data Rate (Mbps)**	**TCP Buffer size (bytes)**	**MN Mobility Detection Factor**	**MNs Random Roaming**
Default/Initial Values	**0.1**	**0.02**	**Enabled**	**Video Conferencing**	**0.005**	**Variable according to scenario as indicated in Chapter 3**	**1**	**8760**	**3**	**Disabled**
Scenario 1										
Test 1.1										
Test 1.2	**0.05**									
Test 1.3	**0.001**									

Test 1.4				**VoIP**						
Test 1.5	**0.05**			**VC & VoIP**						
Scenario 2										
Test 2.1										
Test 2.2	**0.05**									
Test 2.3			**Disabled**							
Test 2.4	**0.05**		**Disabled**							
Test 2.5				**VC & VoIP**						
Test 2.6			**Disabled**	**VoIP**						
Scenario 3										
Test 3.1										
Test 3.2	**0.05**									
Test 3.3			**Disabled**							
Test 3.4	**0.05**		**Disabled**							
Test 3.5				**VoIP**						
Test 3.6			**Disabled**	**VoIP**						
Scenario 4										
Test 4.1										
Test 4.2	**0.05**									
Test 4.3			**Disabled**							
Test 4.4	**0.05**		**Disabled**							
Scenario 5										
Test 5.1										
Test 5.2							**11MB**			
Test 5.3					**HA_A = 0.05**					
Test 5.4					**FR_0 = 0.05**		**1MB**			
Scenario 6										

Test 6.1										
Test 6.2		**FR0_Beacon_interval = 0.01**								
Test 6.3		**All APs & MNs = 0.01**								
Test 6.4		**FR0 & FR1 Beacon interval = 0.01**								
Test 6.5		**FR1 Beacon Interval = 0.01**								
Test 6.6		**HA_A Beacon interval = 0.01**								
Test 6.7						**MN_B Velocity= 30**				
Test 6.8						**MN_B Velocity= 120**				
Test 6.9				**VoIP**						
Test 6.10									**MNB = 1**	
Test 6.11				**VoIP**					**MNB = 1**	
Scenario 7										
Test 7.1										
Test 7.2								**32768**		
Test 7.3				**VoIP**						
Test 7.4				**VoIP**				**32768**		
Scenario 8										
Test 8.1										
Test 8.2					**FR_0 = 0.05**					

Test 8.3					HA_A = 0.05					
Test 8.4					HA_B = 0.05					
Scenario 9										
Test 9.1										
Test 9.2			Disabled							
Test 9.3				VoIP						
Test 9.4				FTP						
Test 9.5						MN_B Velocity= 30				
Test 9.6						MN_B Velocity= 120				
Test 9.7					HA_A = 0.05					
Test 9.8					HA_B = 0.05					
Test 9.9					HA_A & HA_B = 0.05					
Test 9.10					FR0 = 0.05					
Test 9.11							All are 11MB			
Test 9.12		HA_AB = 0.01								
Test 9.13		All HAs&MNs = 0.01								
Test 9.14				VoIP & VC						
Test 9.15									MNB=1	
Test 9.16									MNA & MNB=1	
Test 9.17		All are 0.01					All 11MB		MNA & MNB=1	
Scenario 10										
Test 10.1										HABFR0 – HAAFR0

Test 10.2										**HABFR0 – HAAFR1**
Test 10.3									**MNA&M NB=1**	**HABFR0 – HAAFR1**
Test 10.4		**All 0.01**					**All 11MB**		**MNA&M NB=1**	**HABFR0 – HAAFR1**
Test 10.5										**HABFR1 – HAAFR0**
Test 10.6										**HABFR1 – HAAFR1**

Appendix 2 – Tables of results

Scenario 1

	Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size	Video Called Party Packet Delay Variation	Video Called Party Traffic Received (bytes/sec)	Video Called Party Traffic Sent (bytes/sec)	Video Calling Party Packet Delay Variation	Video Calling Party Traffic Received (bytes/sec)	Video Calling Party Traffic Sent (bytes/sec)
Test 1.1	MN_A	1						0.0000000382	324.89	324.89
	MN_B	1			0.0000000443 < MN_A->MN_B (video/light_video)>	324.89 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>			
Test 1.2	MN_A	1						0.0000001135	324.89	324.89
	MN_B	1			0.0000000104 < MN_A->MN_B (video/light_video)>	324.89 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>			
Test 1.3	MN_A	1						0.0000001733	324.89	324.89
	MN_B	1			0.0000002101 < MN_A->MN_B (video/light_video)>	324.89 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>			
Test 1.5										

Test 1.4

Statistic	Average	Maximum	Minimum
Voice Packet Delay Variation	0.0000000066	0.0000001748	0.0000000038
Voice Packet End-to-End Delay (sec)	0.18341	0.18342	0.18341
Voice Traffic Received (bytes/sec)	2,960.50	3,300.00	0.00
Voice Traffic Sent (bytes/sec)	2,960.81	3,300.00	0.00

Test 1.5

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size	Video Called Party Packet Delay Variation	Video Called Party Traffic Received (bytes/sec)	Video Called Party Traffic Sent (bytes/sec)	Video Calling Party Packet Delay Variation	Video Calling Party Traffic Received (bytes/sec)	Video Calling Party Traffic Sent (bytes/sec)
MN_A	1.00	-	-	-	-	-	0.0000001529	324.89	324.89
MN_B	1.00	-	-	0.0000000056 < MN_A->MN_B (video/light_video)>	324.89 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-

Statistic	Average	Maximum	Minimum
Voice Packet Delay Variation	0.0000000955	0.0000001207	0.0000000940
Voice Packet End-to-End Delay (sec)	0.13347	0.13348	0.13346
Voice Traffic Received (bytes/sec)	2,956.78	3,300.00	0.00
Voice Traffic Sent (bytes/sec)	2,956.96	3,300.00	0.00

Node	Voice Application Packet End-to-End Delay (sec)	Voice Application Traffic Received (bytes/sec)	Voice Application Traffic Sent (bytes/sec)
MN_A	0.13344	1,478.46	1,478.41
MN_B	0.13350	1,478.32	1,478.55

Scenario 2

	Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size	Video Called Party Packet Delay Variation	Video Called Party Traffic Received (bytes/sec)	Video Called Party Traffic Sent (bytes/sec)	Video Calling Party Packet Delay Variation	Video Calling Party Traffic Received (bytes/sec)	Video Calling Party Traffic Sent (bytes/sec)
Test 2.1	HA_B	-	1.0	-	-	-	-	-	-	-
	MN_A	1.0	1.0	-				0.00014073	324.89	324.89
	MN_B	- 1.00 - 0.00221	-	1.9463	0.00013636 < MN_A->MN_B (video/light_video)>	324.57 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-
Test 2.2	HA_B	-	1.00	-	-	-	-	-	-	-
	MN_A	1.00	1.00	-	-	-	-	0.071300	324.89	324.57
	MN_B	- 1.00 - 0.00242	-	1.9464	0.000073867 < MN_A->MN_B (video/light_video)>	324.89 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-
Test 2.3	HA_B	-	1.00	-	-	-	-	-	-	-
	MN_A	1.00	-	-	-	-	-	0.0000000783	324.89	324.89
	MN_B	- 1.00 - 0.0022221	-	1.00	0.000000049 < MN_A->MN_B (video/light_video)>	324.73 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-
Test 2.4	HA_B	-	1.00	-	-	-	-	-	-	-
	MN_A	- 1.00	-	-	-	-	-	0.0000000899	324.89	324.89
	MN_B	- 1.00 - 0.00221	-	1.00	0.00000004 < MN_A->MN_B (video/light_video)>	324.89 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-
Test 2.5	HA_B	-	1.00	-	-	-	-	-	-	-

	MN_A	- 1.00	1.00	-	-	-	-	0.00014282	324.89	324.89
	MN_B	- 1.00 - 0.00249	-	1.9466	0.00013634 < MN_A->MN_B (video/light_video)>	324.89 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-

Test 2.5

Statistic	Average	Maximum	Minimum
Voice Packet Delay Variation	0.0000006406	0.0000006929	0.0000005027
Voice Packet End-to-End Delay (sec)	0.083527	0.083548	0.083509
Voice Traffic Received (bytes/sec)	2,951.67	3,300.00	0.00
Voice Traffic Sent (bytes/sec)	2,951.67	3,300.00	0.00

Node	Voice Application Packet End-to-End Delay (sec)	Voice Application Traffic Received (bytes/sec)	Voice Application Traffic Sent (bytes/sec)
MN_A	0.083560	1,475.86	1,475.81
MN_B	0.083494	1,475.81	1,475.86

Test 2.6

Statistic	Average	Maximum	Minimum
Voice Packet Delay Variation	0.0000000108	0.0000003052	0.0000000065
Voice Packet End-to-End Delay (sec)	0.28486	0.28487	0.28485
Voice Traffic Received (bytes/sec)	2,949.78	3,300.00	0.00
Voice Traffic Sent (bytes/sec)	2,950.42	3,300.00	0.00

Node	Voice Application Packet End-to-End Delay (sec)	Voice Application Traffic Received (bytes/sec)	Voice Application Traffic Sent (bytes/sec)
MN_A	0.28487	1,475.07	1,475.02
MN_B	0.28485	1,474.71	1,475.40

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size
HA_B	-	1.00	-
MN_A	1.00000	-	-
MN_B	• 1.00000 • 0.00221	-	1.00

Scenario 3

	Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size	Video Called Party Packet Delay Variation	Video Called Party Traffic Received (bytes/sec)	Video Called Party Traffic Sent (bytes/sec)	Video Calling Party Packet Delay Variation	Video Calling Party Traffic Received (bytes/sec)	Video Calling Party Traffic Sent (bytes/sec)
Test 3.1	HA_B	-	0.73071	-	-	-	-	-	-	-
	MN_A	1.0	0.73132	-	-	-	-	0.67798	324.53	333.58
	MN_B	- 0.73073 - 0.44588	-	1.4620	0.000017280 < MN_A->MN_B (video/light_video)>	322.98 < MN_A->MN_B (video/light_video)>	333.61 < MN_A->MN_B (video/light_video)>	-	-	-
Test 3.2	HA_B	-	0.73050	-	-	-	-	-	-	-
	MN_A	1.0	0.73102	-	-	-	-	0.84012	324.80	333.58
	MN_B	- 0.73037 - 0.44695	-	1.4612	0.0000037289< MN_A->MN_B (video/light_video)>	323.41 < MN_A->MN_B (video/light_video)>	333.61 < MN_A->MN_B (video/light_video)>	-	-	-
Test 3.3	HA_B	-	0.73041	-	-	-	-	-	-	-
	MN_A	1.0	-	-	-	-	-	0.67787	324.72	333.58
	MN_B	- 0.73042 - 0.44720	-	0.73121	0.0018193 < MN_A->MN_B (video/light_video)>	323.33 < MN_A->MN_B (video/light_video)>	333.61 < MN_A->MN_B (video/light_video)>	-	-	-
Test 3.4	HA_B	-	0.73077	-	-	-	-	-	-	-
	MN_A	1.0	-	-	-	-	-	0.83977	324.72	333.58
	MN_B	- 0.73077 - 0.447664	-	0.73130	0.00047974 < MN_A->MN_B (video/light_video)>	323.50 < MN_A->MN_B (video/light_video)>	333.61 < MN_A->MN_B (video/light_video)>	-	-	-

Test 3.5

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size
HA_B	-	0.73001	-
MN_A	1.00000	0.73057	-
MN_B	• 0.73003 • 0.44743	-	1.4606

Statistic	Average	Maximum	Minimum
Voice Packet Delay Variation	0.4051	2.3168	0.0000
Voice Packet End-to-End Delay (sec)	0.504	15.926	0.183
Voice Traffic Received (bytes/sec)	3,036.75	3,300.00	0.00
Voice Traffic Sent (bytes/sec)	3,114.99	3,300.00	0.00

Node	Voice Application Packet End-to-End Delay (sec)	Voice Application Traffic Received (bytes/sec)	Voice Application Traffic Sent (bytes/sec)
MN_A	0.63004	1,522.80	1,557.44
MN_B	0.35705	1,513.95	1,557.55

Test 3.6

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size
HA_B	-	0.73028	-
MN_A	1.00000	-	-
MN_B	• 0.73030 • 0.44722	-	0.73099

Statistic	Average	Maximum	Minimum
Voice Packet Delay Variation	0.6155	3.4119	0.0000
Voice Packet End-to-End Delay (sec)	0.511	16.394	0.183
Voice Traffic Received (bytes/sec)	3,030.20	3,300.00	0.00
Voice Traffic Sent (bytes/sec)	3,114.99	3,300.00	0.00

Node	Voice Application Packet End-to-End Delay (sec)	Voice Application Traffic Received (bytes/sec)	Voice Application Traffic Sent (bytes/sec)
MN_A	0.61711	1,519.65	1,557.44
MN_B	0.38253	1,510.55	1,557.55

Scenario 4

	Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size	Video Called Party Packet Delay Variation	Video Called Party Traffic Received (bytes/sec)	Video Called Party Traffic Sent (bytes/sec)	Video Calling Party Packet Delay Variation	Video Calling Party Traffic Received (bytes/sec)	Video Calling Party Traffic Sent (bytes/sec)
Test 4.1	HA_B	-	0.72525	-	-	-	-	-	-	-
	MN_A	1.0	0.72587	-	-	-	-	0.53230	312.38	334.17
	MN_B	- 0.67770 - 0.49605 - 0.14759	-	1.4512	0.0013533 < MN_A->MN_B (video/light_video)>	310.34 < MN_A->MN_B (video/light_video)>	334.20 < MN_A->MN_B (video/light_video)>	-	-	-
Test 4.2	HA_B	-	0.72505	-	-	-	-	-	-	-
	MN_A	1.0	0.72572	-	-	-	-	0.53226	312.47	334.17
	MN_B	- 0.67733 - 0.49614 - 0.14792	-	1.4509	0.00034715 < MN_A->MN_B (video/light_video)>	310.34 < MN_A->MN_B (video/light_video)>	334.20 < MN_A->MN_B (video/light_video)>	-	-	-
Test 4.3	HA_B	-	0.69653	-	-	-	-	-	-	-
	MN_A	1.0	-	-	-	-	-	0.53138	312.47	334.17
	MN_B	- 0.64657 - 0.51032 - 0.14142	-	0.69726	0.00117182 < MN_A->MN_B (video/light_video)>	311.50 < MN_A->MN_B (video/light_video)>	334.47 < MN_A->MN_B (video/light_video)>	-	-	-
Test 4.4	HA_B	-	0.69646	-	-	-	-	-	-	-
	MN_A	1.0	-	-	-	-	-	6.8673	313.42	334.44
	MN_B	- 0.64035 - 0.51027 - 0.14172	-	0.69732	0.00045300 < MN_A->MN_B (video/light_video)>	311.75 < MN_A->MN_B (video/light_video)>	334.47 < MN_A->MN_B (video/light_video)>	-	-	-

Scenario 5

	Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size	Video Called Party Packet Delay Variation	Video Called Party Traffic Received (bytes/sec)	Video Called Party Traffic Sent (bytes/sec)	Video Calling Party Packet Delay Variation	Video Calling Party Traffic Received (bytes/sec)	Video Calling Party Traffic Sent (bytes/sec)
Test 5.1	HA_B	-	0.83399	-	-	-	-	-	-	-
	MN_A	1.0	0.83446	-	-	-	-	0.08066	331.79	337.12
	MN_B	- 0.58597 - 0.41515 - 0.28263	-	1.6683	0.0007094 < MN_A->MN_B (video/light_video)>	329.55 < MN_A->MN_B (video/light_video)>	337.14 < MN_A->MN_B (video/light_video)>	-	-	-
Test 5.2	HA_B	-	0.83366	-	-	-	-	-	-	-
	MN_A	1.0	0.72252	-	-	-	-	0.20517	316.54	337.12
	MN_B	- 0.58647 - 0.41343 - 0.28371	-	1.6678	0.0042136 < MN_A->MN_B (video/light_video)>	317.91 < MN_A->MN_B (video/light_video)>	337.14 < MN_A->MN_B (video/light_video)>	-	-	-
Test 5.3	HA_B	-	1.00	-	-	-	-	-	-	-
	MN_A	1.0	1.00	-	-	-	-	0.0015038	172.40	337.12
	MN_B	- 0.85143 - 0.18705 - 0.13969	-	1.7901	0.0013187 < MN_A->MN_B (video/light_video)>	274.28 < MN_A->MN_B (video/light_video)>	337.14 < MN_A->MN_B (video/light_video)>	-	-	-

Test 5.4

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size	Video Calling Party Packet Delay Variation	Video Calling Party Traffic Received (bytes/sec)	Video Calling Party Traffic Sent (bytes/sec)
HA_B	-	1.00	-	-	-	-
MN_A	1.00000	-	-	-	0.00	0.00
MN_B	• 1.00000 • 0.14036	-	1.00	-	-	-

Scenario 6

Test 6.1

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size	Video Called Party Packet Delay Variation	Video Called Party Traffic Received (bytes/sec)	Video Called Party Traffic Sent (bytes/sec)	Video Calling Party Packet Delay Variation	Video Calling Party Traffic Received (bytes/sec)	Video Calling Party Traffic Sent (bytes/sec)
HA_B	-	0.84032	-	-	-	-	-	-	-
MN_A	1.00000	0.84139	-	-	-	-	0.087679	325.37	326.80
MN_B	• 0.64211 • 0.38329 • 0.27658 • 0.25362	-	1.6814	0.0015658 < MN_A->MN_B (video/light_video)>	320.21 < MN_A->MN_B (video/light_video)>	326.85 < MN_A->MN_B (video/light_video)>	-	-	-

Test 6.2

HA_B	-	0.84171	-	-	-	-	-	-	-
MN_A	1.00000	0.84275	-	-	-	-	0.0015290	326.80	326.80
MN_B	• 0.64339 • 0.38423 • 0.27922 • 0.24890	-	1.6842	0.0015582 < MN_A->MN_B (video/light_video)>	321.64 < MN_A->MN_B (video/light_video)>	326.85 < MN_A->MN_B (video/light_video)>	-	-	-

Test 6.3

HA_B	-	0.84032	-	-	-	-	-	-	-
MN_A	1.00000	0.84149	-	-	-	-	0.086144	325.94	326.80
MN_B	• 0.64117 • 0.38379 • 0.27792 • 0.25174	-	1.6815	0.0015467 < MN_A->MN_B (video/light_video)>	321.35 < MN_A->MN_B (video/light_video)>	326.85 < MN_A->MN_B (video/light_video)>	-	-	-

Test 6.4

HA_B	-	0.84158	-	-	-	-	-	-	-
MN_A	1.00000	0.84291	-	-	-	-	0.0015585	326.80	326.80
MN_B	• 0.64273 • 0.38442 • 0.27973 • 0.24858	-	1.6844	0.0015433 < MN_A->MN_B (video/light_video)>	321.78 < MN_A->MN_B (video/light_video)>	326.85 < MN_A->MN_B (video/light_video)>	-	-	-

Test 6.5 - FR1 Beacon interval 0.01

HA_B	-	0.84087	-	-	-	-	-	-	-
MN_A	1.00000	0.84228	-	-	-	-	0.079125	325.37	326.80
MN_B	• 0.64268 • 0.38424 • 0.27682 • 0.25295	-	1.6833	0.0015385 < MN_A->MN_B (video/light_video)>	319.92 < MN_A->MN_B (video/light_video)>	326.85 < MN_A->MN_B (video/light_video)>	-	-	-

Test 6.6

HA_B	-	0.84045	-	-	-	-	-	-	-
MN_A	1.00000	0.84162	-	-	-	-	0.092992	325.51	326.80
MN_B	• 0.64243 • 0.38359 • 0.27607 • 0.25358	-	1.6816	0.0015515 < MN_A->MN_B (video/light_video)>	320.21 < MN_A->MN_B (video/light_video)>	326.85 < MN_A->MN_B (video/light_video)>	-	-	-

Test 6.7

HA_B	-	0.82401	-	-	-	-	-	-	-
MN_A	1.00000	0.82474	-	-	-	-	0.42323	327.37	330.24
MN_B	• 0.62059 • 0.36672 • 0.26739 • 0.25658	-	1.6485	0.0015872 < MN_A->MN_B (video/light_video)>	323.59 < MN_A->MN_B (video/light_video)>	330.28 < MN_A->MN_B (video/light_video)>	-	-	-

Test 6.8 - Velocity 120

HA_B	-	0.80956	-	-	-	-	-	-	-
MN_A	1.00000	0.81070	-	-	-	-	0.019111	325.59	325.89
MN_B	• 0.58876 • 0.36731 • 0.28061 • 0.26814	-	1.6200	0.0015791 < MN_A->MN_B (video/light_video)>	320.46 < MN_A->MN_B (video/light_video)>	325.95 < MN_A->MN_B (video/light_video)>	-	-	-

Test 6.9

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size
HA_B	-	0.83998	-
MN_A	1.00000	0.84131	-
MN_B	• 0.64099 • 0.38408 • 0.27636 • 0.25415	-	1.6813

Statistic	Average	Maximum	Minimum
Voice Packet Delay Variation	0.15704	0.44824	0.00000
Voice Packet End-to-End Delay (sec)	0.2452	4.4759	0.0837
Voice Traffic Received (bytes/sec)	2,927.27	3,781.25	0.00
Voice Traffic Sent (bytes/sec)	2,997.48	3,300.00	0.00

Node	Voice Application Packet End-to-End Delay (sec)	Voice Application Traffic Received (bytes/sec)	Voice Application Traffic Sent (bytes/sec)
MN_A	0.28709	1,479.28	1,498.65
MN_B	0.15711	1,447.99	1,498.83

Test 6.10 – Mobility detection factor 1

HA_B	-	0.84095	-	-	-	-	-	-	-
MN_A	1.00000	0.84198	-	-	-	-	0.029114	324.51	326.8
MN_B	• 0.64439 • 0.38216 • 0.27616 • 0.25308	-	1.6826	0.0015453 < MN_A->MN_B (video/light_video)>	320.64 < MN_A->MN_B (video/light_video)>	325.85 < MN_A->MN_B (video/light_video)>	-	-	-

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size
HA_B	-	0.83995	-
MN_A	1.00000	0.84099	-
MN_B	• 0.64282 • 0.38102 • 0.27616 • 0.25402	-	1.6809

Test 6.11 – VoIP MNB Mobility Detection factor 1

Statistic	Average	Maximum	Minimum
Voice Packet Delay Variation	0.11471	0.30510	0.00000
Voice Packet End-to-End Delay (sec)	0.2138	2.6811	0.0834
Voice Traffic Received (bytes/sec)	2,930.82	3,300.00	0.00
Voice Traffic Sent (bytes/sec)	2,988.62	3,300.00	0.00

Node	Voice Application Packet End-to-End Delay (sec)	Voice Application Traffic Received (bytes/sec)	Voice Application Traffic Sent (bytes/sec)
MN_A	0.23640	1,477.63	1,494.22
MN_B	0.15838	1,453.19	1,494.40

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size
HA_B	-	0.83995	-
MN_A	1.00000	0.84099	-
MN_B	• 0.64282 • 0.38102 • 0.27616 • 0.25402	-	1.6809

Scenario 7

Test 7.1

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size	Video Called Party Packet Delay Variation	Video Called Party Traffic Received (bytes/sec)	Video Called Party Traffic Sent (bytes/sec)	Video Calling Party Packet Delay Variation	Video Calling Party Traffic Received (bytes/sec)	Video Calling Party Traffic Sent (bytes/sec)
HA_A	-	0.54679	-	-	-	-	-	-	-
HA_B	-	0.57380	-	-	-	-	-	-	-
MN_A	• 0.62968 • 0.54683	0.57451	1.0945	-	-	-	0.28038	325.37	333.25
MN_B	• 0.57694 • 0.57383	0.54719	1.1486	0.000021378 < MN_A->MN_B (video/light_video)>	324.92 < MN_A->MN_B (video/light_video)>	333.28 < MN_A->MN_B (video/light_video)>	-	-	-

Test 7.2

Same as 7.1

Test 7.3

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size
HA_A	-	0.54601	-
HA_B	-	0.57357	-
MN_A	• 0.63036 • 0.54604	0.57432	1.0929
MN_B	• 0.57721 • 0.57360	0.54638	1.1482

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size
HA_A	-	0.54601	-
HA_B	-	0.57357	-
MN_A	• 0.63036 • 0.54604	0.57432	1.0929
MN_B	• 0.57721 • 0.57360	0.54638	1.1482

Statistic	Average	Maximum	Minimum
Voice Packet Delay Variation	0.4572	1.9930	0.0000
Voice Packet End-to-End Delay (sec)	0.387	13.216	0.183
Voice Traffic Received (bytes/sec)	3,037.05	3,300.00	0.00
Voice Traffic Sent (bytes/sec)	3,109.20	3,300.00	0.00

Node	Voice Application Packet End-to-End Delay (sec)	Voice Application Traffic Received (bytes/sec)	Voice Application Traffic Sent (bytes/sec)
MN_A	0.45664	1,520.23	1,554.54
MN_B	0.27234	1,516.82	1,554.66

Test 7.4
Same as 7.3

Scenario 8

Test 8.1

HA_A	-	0.63394	-	-	-	-	-	-	-
HA_B	-	0.49016	-	-	-	-	-	-	-
MN_A	• 0.63397 • 0.53364	0.49067	1.2683	-	-	-	0.16529	327.60	334.44
MN_B	• 0.62429 • 0.49019	0.63447	0.9812	0.0018042 < MN_A->MN_B (video/light_video)>	327.28 < MN_A->MN_B (video/light_video)>	334.47 < MN_A->MN_B (video/light_video)>	-	-	-

Test 8.2

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size	Video Calling Party Packet Delay Variation	Video Calling Party Traffic Received (bytes/sec)	Video Calling Party Traffic Sent (bytes/sec)
HA_A	-	0.77019	-	-	-	-
HA_B	-	1.00000	-	-	-	-
MN_A	• 0.77021 • 0.39045	-	0.77104	-	0.00	0.00
MN_B	• 1.00000 • 0.21560	-	1.00000	-	-	-

Test 8.3

HA_A	-	0.45090	-	-	-	-	-	-	-
HA_B	-	1.00000	-	-	-	-	-	-	-
MN_A	• 0.71678 • 0.45094	1.00000	1.4505	-	-	-	0.0014595	193.18	334.44
MN_B	• 1.00000 • 0.45767 • 0.23360	1.00000	1.9989	0.0015619 < MN_A->MN_B (video/light_video)>	156.23 < MN_A->MN_B (video/light_video)>	334.47 < MN_A->MN_B (video/light_video)>	-	-	-

Test 8.4

MN_A	1.00	-	-	-	-	-	0.0000000959	192.62	334.44
MN_B	1.00	-	-	307.11 < MN_A->MN_B (video/light_video)>	192.78 < MN_A->MN_B (video/light_video)>	334.47 < MN_A->MN_B (video/light_video)>	-	-	-

Scenario 9

Test 9.1

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size	Video Called Party Packet Delay Variation	Video Called Party Traffic Received (bytes/sec)	Video Called Party Traffic Sent (bytes/sec)	Video Calling Party Packet Delay Variation	Video Calling Party Traffic Received (bytes/sec)	Video Calling Party Traffic Sent (bytes/sec)
HA_A	-	0.52593	-	-	-	-	-	-	-
HA_B	-	0.78162	-	-	-	-	-	-	-
MN_A	• 0.54471 • 0.26787	0.77769	1.0537	-	-	-	0.13142	312.31	324.89
MN_B	• 0.35474 • 0.31362 • 0.31093	0.52692	1.5634	0.12596 < MN_A->MN_B (video/light_video)>	308.17 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-

Test 9.2

HA_A	-	0.52569	-	-	-	-	-	-	-
HA_B	-	0.78051	-	-	-	-	-	-	-
MN_A	• 0.54515 • 0.26765	-	0.52714	-	-	-	0.12618	314.06	324.89
MN_B	• 0.35327 • 0.31425 • 0.31190	-	0.73347	0.12053 < MN_A->MN_B (video/light_video)>	312.15 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-

Test 9.3

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size
HA_A	-	0.52551	-
HA_B	-	0.78015	-
MN_A	• 0.54537 • 0.26801	1.00000	1.5255
MN_B	• 0.35362 • 0.31411 • 0.31228	1.00000	1.1883

Statistic	Average	Maximum	Minimum
Voice Packet Delay Variation	2.3064	5.6682	0.0000
Voice Packet End-to-End Delay (sec)	2.709	14.347	0.084
Voice Traffic Received (bytes/sec)	1,112.38	3,330.56	0.00
Voice Traffic Sent (bytes/sec)	2,960.81	3,300.00	0.00

Node	Voice Application Packet End-to-End Delay (sec)	Voice Application Traffic Received (bytes/sec)	Voice Application Traffic Sent (bytes/sec)
MN_A	1.8585	632.71	1,480.30
MN_B	2.0560	479.67	1,480.51

Test 9.4

Statistic	Average	Maximum	Minimum
Ftp Download Response Time (sec)	2.6672	3.2033	1.8057
Ftp Traffic Received (bytes/sec)	187.08	4,677.04	0.00
Ftp Traffic Sent (bytes/sec)	187.08	4,677.04	0.00
Ftp Upload Response Time (sec)	2.7922	2.7922	2.7922

Node	Client Ftp Download Response Time (sec)	Client Ftp Traffic Received (bytes/sec)	Client Ftp Traffic Sent (bytes/sec)	Client Ftp Upload Response Time (sec)
MN_A	2.6672	139.36	47.719	2.7922

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size
HA_A	-	0.52545	-
HA_B	-	0.78125	-
MN_A	• 0.54516 • 0.26739	0.74977	0.5271
MN_B	• 0.35486 • 0.31354 • 0.31126	-	1.0537

Test 9.5

HA_A	-	0.33329	-	-	-	-	-	-	-
HA_B	-	0.79536	-	-	-	-	-	-	-
MN_A	0.69660	0.79582	0.6671	-	-	-	0.46324	320.85	331.25
MN_B	• 0.36648 • 0.32164 • 0.28519 • 0.25363	0.33340	1.5924	0.11491 < MN_A->MN_B (video/light_video)>	317.24 < MN_A->MN_B (video/light_video)>	331.30 < MN_A->MN_B (video/light_video)>	-	-	-

Test 9.6

HA_A	-	0.70747	-	-	-	-	-	-	-
HA_B	-	0.76593	-	-	-	-	-	-	-
MN_A	• 0.44405 • 0.41433 • 0.31010	0.76601	1.4166	-	-	-	0.028684	308.17	319.43
MN_B	• 0.34225 • 0.33332	0.70905	1.5344	0.034403 < MN_A->MN_B (video/light_video)>	265.37 < MN_A->MN_B (video/light_video)>	319.50 < MN_A->MN_B (video/light_video)>	-	-	-

Test 9.7

HA_A	-	1	-	-	-	-	-	-	-
HA_B	-	1	-	-	-	-	-	-	-
MN_A	• 0.88816 • 0.16583	1	1.9975	-	-	-	0.0021742	92.211	324.89
MN_B	• 0.81025 • 0.19550 • 0.11264	1	1.7639	0.0013206 < MN_A->MN_B (video/light_video)>	168.66 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-

Test 9.8

HA_A	-	0.92485	-	-	-	-	-	-	-
HA_B	-	0.89739	-	-	-	-	-	-	-
MN_A	• 0.93853 • 0.18776	-	1.6966	-	-	-	9.3906	114.35	324.89
MN_B	• 0.75066 • 0.31953	0.92684	1.8144	0.0021526 < MN_A->MN_B (video/light_video)>	60.678 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-

Test 9.9

HA_A	-	0.06117	-	-	-	-	-	-	-
HA_B	-	1.00000	-	-	-	-	-	-	-
MN_A	• 0.57568 • 0.64698	-	0.6953	-	-	-	0.0018000	65.456	324.89
MN_B	• 1.00000 • 0.11303	-	1.1196	0.00026808 < MN_A->MN_B (video/light_video)>	55.263 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-

Test 9.11

HA_A	-	0.52949	-	-	-	-	-	-	-
HA_B	-	0.78356	-	-	-	-	-	-	-
MN_A	• 0.54457 • 0.26947	0.77074	1.0609	-	-	-	0.15847	287.14	324.89
MN_B	• 0.35801 • 0.30866 • 0.30700	0.53058	1.5582	0.0021479 < MN_A->MN_B (video/light_video)>	283.48 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-

Test 9.12

HA_A	-	0.52572	-	-	-	-	-	-	-
HA_B	-	0.77764	-	-	-	-	-	-	-
MN_A	• 0.54504 • 0.26802	0.77321	1.0521	-	-	-	0.0030104	315.01	324.89
MN_B	• 0.35435 • 0.31988 • 0.31337	0.52614	1.5543	0.12498 < MN_A->MN_B (video/light_video)>	311.03 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-

Test 9.14

HA_A	-	0.52563	-	-	-	-	-	-	-
HA_B	-	0.78167	-	-	-	-	-	-	-
MN_A	• 0.54531 • 0.26805	0.77734	1.0528	-	-	-	0.10536	312.31	324.89
MN_B	• 0.35452 • 0.31357 • 0.31056	0.52648	1.5625	0.11101 < MN_A->MN_B (video/light_video)>	308.17 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-

Test 9.15

HA_A	-	0.52536	-	-	-	-	-	-	-
HA_B	-	0.78312	-	-	-	-	-	-	-
MN_A	• 0.54527 • 0.25763	0.77771	1.0521	-	-	-	0.0037084	293.83	324.89
MN_B	• 0.35563 • 0.31264 • 0.30740	0.52610	1.5652	0.12033 < MN_A->MN_B (video/light_video)>	308.80 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-

Test 9.16

HA_A	-	0.52521	-	-	-	-	-	-	-
HA_B	-	0.78149	-	-	-	-	-	-	-
MN_A	• 0.54580 • 0.26692	0.65630	1.0543	-	-	-	0.0036025	293.33	324.89
MN_B	• 0.35500 • 0.30884 • 0.30878	0.52830	1.5640	0.046336 < MN_A->MN_B (video/light_video)>	307.85 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-

Test 9.17

HA_A	-	0.53203	-	-	-	-	-	-	-
HA_B	-	0.78224	-	-	-	-	-	-	-
MN_A	• 0.54165 • 0.27320	0.65401	1.0679	-	-	-	0.044155	280.46	324.89
MN_B	• 0.35760 • 0.30988 • 0.30948	0.43032	1.5545	0.0028822 < MN_A->MN_B (video/light_video)>	277.27 < MN_A->MN_B (video/light_video)>	324.95 < MN_A->MN_B (video/light_video)>	-	-	-

Scenario 10

Test 10.1

Node	Mobile IPv6 Active Access Point	Mobile IPv6 Binding Cache Table Size	Mobile IPv6 Binding Update List Size	Video Called Party Packet Delay Variation	Video Called Party Traffic Received (bytes/sec)	Video Called Party Traffic Sent (bytes/sec)	Video Calling Party Packet Delay Variation	Video Calling Party Traffic Received (bytes/sec)	Video Calling Party Traffic Sent (bytes/sec)
HA_A	-	0.73126	-	-	-	-	-	-	-
HA_B	-	0.18865	-	-	-	-	-	-	-
MN_A	• 0.73129 • 0.61989	0.13632	1.4529	-	-	-	0.019452	324.85	330.24
MN_B	• 0.86752 • 0.18882	0.73212	0.3767	0.000040661 < MN_A->MN_B (video/light_video)>	323.36 < MN_A->MN_B (video/light_video)>	330.28 < MN_A->MN_B (video/light_video)>	-	-	-

Test 10.2

HA_A	-	0.42051	-	-	-	-	-	-	-
HA_B	-	0.14967	-	-	-	-	-	-	-
MN_A	• 0.79271 • 0.42059	0.14926	0.84284	-	-	-	0.0017801	328.29	330.24
MN_B	• 0.89489 • 0.14975	0.42113	0.30009	0.000039355 < MN_A->MN_B (video/light_video)>	328.63 < MN_A->MN_B (video/light_video)>	330.28 < MN_A->MN_B (video/light_video)>	-	-	-

Test 10.3

HA_B	-	0.21645	-	-	-	-	-	-	-
MN_A	1.00000	0.21660	-	-	-	-	0.26056	324.51	330.24
MN_B	• 0.84834 • 0.21654	-	0.43437	0.000019947 < MN_A->MN_B (video/light_video)>	323.25 < MN_A->MN_B (video/light_video)>	330.28 < MN_A->MN_B (video/light_video)>	-	-	-

Test 10.4

HA_A	-	0.26524	-	-	-	-	-	-	-
HA_B	-	0.77728	-	-	-	-	-	-	-
MN_A	• 0.81437 • 0.26531	0.77920	0.5316	-	-	-	0.47076	274.17	330.24
MN_B	• 0.77730 • 0.29525	0.00000	1.5569	0.000094400 < MN_A->MN_B (video/light_video)>	254.19 < MN_A->MN_B (video/light_video)>	330.28 < MN_A->MN_B (video/light_video)>	-	-	-

Test 10.5

HA_A	-	0.42051	-	-	-	-	-	-	-
HA_B	-	0.14967	-	-	-	-	-	-	-
MN_A	• 0.79271 • 0.42059	0.14926	0.84284	-	-	-	0.0017801	328.29	330.24
MN_B	• 0.89489 • 0.14975	0.42113	0.30009	0.000039355 < MN_A->MN_B (video/light_video)>	328.63 < MN_A->MN_B (video/light_video)>	330.28 < MN_A->MN_B (video/light_video)>	-	-	-

Test 10.6

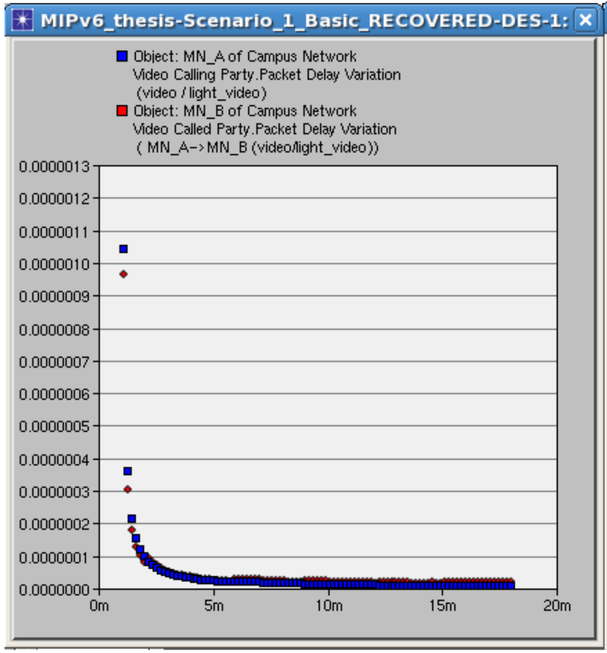
HA_A	-	1.00000	-	-	-	-	-	-	-
HA_B	-	0.22181	-	-	-	-	-	-	-
MN_A	• 1.00000 • 0.60912	0.22148	1.9972	-	-	-	0.000087275	329.21	330.24
MN_B	• 0.85674 • 0.22189	1.00000	0.4444	0.000030874 < MN_A->MN_B (video/light_video)>	328.52 < MN_A->MN_B (video/light_video)>	330.28 < MN_A->MN_B (video/light_video)>	-	-	-

APPENDIX 3

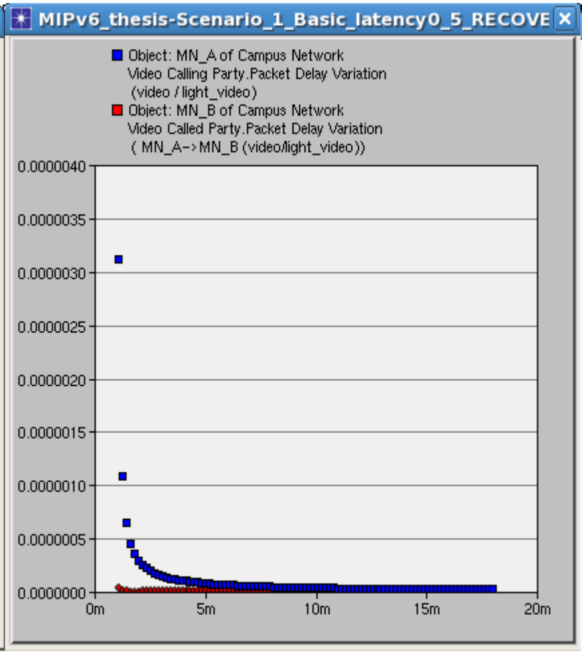
Supplementary graphs

Scenario 1 - Delay Variation

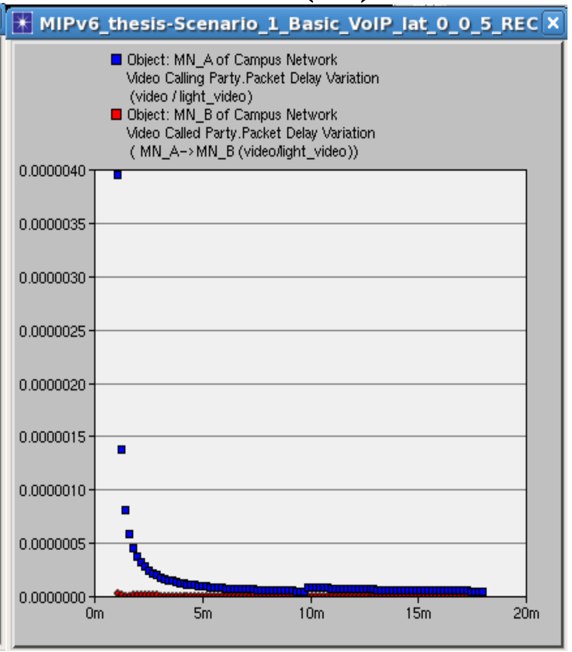
Scenario 1 – Test 1.1



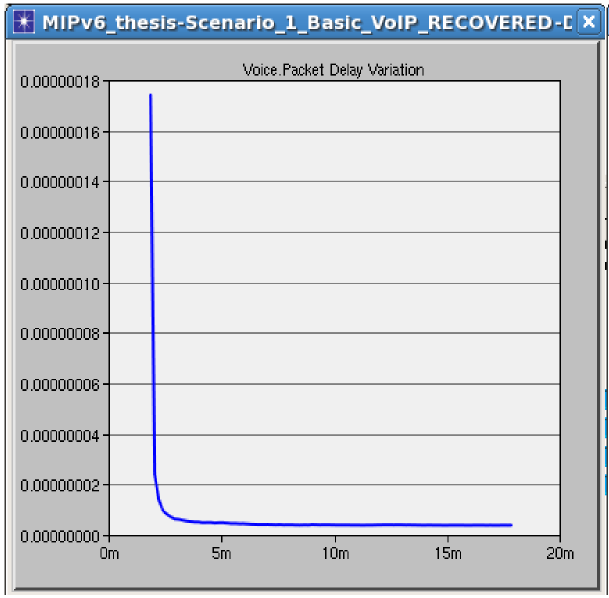
Scenario 1 – Test 1.2



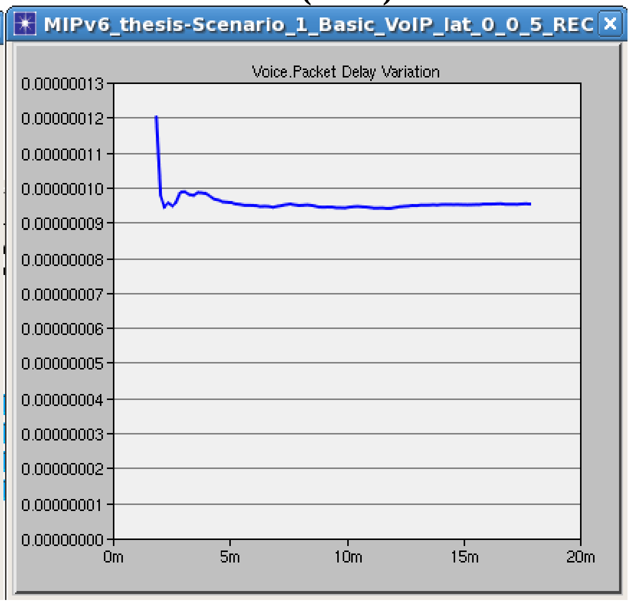
Scenario 1 – Test 1.5 (VC)



Scenario 1 – Test 1.4

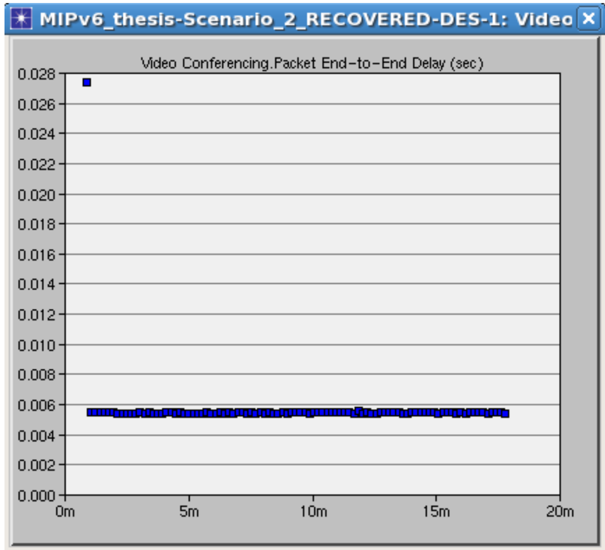


Scenario 1 – Test 1.5 (VoIP)

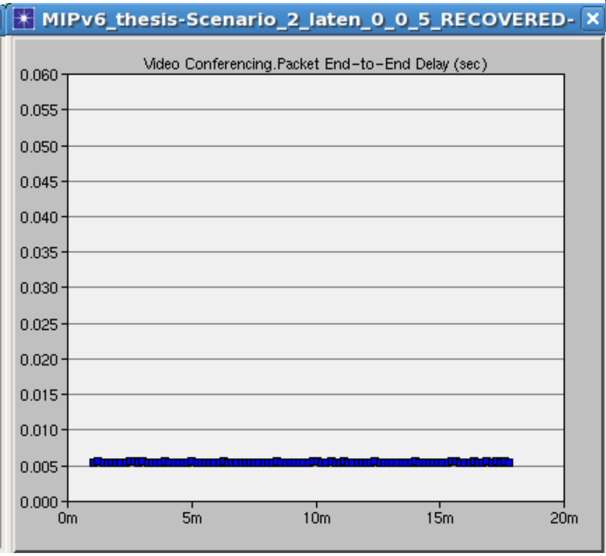


Scenario 2 – End-to-End Delay

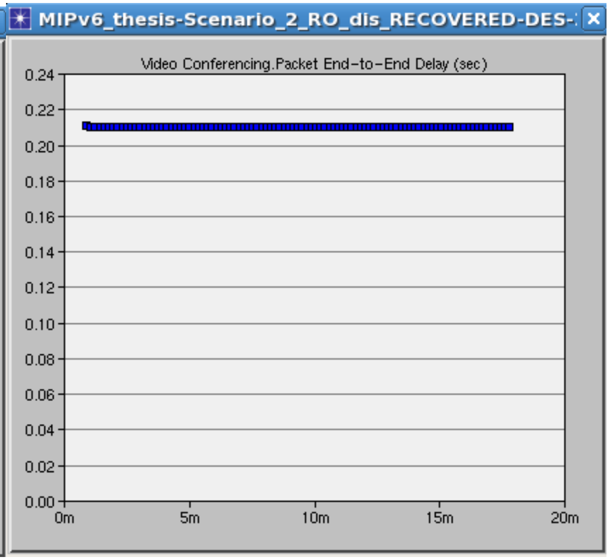
Scenario 2 – Test 2.1



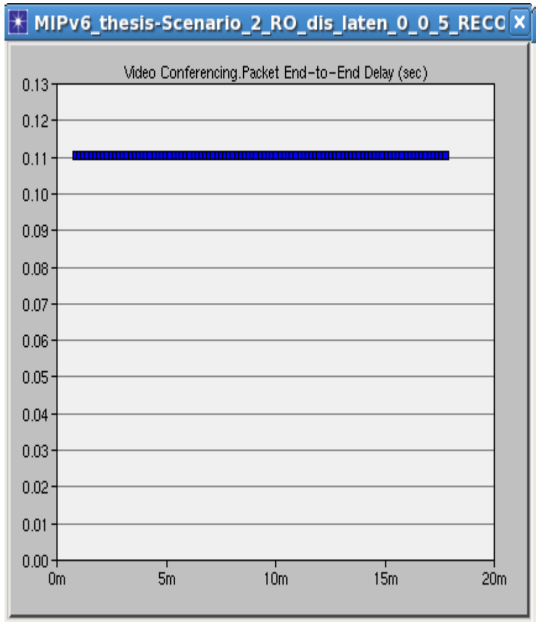
Scenario 2 – Test 2.2



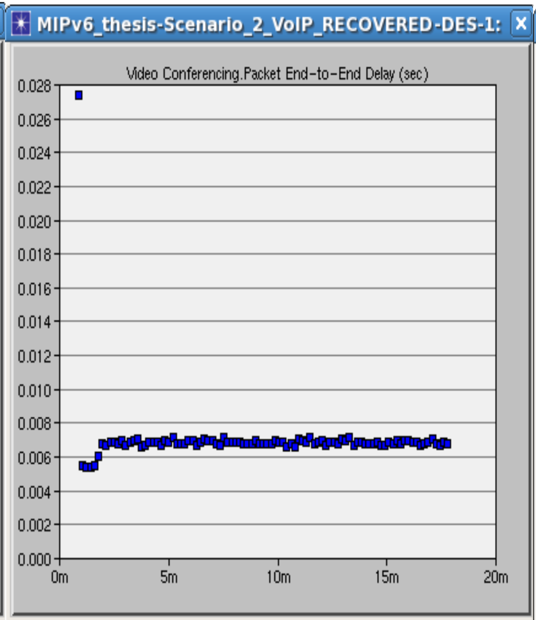
Scenario 2 – Test 2.3



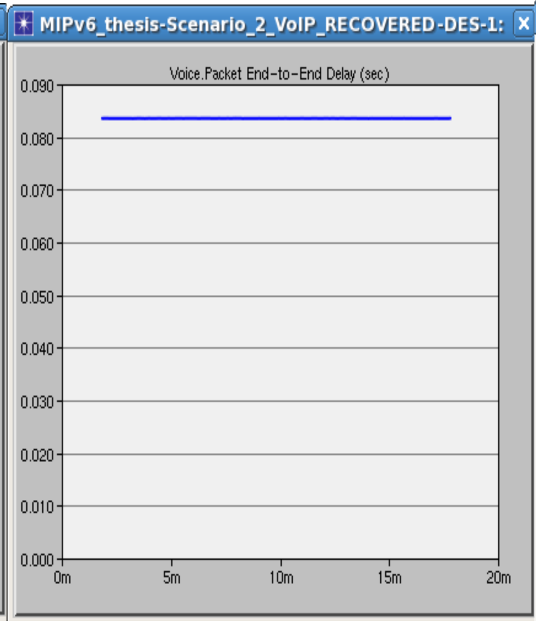
Scenario 2 – Test 2.4



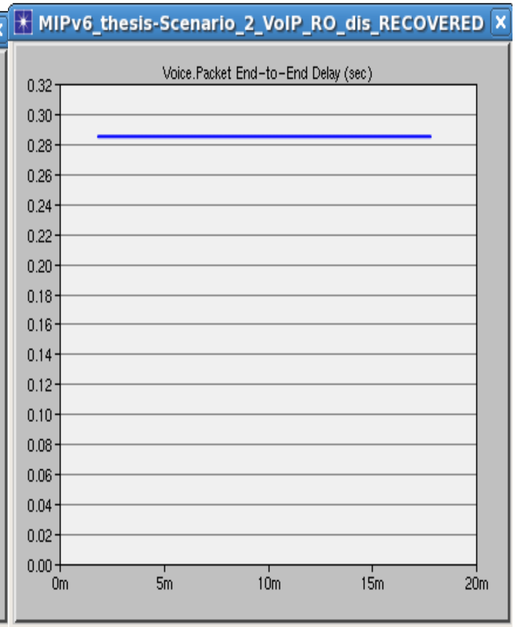
Scenario 2 – Test 2.5 (VC)



Scenario 2 – Test 2.5 (VoIP)

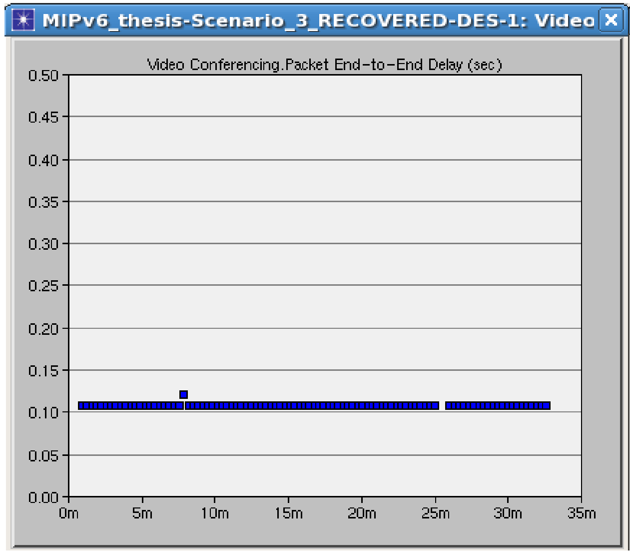


Scenario 2 – Test 2.6

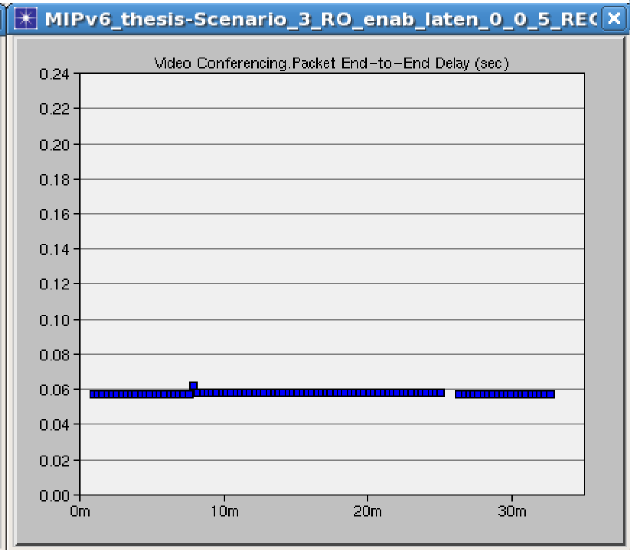


Scenario 3 – End-to-End Delay

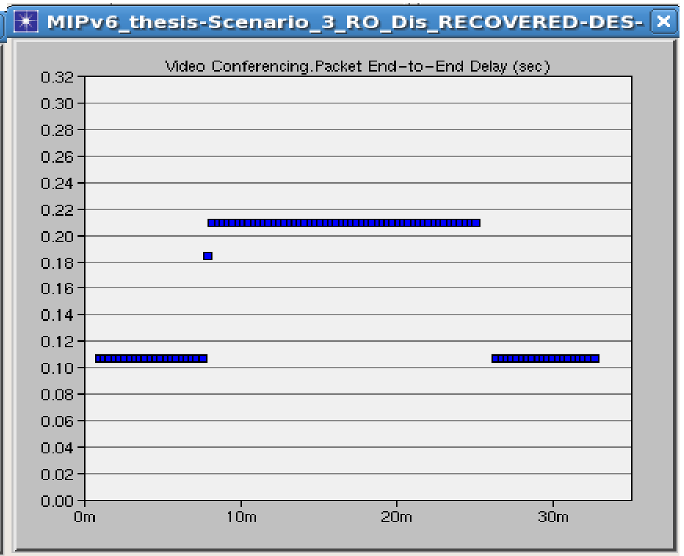
Scenario 3 – Test 3.1



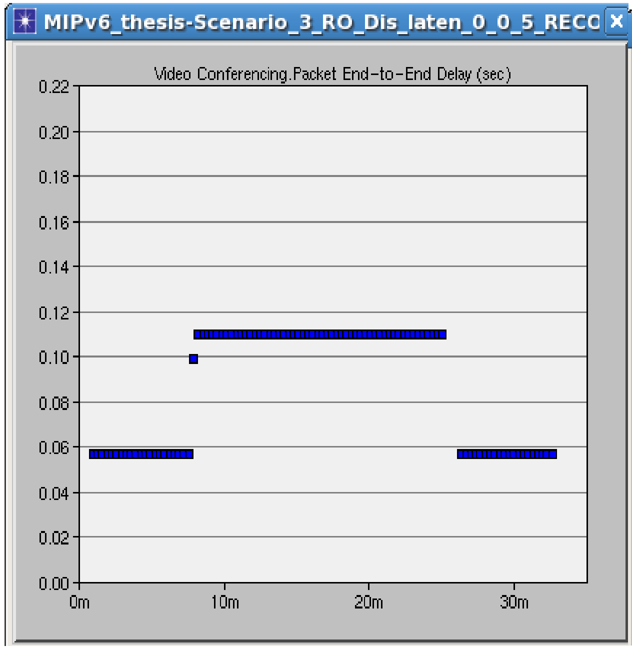
Scenario 3 – Test 3.2



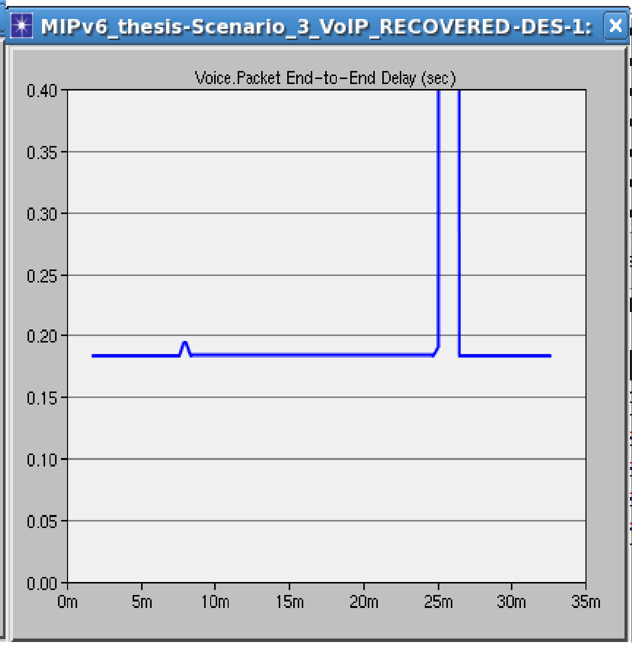
Scenario 3 – Test 3.3



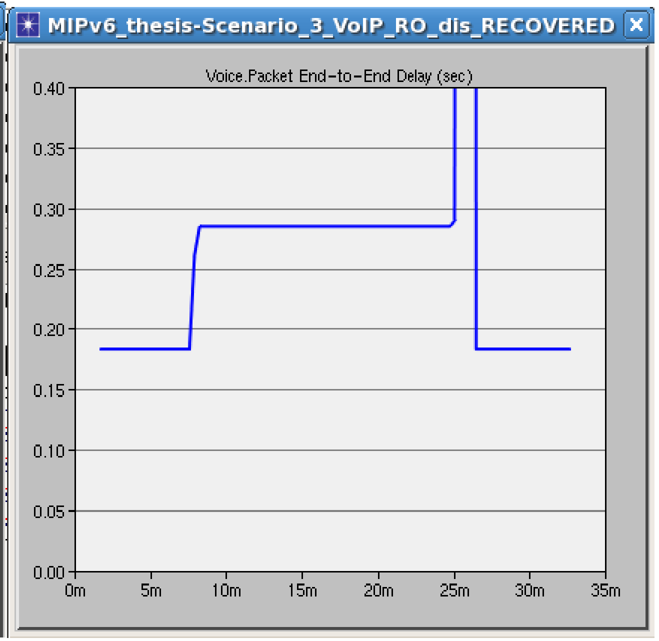
Scenario 3 – Test 3.4



Scenario 3 – Test 3.5 (delay up to 15,9sec)

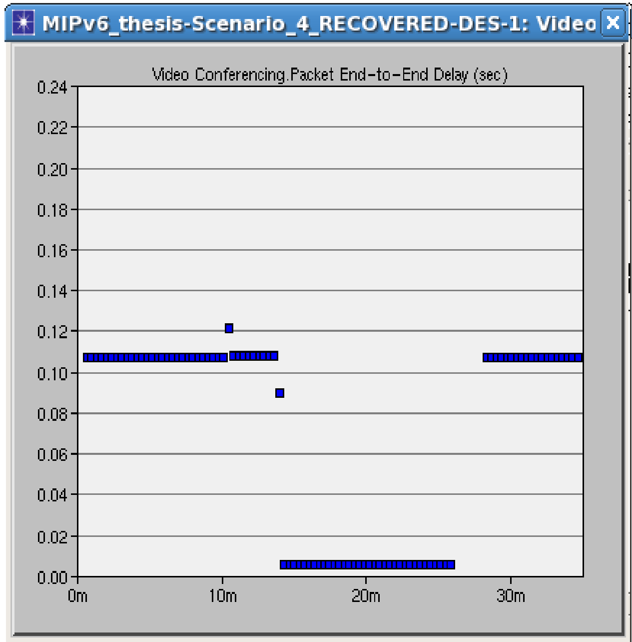


Scenario 3 – Test 3.5 (delay up to 16,4sec)

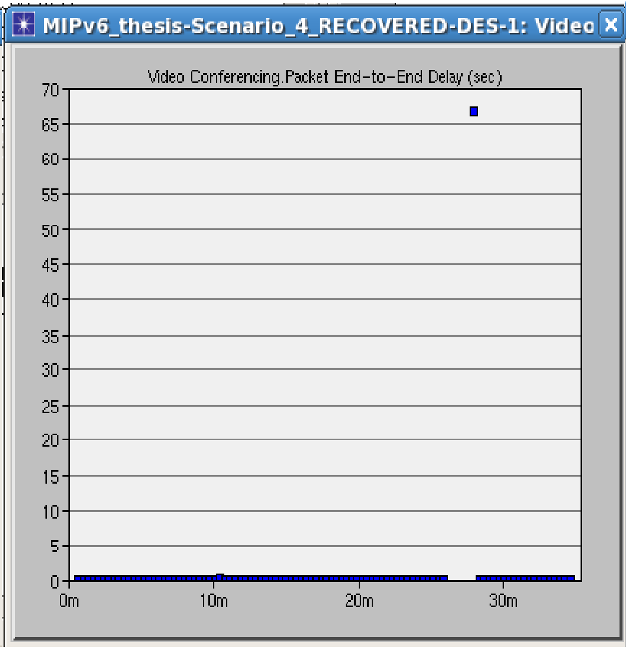


Scenario 4 – End-to-End Delay

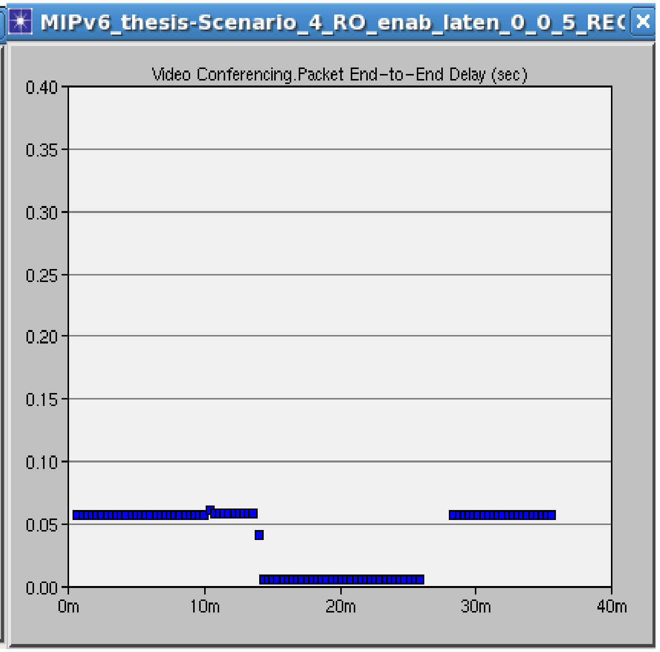
Scenario 4 – Test 4.1



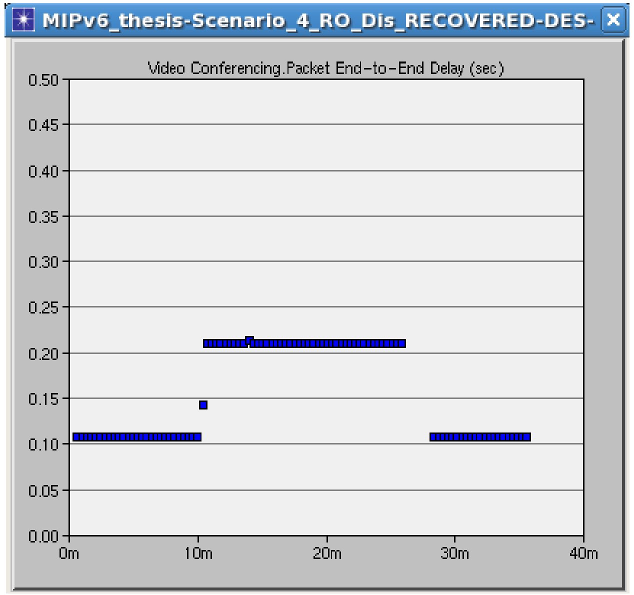
Scenario 4 – Test 4.1



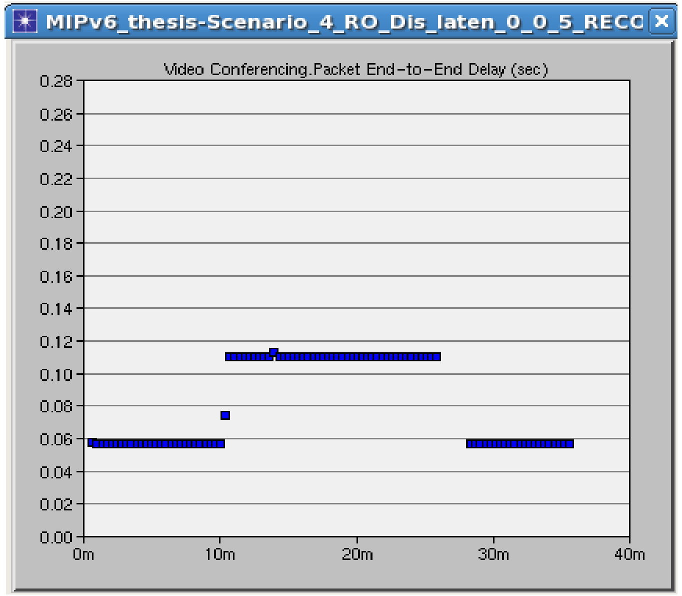
Scenario 4 – Test 4.2



Scenario 4 – Test 4.3

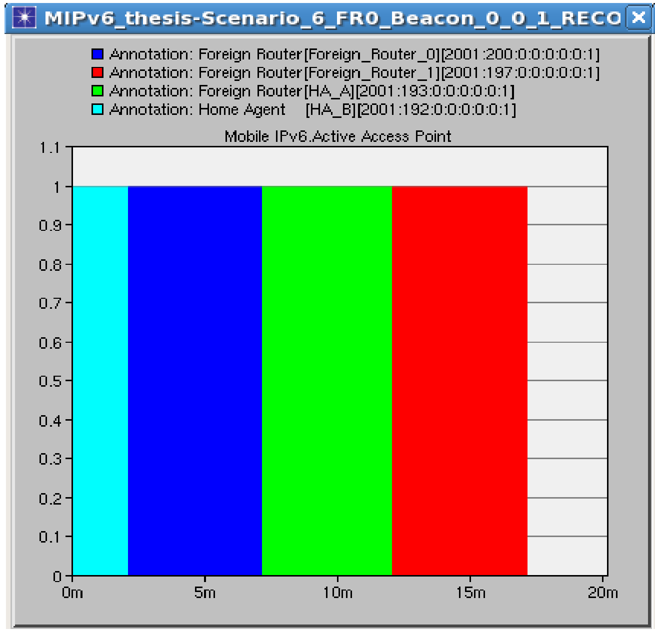


Scenario 4 – Test 4.4

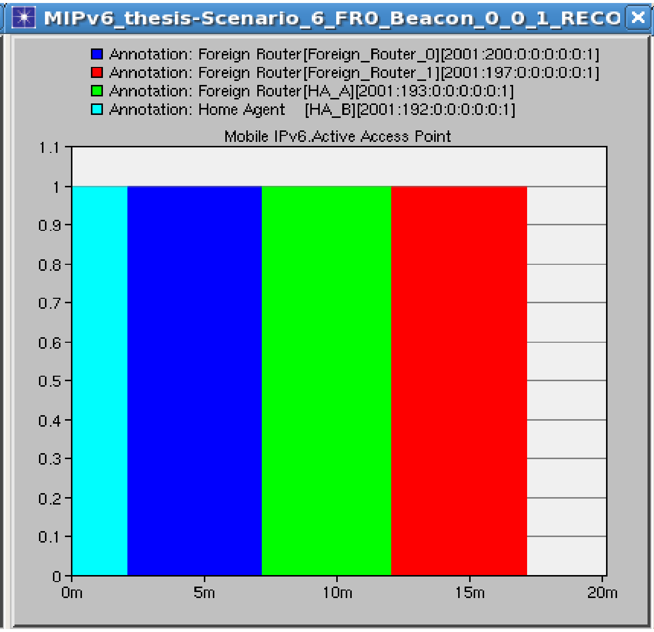


Scenario 6 – Visited Access Points

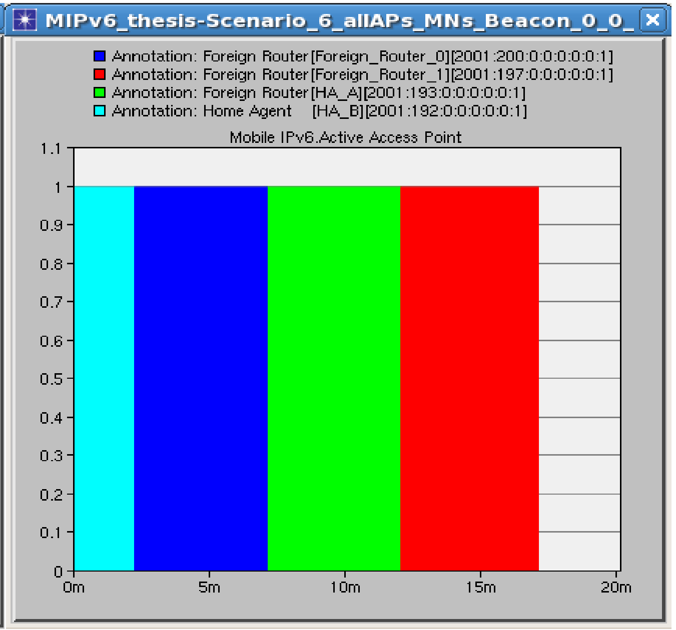
Scenario 6 – Test 6.1



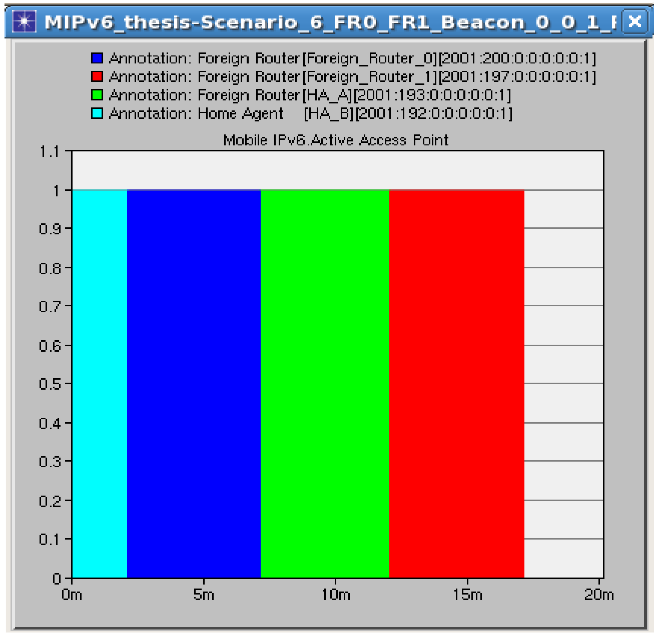
Scenario 6 – Test 6.2



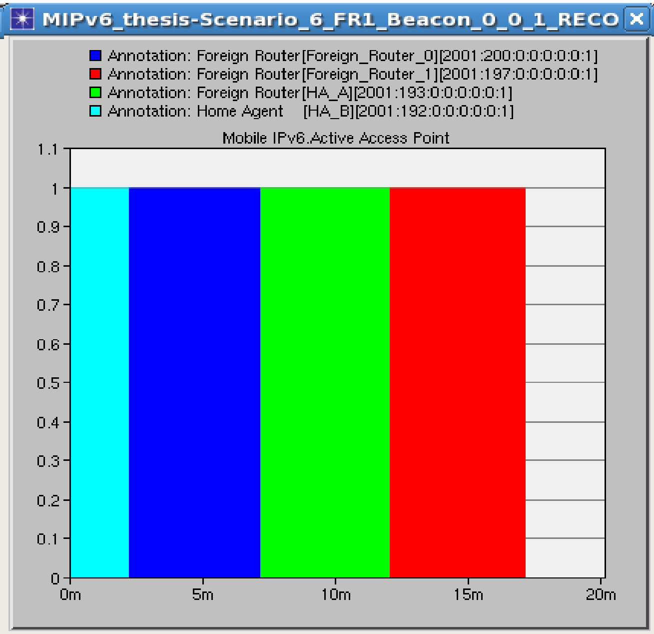
Scenario 6 – Test 6.3



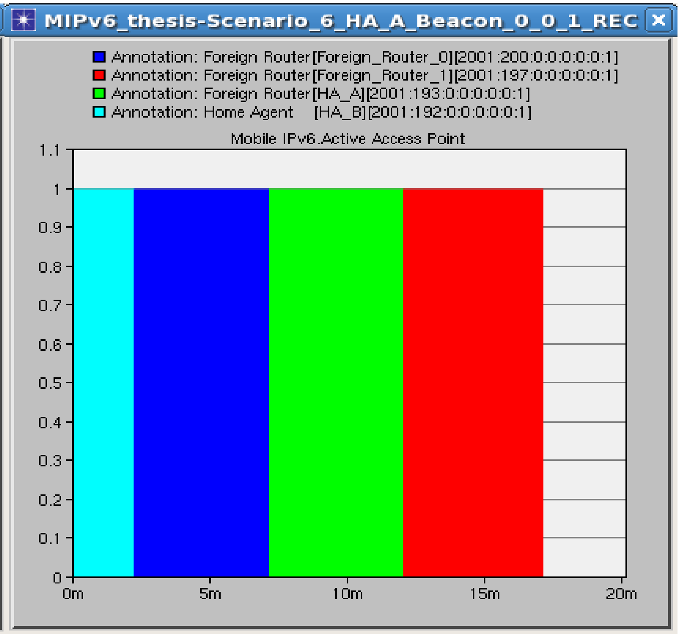
Scenario 6 – Test 6.4



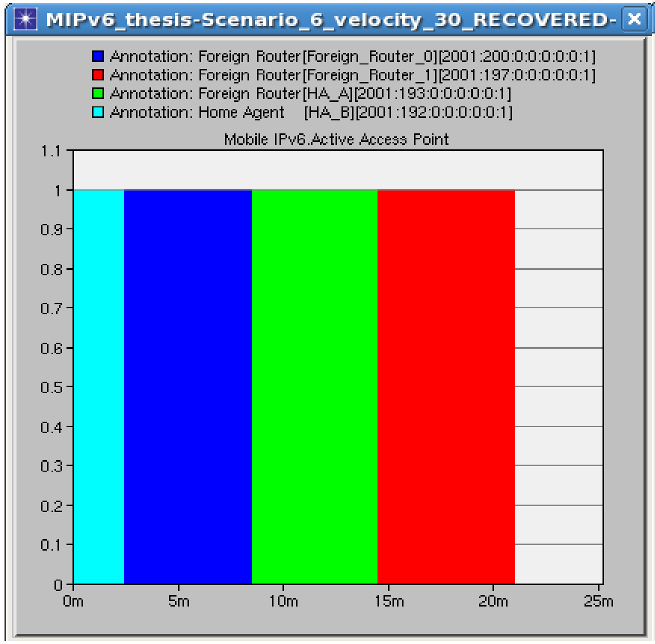
Scenario 6 – Test 6.5



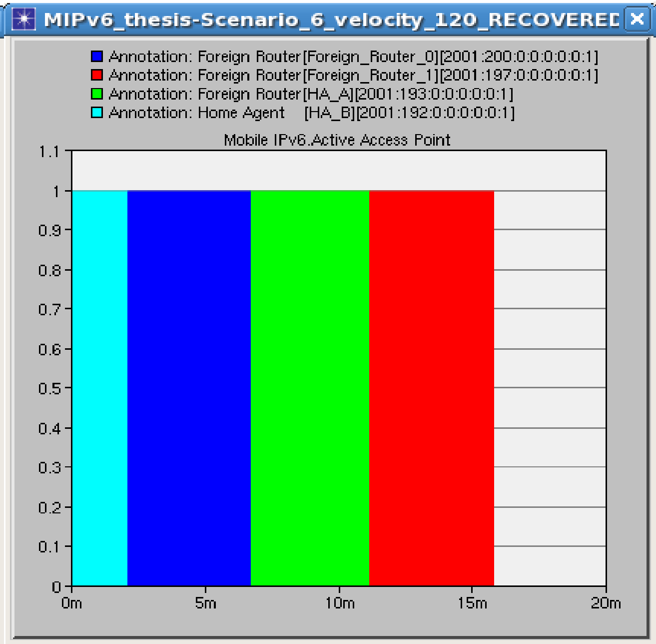
Scenario 6 – Test 6.6



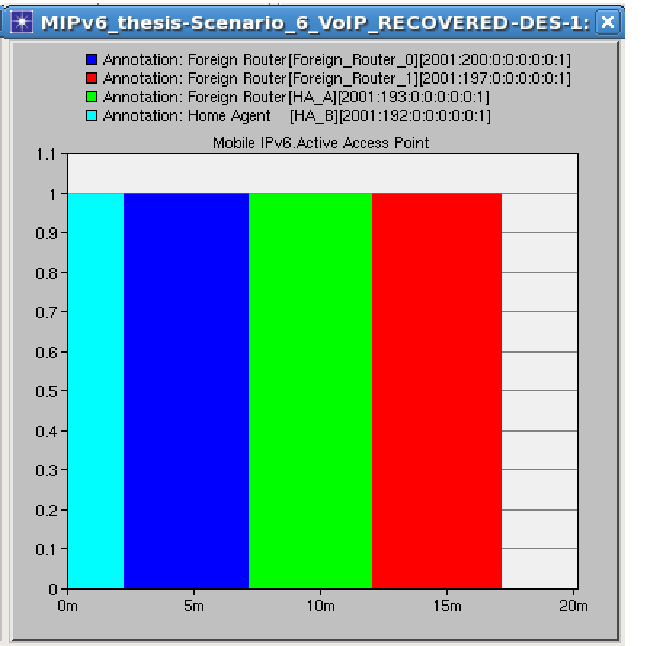
Scenario 6 – Test 6.7



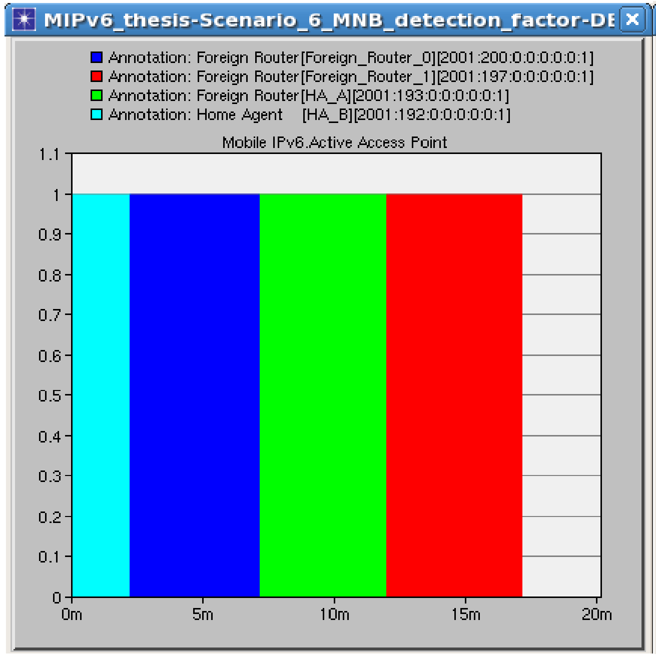
Scenario 6 – Test 6.8



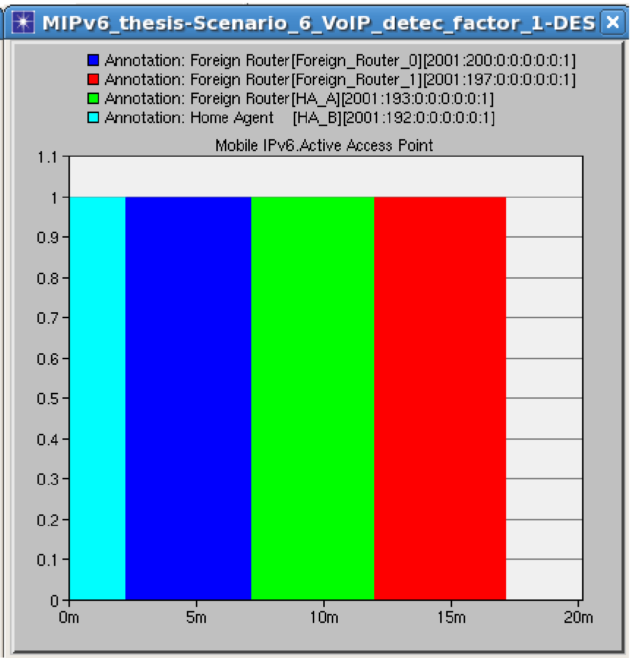
Scenario 6 – Test 6.9



Scenario 6 – Test 6.10

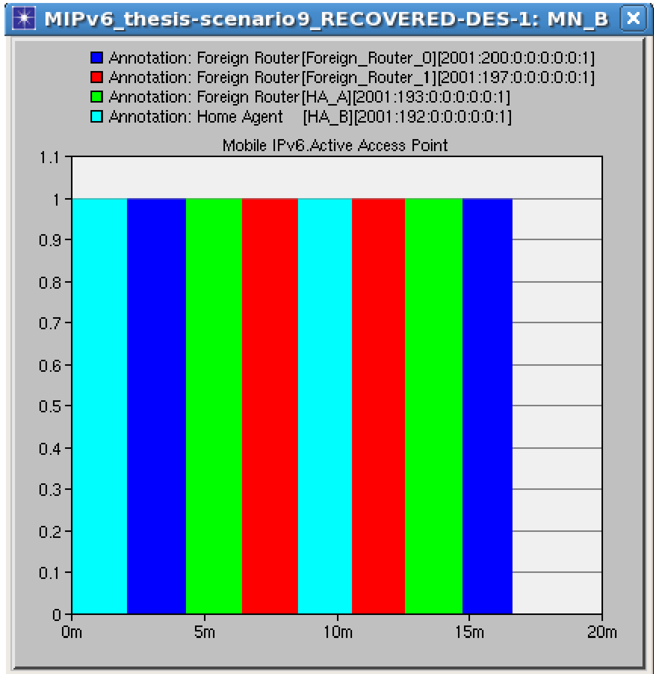


Scenario 6 – Test 6.11

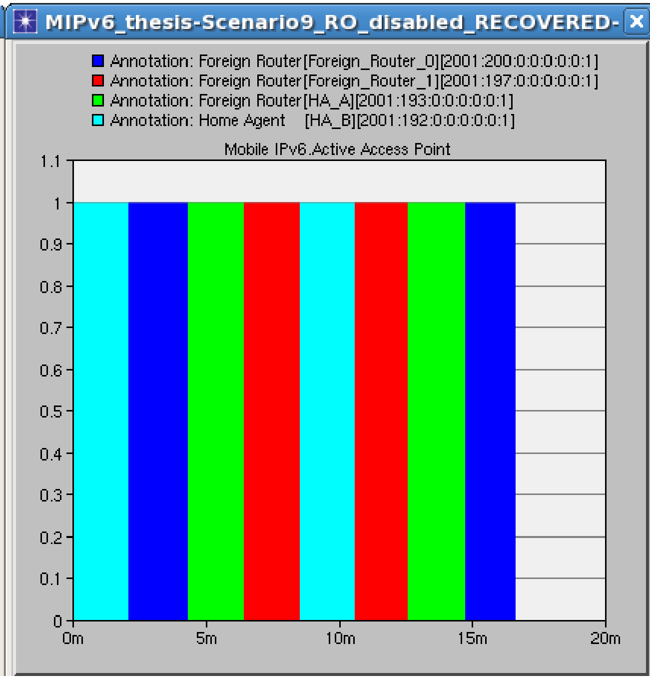


Scenario 9 – Mobile Node B Visited Access Points

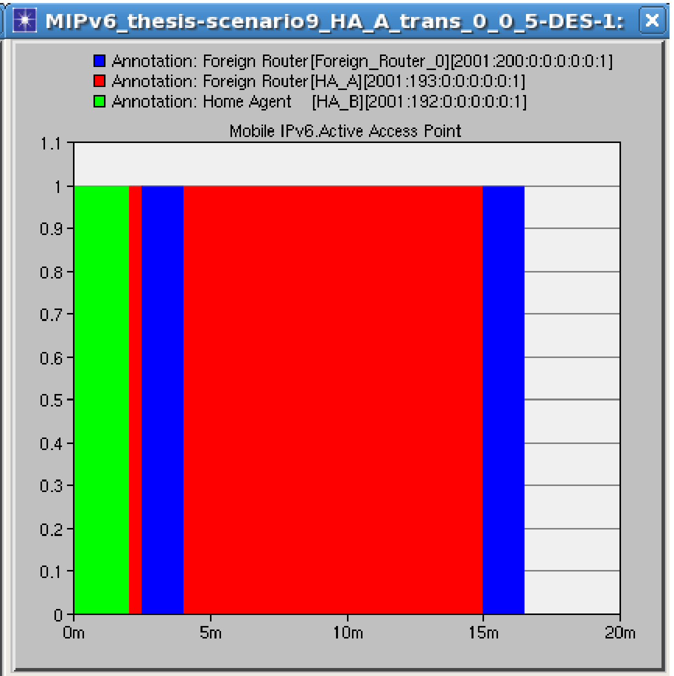
Scenario 9 – Test 9.1



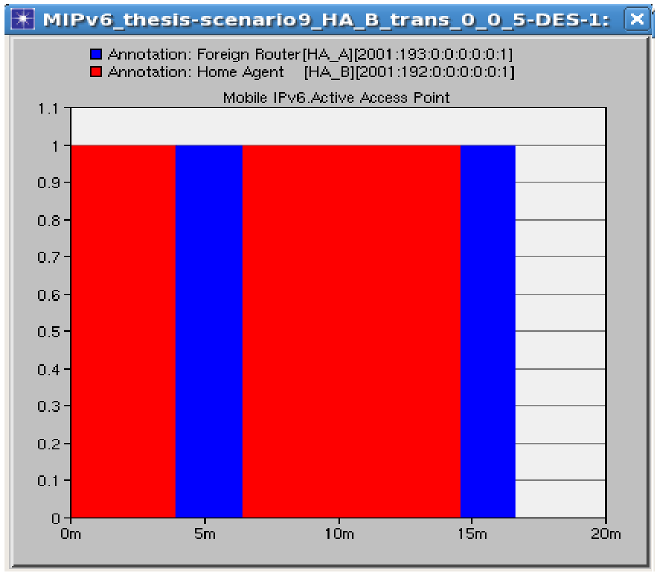
Scenario 9 – Test 9.2



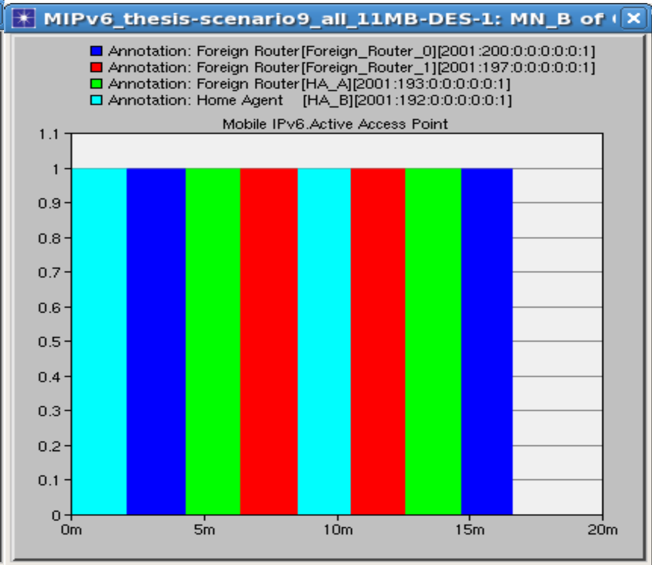
Scenario 9 – Test 9.7



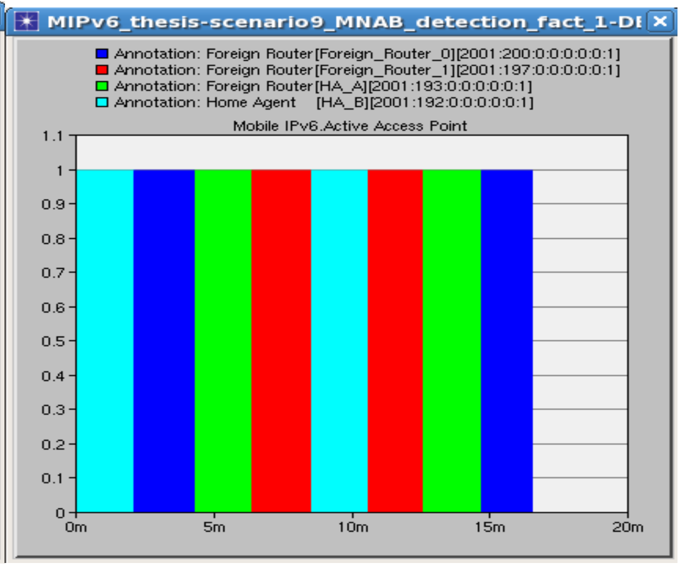
Scenario 9 – Test 9.8



Scenario 9 – Test 9.11

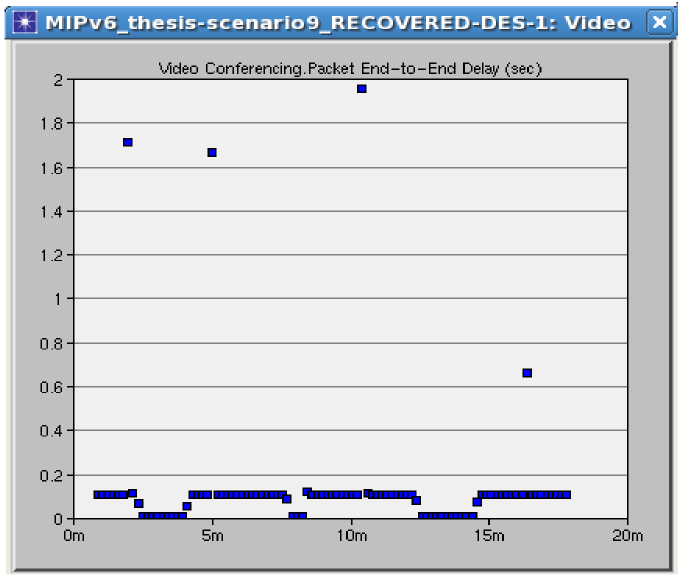


Scenario 9 – Test 9.16

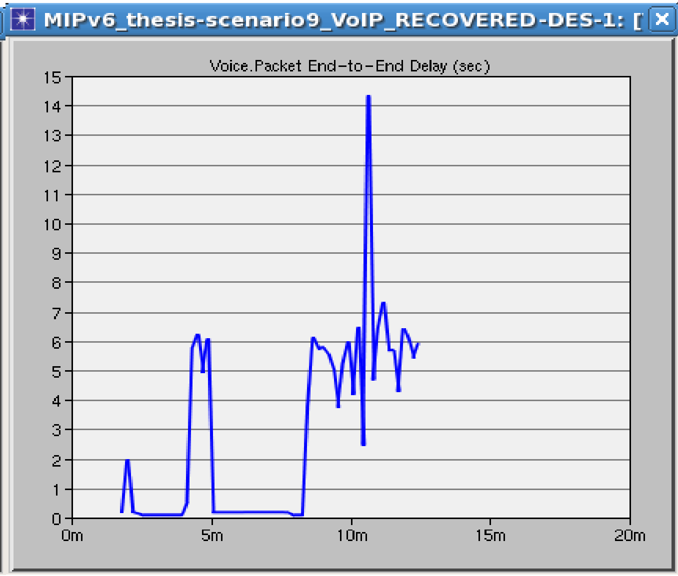


Scenario 9 – End-to-End Delay

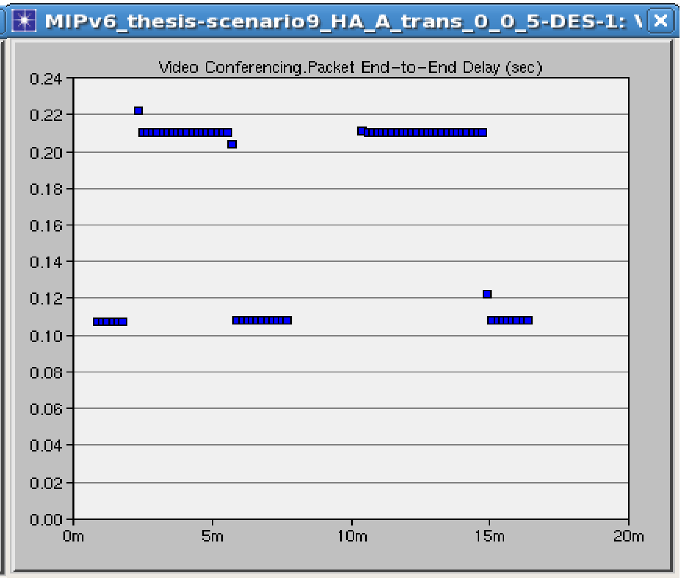
Scenario 9 – Test 9.1



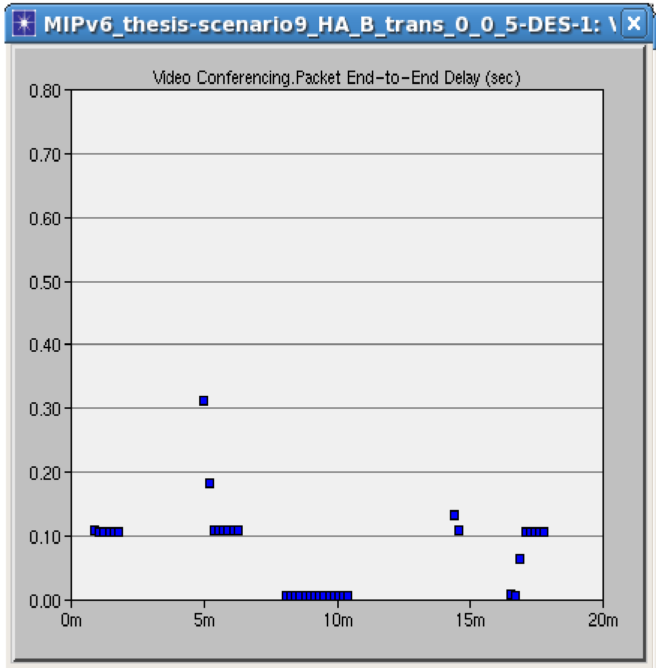
Scenario 9 – Test 9.3



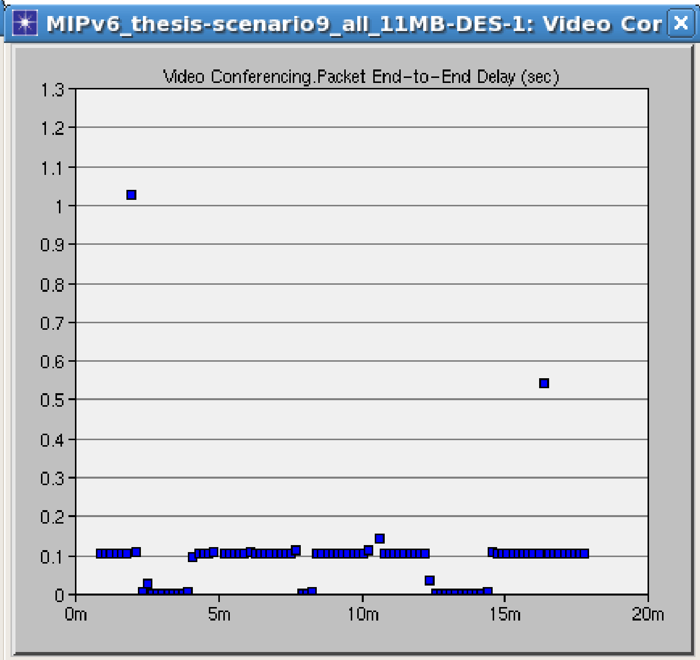
Scenario 9 – Test 9.7



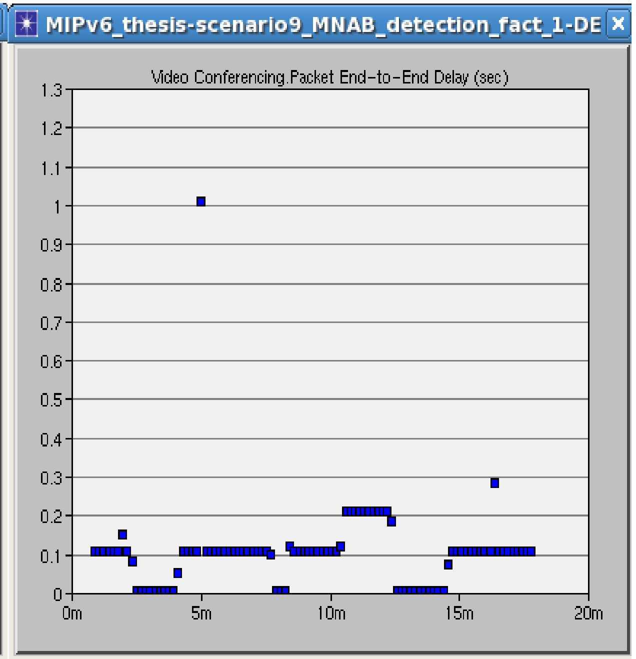
Scenario 9 – Test 9.8



Scenario 9 – Test 9.11

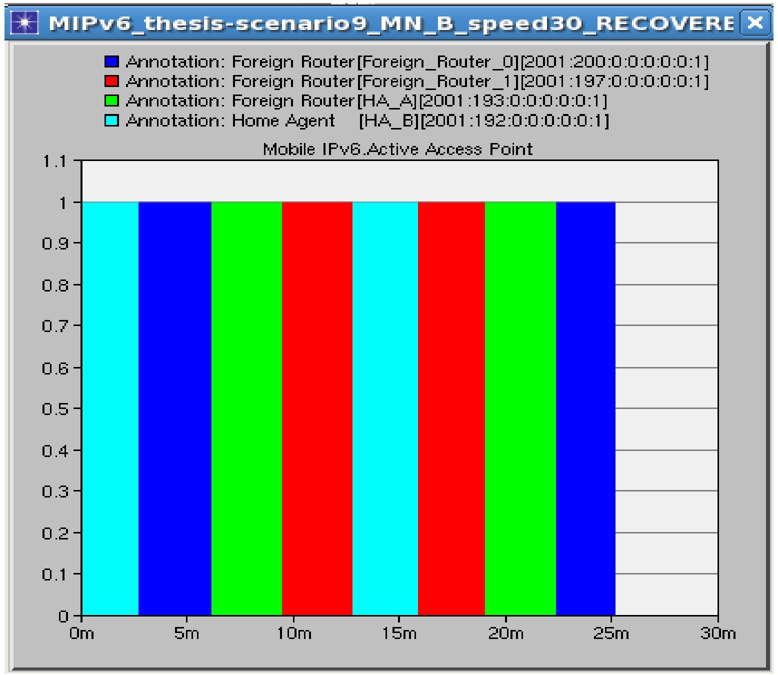


Scenario 9 – Test 9.16

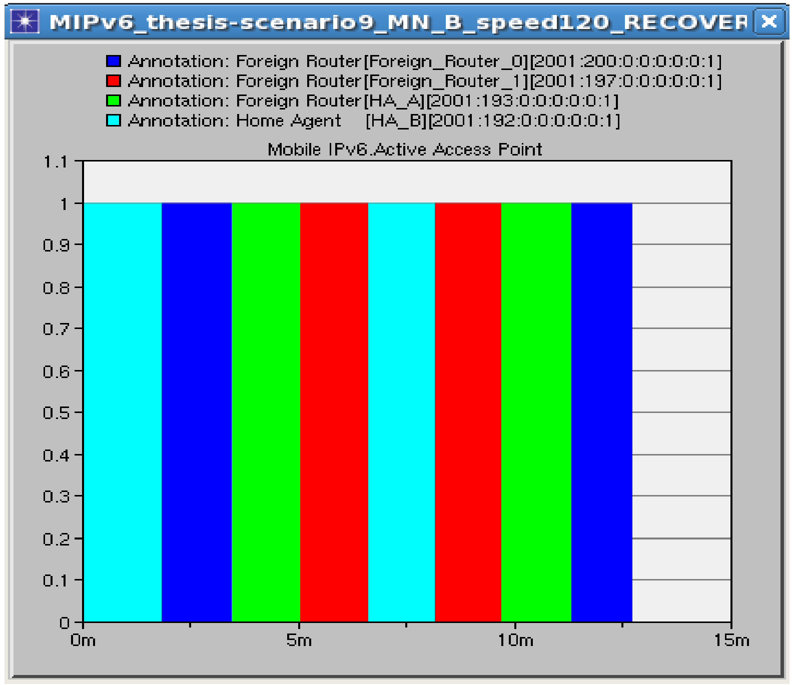


Scenario 9 – Visited Access Points

Scenario 9 – Test 9.5

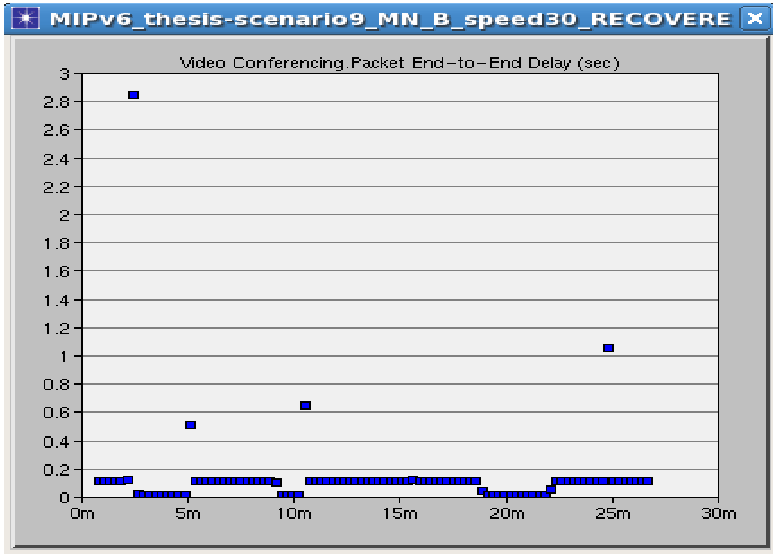


Scenario 9 – Test 9.6



Scenario 9 – End – to – End delay

Scenario 9 – Test 9.5



Scenario 9 – Test 9.6