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# Mechamisms to Provide Quality of Service on 4G New Generation Networks

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## 1. Introduction

### 1.1 New generation nerworks (4G)

Currently, the 3rd Generation Partnership Project forum (3GPP) is working to complete the standard that aims to ensure the competitiveness of UMTS in the future. As a result of this work, in 2004 the Long Term Evolution project (LTE) arises, which is expected to become the 4G standard. We can find the requirements for 4G standardization in recent works like "Release 10" and "Advanced LTE".

On the other hand, the System Architecture Evolution (SAE) is a project that seeks to define a new core component of the all-IP network called Evolved Packet Core (EPC). We can consider IPv6/MPLS as part of the development of the LTE standard included in the all-IP concept to meet some requirements of LTE, such as end-to-end quality of service (MPLS, Diffserv, IntServ). SAE allows interoperability with existing technologies in both the core and access networks.

The figure 1 shows the relation between 2G, 3G & LTE technologies and the packet core that is intended to evolve with SAE.

Due to the increasing demand of QoS by users, it is necessary to adopt mechanisms to ensure the requirements of LTE/SAE. As is well known, an all-IP network provides the so-called Best Effort quality of service. For this reason, in order to provide QoS to the LTE/SAE network's core and to the access networks, we propose the implementation of IPv6 (extensions/MPLS into the Evolved Packet Core (EPC).

### 1.2 Requirements of LTE/SAE

Some of the most important requirements of LTE/SAE are:

• Low cost per bit.
• Increase of the services provided: more services at lower cost to improve the user's experience.
• Flexible use of existing and new frequency bands.
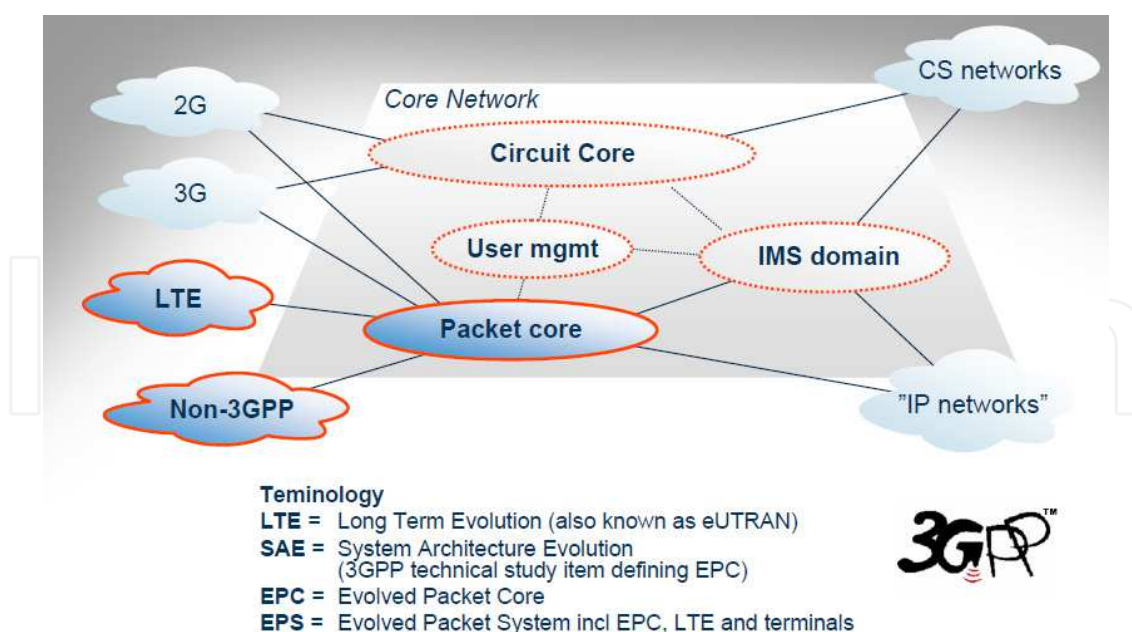• Simplified architecture.

Fig. 1. LTE/SAE

• Reasonable energy consumption.

In addition to the requirements mentioned above, there would be other important requirements as part of the standard, such as throughput optimising, latency reduction and end-to-end QoS for both the core and the access networks. In order to improve these conditions, we have considered the handover a priority. One of the key elements in the all-IP concept is the MPLS protocol as a fundamental part of all IPv6/MPLS architecture to provide quality of service to access networks and core network since it will be compatible with other architectures in the next generation mobile networks.

### 1.3 MPLS

In 1996, companies like Nokia, Cisco, IBM and Toshiba, among others, introduced proprietary solutions to the problem of multilayer switching. This was not only a solution to integrate ATM with IP, but offered brand new services. Unfortunately, these solutions were not compatible despite the large number of aspects in common. MPLS (Multi-Protocol Label Switch) came up from the work of the IETF in 1997 to standardise the proprietary multilayer switching technologies mentioned above. The main feature of MPLS is the combination of layer 3 routing and the simplicity of level 2 switching.

Another important feature of MPLS is that it provides a good balance between connection-oriented technologies to improve non-IP connection-oriented mechanisms (they can only deliver a Best Effort level of service). On the other hand, MPLS adds labels to the packets, so no routing is based on layer 3 addresses but in label switching. This allows interoperability between IP and ATM networks. It also increases the speed of the packets traversing the network because they do not run complex routing algorithms at every hop; they are forwarded considering the packet's label only. This labelling system is also very useful to classify the incoming traffic according to its higher or lower QoS requirements contracted or required.

Since MPLS is a standard solution, it also reduces the operational complexity between IP networks and gives IP advanced, routing capabilities in order to use traffic-engineering techniques that were only possible on ATM.

### 1.4 IPv6 extensions

The extensions of the IPv6 protocol were designed to migrate IPv6 to mobile environments. There are several extensions of IPv6 designed with this purpose. We have chosen the following IPv6 extensions: HMIPv6, FHMIPv6 and FHAHMIPv6, The first and second extensions were designed to be used at micro-level mobility, because the signalling, lad at this level is higher, With regards to the FHAMIPv6 protocol, this is a protocol that we have designed to provide hierarchical addresses support in an ad hoc network.

### 1.5 IPv6/MPLS on LTE/SAE

So far, we have briefly described what LTE/SAE consists of, the current requirements that have to be met to become the 4G standard and the most relevant concepts related to MPLS. Let us now look into the importance of supporting the LTE/SAE core with IP/MPLS.

The use of MPLS on LTE allows reusing much of 2G and 3G technologies, which means a low cost per bit. In addition, MPLS can handle the IP requirements for the wide range of services it supports. MPLS also supports any topology, including star, tree and mesh. On the other hand, IPv6/MPLS can give IP advanced traffic engineering, ensuring that traffic is properly prioritised according to its characteristics (voice, data, video, etc.) and the routes through the network are set up to prevent link failures. The use of differentiated services is also an important feature of MPLS, since Forwarding Equivalent Class (FEC) can perform different treatments to the services provided by IP, including an eventual integration with Diffserv. This contributes to provide a better quality of service (QoS).

In addition, because MPLS creates virtual circuits before starting the data transmission and uses special labelling, it is possible to deliver a better level of security when packets experience higher rates of transmission and processing, since the forwarding is performed according to the label without routing algorithms. This is another important aspect of IPv6/MPLS in order to meet the requirements related to the throughput. Finally, MPLS promotes the simplification of the integration architecture of IP and ATM and improves the users' QoS experience providing redundant paths to different FECs to prevent packet loss. The following figure shows how the transition to IPv6/MPLS will be as part of LTE.

Service providers and network operators want to ensure that their Radio Access Network (RAN) is able to support current technologies such as GSM and UMTS and new technologies such as LTE and WIMAX. At the same time, future broadband requirements must be met in an efficient and effective way. That is why service providers are choosing solutions based on IPv6/MPLS. This technology can fulfil current and future needs while reducing costs.

It is important to point out that the standard WIMAX and advanced WIMAX or mobile WIMAX, which is part of the evolution of IEEE (802.11, 802.16, etc.), complies with the requirements for 4G standard. WIMAX (802.16) can operate in both the core and access networks with IPv6/MPLS.
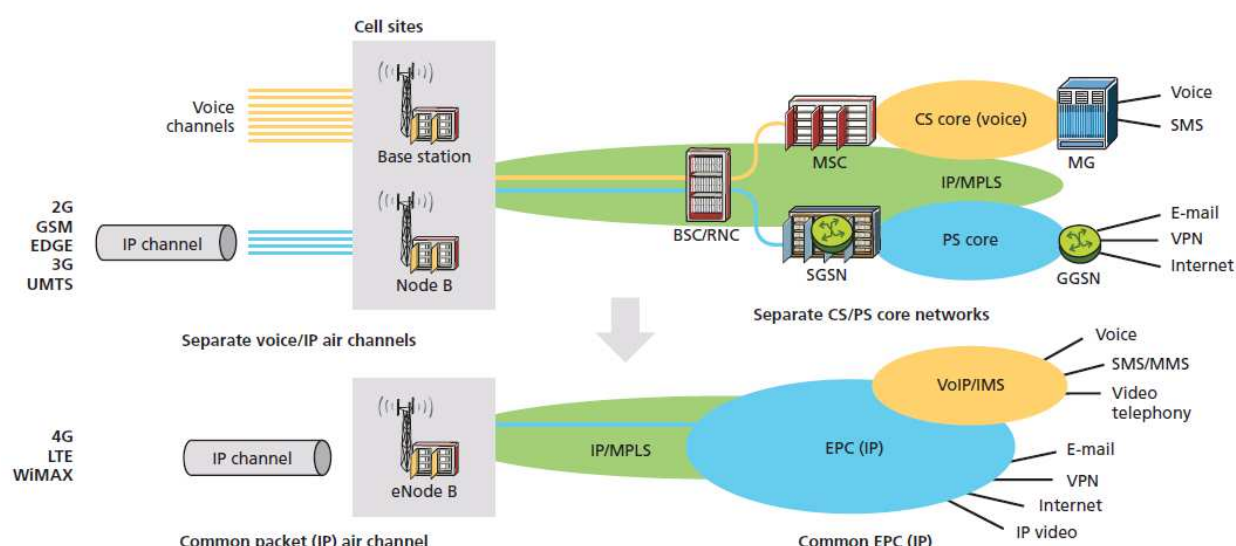
Fig. 2. LTE to IP/MPLS and EPC

Currently, there is competition for the dominant 4G standard. Advanced LTE has a higher market share than advanced WIMAX because it is part of the evolution of GSM and UMTS networks and represents 80% of the worldwide market. However, WIMAX today has a significant market share in the United States. We believe that both LTE and WIMAX meet standard requirements and are compatible with the architectures proposed for an all IPv6/MPLS approach both in access networks as the core of the network.

This chapter is focusing in the integration of mobility protocol (IPv6 extensions) and the protocol of quality of services (MPLS). The RSVP protocol has been used as signalization protocol. The metrics of quality of services tested are: Delay, jitter, throughput, the send and received packets, these metrics were chosen because they are the most sensitives in a handover. The integrations tested in this chapter were: HMIPv6/MPLS, FHM IPv6/MPLS, FHAMIPv6/AODV and FHAMIPv6/MPLS. In order to achieve these integration was necessary modify the source codes and adapt the simulator versions (NS-2). In order to integrated protocols performance as a new protocol.

## 2. HMIPv6/MPLS integration

In response to the demands of multimedia services on existing mobile systems, cellular areas will have a smaller radius in order to support higher throughput, ensuring acceptable error rates. Having small cells means that the MN can cross borders more frequently and signalling capacity will increase rapidly. In this section, we will integrate HMIPv6 and MPLS. The architecture used is the proposal by Robert Hsieh. We use us the scenario base (R. Hsieh) and then increasing the number nodes and flow of traffic in order to analyse the scalability of this integration. We analyse the relationship between the different metrics and the number nodes, the main idea is that in an handover the metrics of quality of service will be optimized or by default it's were not degraded. The metrics used were: delay, jitter, send and received packets and throughput. This metrics were chosen because they are most sensitive in a handover.

In other work, was evaluating the HMIPv6/MPLS integration, this works were tested in different scenarios [2,],[8],[9],[10] the integrations were HMIPv6/MPLS/RSVP and the

simulation scenario was made in a LAN and WAN networks. In these integrations, the RSVP protocol was used as signalling protocol while hierarchical MPLS nodes were used to achieve interoperability of HMIPv6 and MPLS.

The results obtained in [2],[8],[9],[10] showed that this interoperability is a good alternative to provide QoS in LAN and WLAN networks. In order to better the load signalisation in a handover, in case of Binding Update the HMIPv6/MPLS was used as preliminary work with the idea of future integration FHMIPv6/MPLS and FHMIPv6/MPLS in Ad hoc networks.

## 2.1 HMIPv6/MPLS integration in a scenario with CBR

### 2.1.1 Simulation scenario

The scenario simulated is shown (R. Hsieh) in figure 3. The MN is in the area of HA. The traffic used was CBR because is most sensitive in audio/video application. The Bandwidth configuration and delay of each link go as follows:

| Link | Delay | Bandwidth |
|---|---|---|
| CN-LSR1 | 2ms | 100Mb |
| LSR1-HA | 2ms | 100Mb |
| LSR1-MAP | 50ms | 100Mb |
| MAP-LSR2 | 2ms | 10Mb |
| MAP-LSR3 | 2ms | 10Mb |
| LSR2-PAR | 2ms | 1Mb |
| LSR3-NAR | 2ms | 1Mb |

Table 1. Simulation scenarios

The traffic used was CBR, since it allows audio and video simulation in real time. These applications have a high demand of QoS.

The figure 3 shows the topology of the simulated network. MPLS is the core of the network and is constituted by the following nodes: 1 (MAP), 2 (LSR1), 3 (LSR2), 4 (LSR3), 7 (LER1 for MPLS and PAR for HMIPv6) and 8 (LER2 for MPLS and NAR for HMIPv6); the tag distribution protocol used by MPLS is RSVP. Finally number 6 is the MN.

Every link shows two of their characteristics: bandwidth (in megabits or kilobits) and delay (in milliseconds).

The figure 3 shows the topology of the simulated network. MPLS is the core of the network and is constituted by the following nodes: 1 (MAP), 2 (LSR1), 3 (LSR2), 4 (LSR3), 7 (LER1 for MPLS and PAR for HMIPv6) and 8 (LER2 for MPLS and NAR for HMIPv6); the tag distribution protocol used by MPLS is RSVP. Finally number 6 is the MN.

Every link shows two of their characteristics: bandwidth (in megabits or kilobits) and delay (in milliseconds).

A few seconds later MN moves toward area PAR/LER as the figure 4 illustrate, finally the MN moves to area NAR/LER as the figure 5 illustrates.
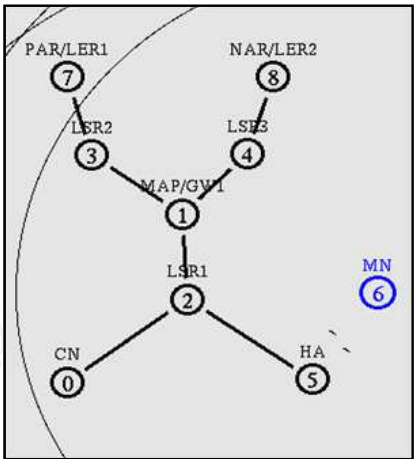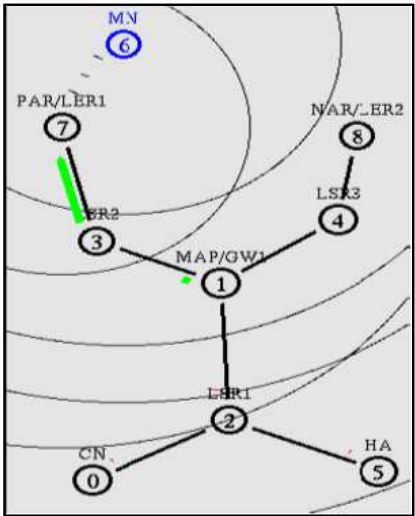
Fig. 3. Scenario of HMIPv6/MPLS simulation
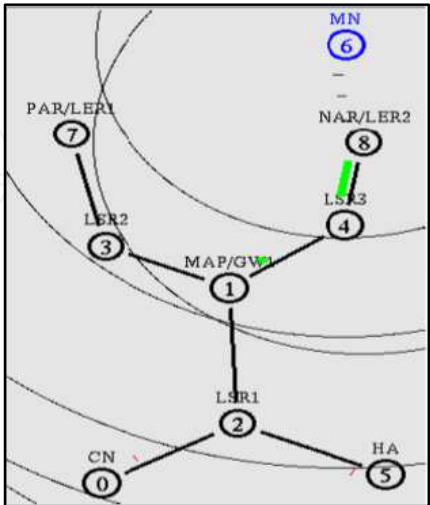


Fig. 4. MN moves the area PAR/LER



Fig. 5. MN moves the area NAR/LER

Finally, the MN moves to area NAR/LER as the figure 5 illustrates.

### 2.1.2 Description of simulation

Initially, the MN is located in the area of the HA. 2 seconds after the start of the simulation, the HA moves towards the area of the PAR at 100 m/s, arriving at t=3.5 s approximately. At t=5 s, the CN begins sending CBR traffic to the MN following the route CN→LSR1→HA→LSR1→MAP→LSR2→PAR-MN as shown in figure 3. Then, at t=10 s, the MN starts moving to the area of the NAR at 10 m/s. At the same time, the handover takes places at around t=13.12 s and the MN receives one of the first packets from the NAR. Afterwards, the MN places in the area of the NAR at around t=17 s. Finally, at t=19 s, the CN stops sending traffic flow towards the MN.

**Simulation scenarios**
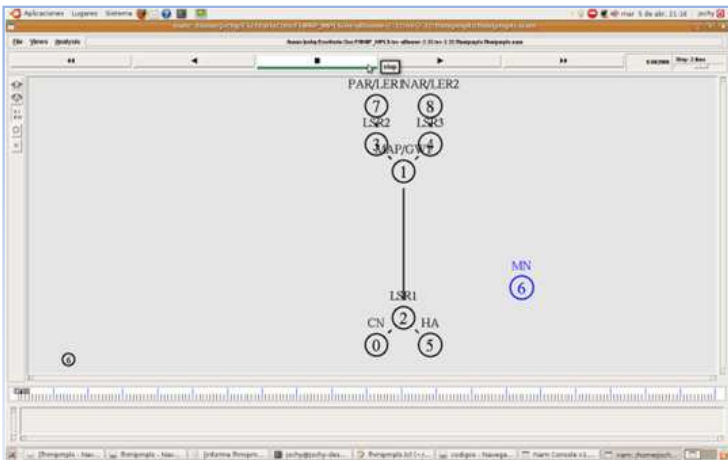


Fig. 6. Scenario with 9 nodes Figure
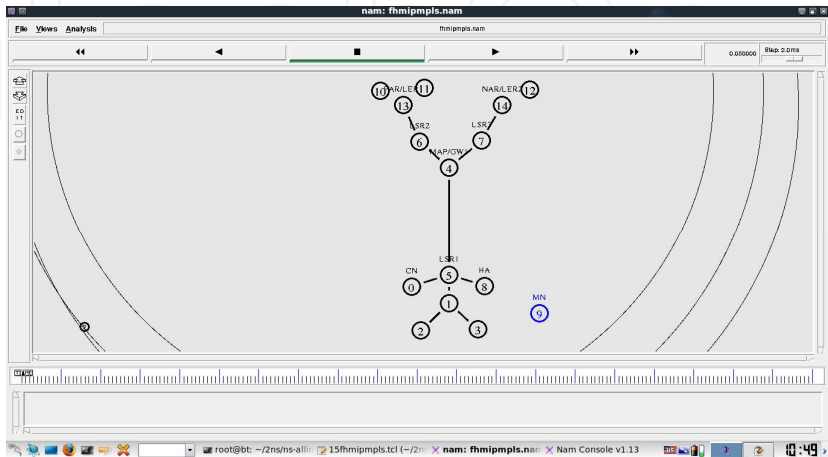


Fig. 7. Scenario with 15
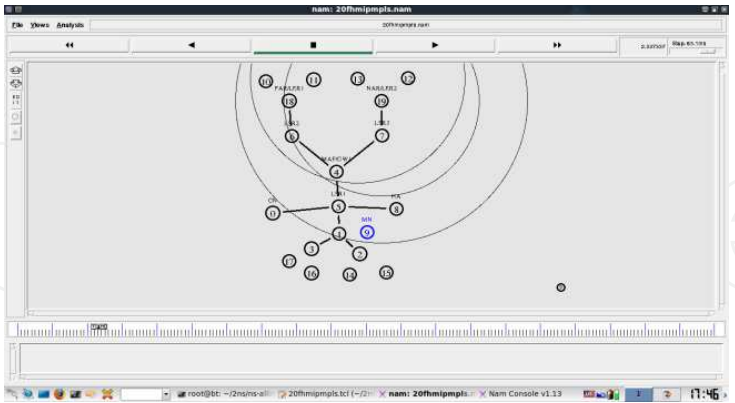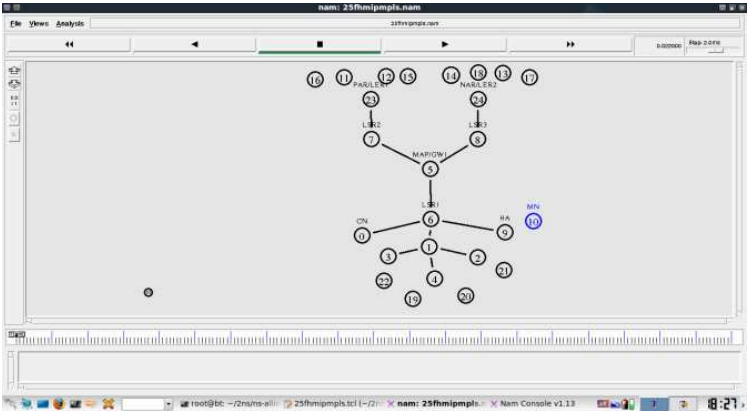
Fig. 8. Scenario with 20 nodes
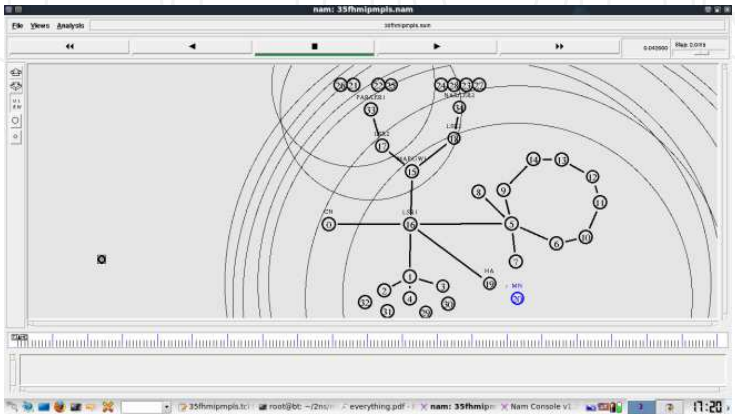


Fig. 9. Scenario with 25 nodes
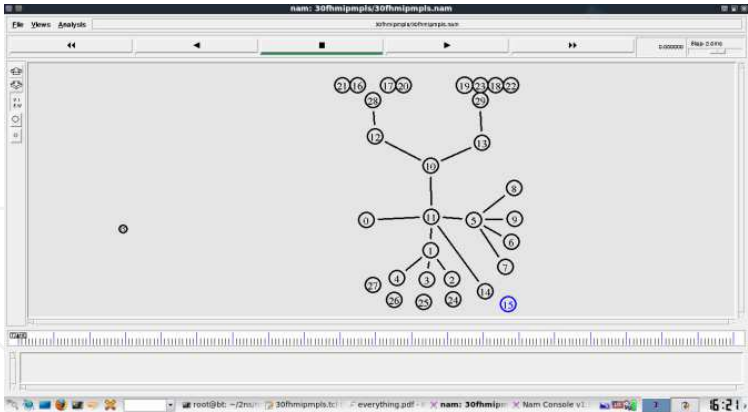


Fig. 10. Scenario with 30 nodes
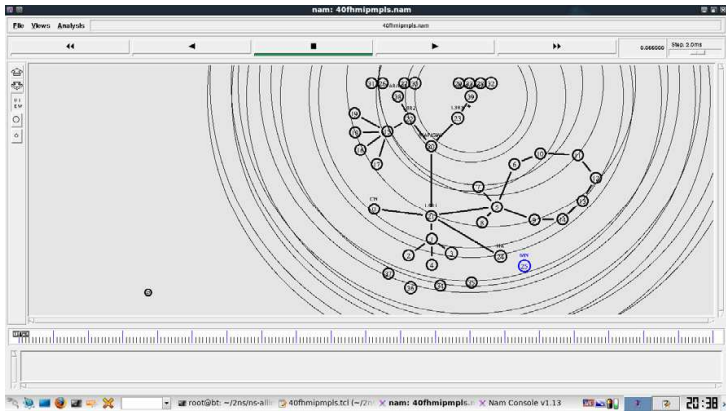
Fig. 11. Scenario with 35 nodes



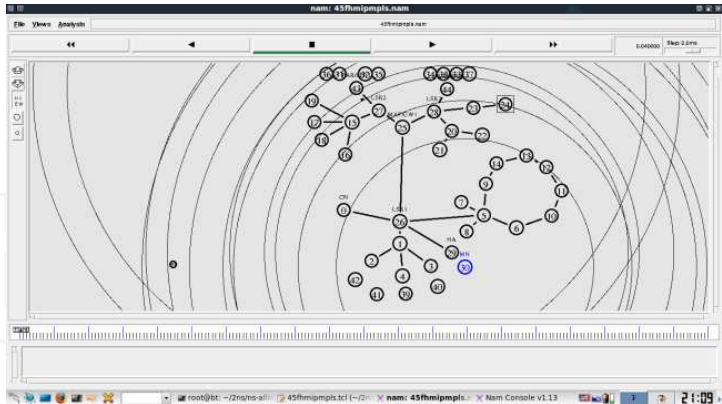Fig. 12. Scenario with 40 nodes.



Fig. 13. Scenario with 45 nodes.

## 2.2 Scalability

The objective of this simulation with different scenarios was to analyse QoS metrics in HMIPv6/MPLS integration with CBR traffic and the scalability. The table2 show the different scenarios simulated. The first scenario was proposal by R.Hsieh, the other scenarios were increasing the number nodes in order to test the scalability, the table show the results of different metrics analysed.

| Scenario\ Metrics | Delay(ms) | Jitter(ms) | Throughput (Kbps) | Sends Packets | Received Packets | Lost Packets (%) |
|---|---|---|---|---|---|---|
| 9 Nodes | 66,85 | 0,46 | 424,80 | 3734 | 3734 | 0% |
| 15 Nodes | 226,66 | 1,97 | 356,11 | 3734 | 3151 | 15,61% |
| 20 Nodes | 254,70 | 1,84 | 359,60 | 3734 | 3204 | 14,20% |
| 25 Nodes | 317,92 | 4,0 | 277,60 | 3734 | 2476 | 33,70% |
| 30 Nodes | 310,73 | 3,60 | 288,27 | 3734 | 2571 | 31,15% |
| 35 Nodes | 312,95 | 3,80 | 279,96 | 3734 | 2497 | 33,13% |
| 40 Nodes | 331,80 | 4,31 | 268,22 | 3734 | 2392 | 35,94% |
| 45 Nodes | 341,70 | 4,60 | 261,90 | 3467 | 2156 | 37,81% |

Table 2. Results of different scenarios HMIPv6/MPLS integration

The table 2 shows the results of HMIPv6/MPLS integration. The metrics analysed were: delay, jitter, throughput, sent packets, received packets and lost packets. From the results obtained, we can affirm that, in general, the delay increases as the number of nodes increases. The jitter grows significantly when there are more than 25 nodes. The throughput shows a slight variation, but it does not follow a particular pattern. Sent packets, normally, remain constant; the received packets, generally, decrease as the number of nodes grows and the number of lost packets increases significantly when there are more than 25 nodes.

The figure 14 shows the results of the following metrics obtained of the table 2. In this manner can visualize the behaviour of delay, throughput, send and received packets against the quantity of number of nodes.
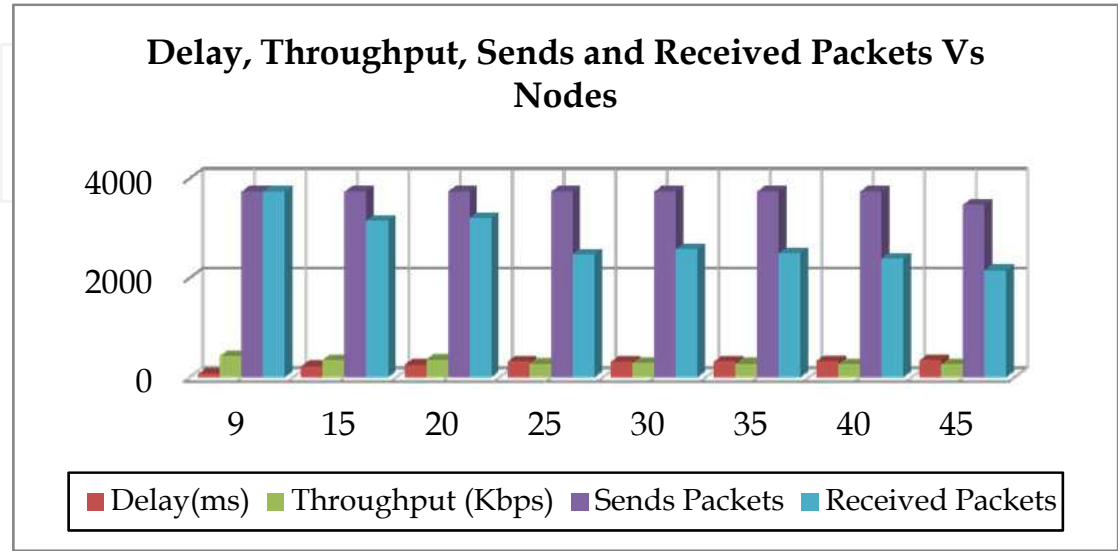


Fig. 14. Delay, throughput, send an received packets Vs. Number nodes

In order to extend the different results obtained in the simulations, the functions (figure15) show the behaviour of the different simulation scenarios. With these functions we could predict what will happen with the metrics (Delay, Throughput, Send and Received Packets) against the number of nodes. In this manner, we could predict what happen when the number of nodes and flow are traffic is increased.
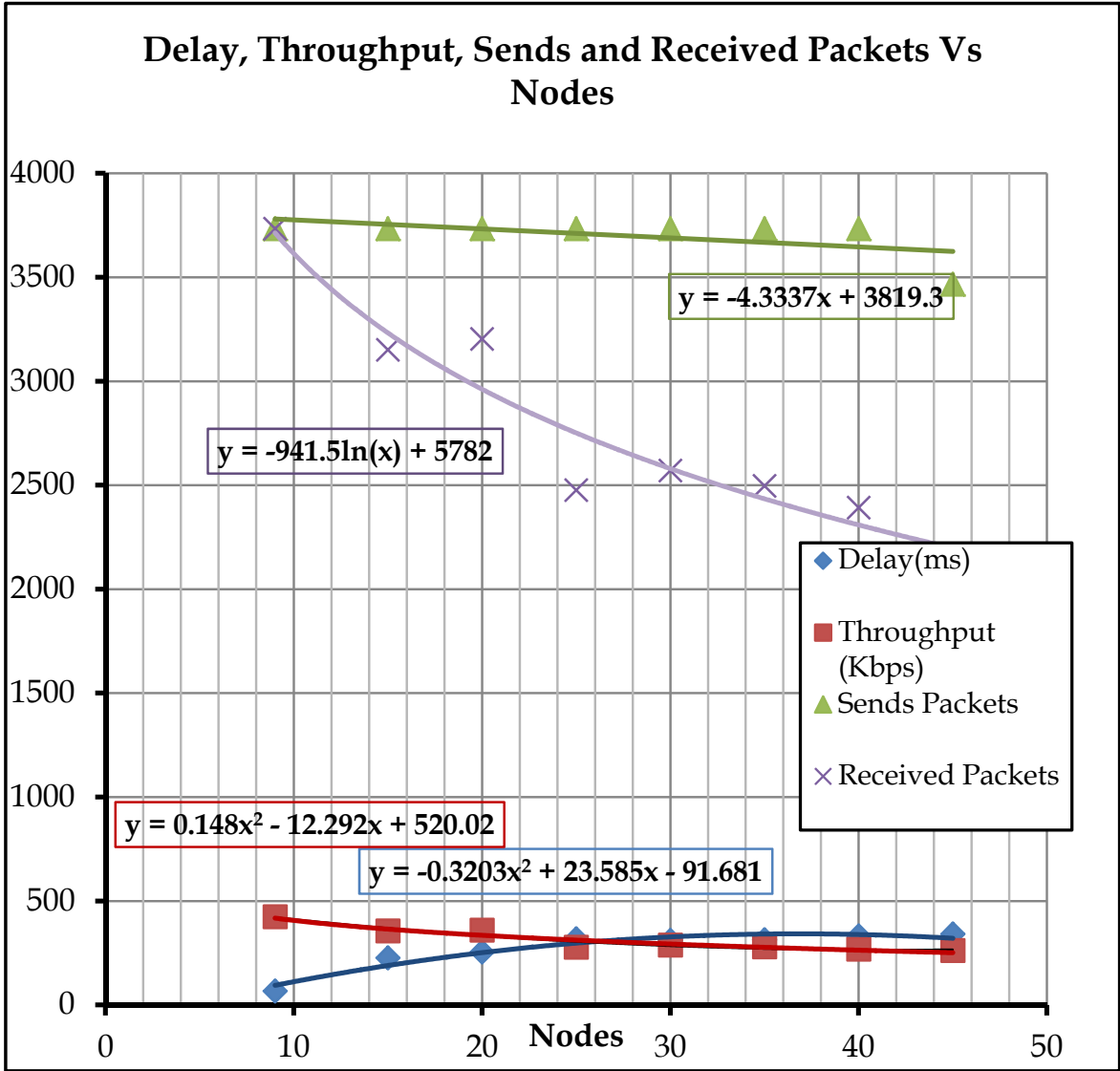


Fig. 15. The functions show the scalability of Delay, Throughput, send and received packets.

The figure 16 shows the results of the following metrics obtained of the table 2. In this manner can visualize the behaviour of Jitter and Lost Packets with different number nodes.
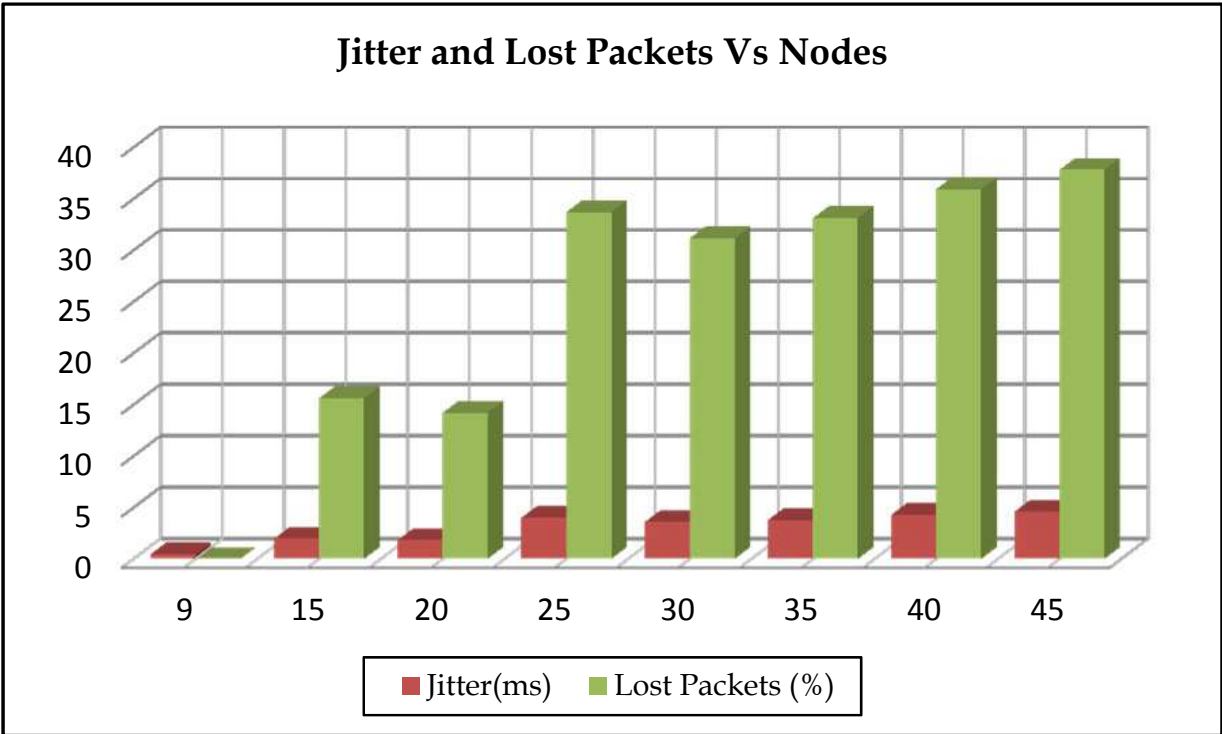


Fig. 16. Jitter and Lost Packets vs. Number nodes

In order to extend the different results obtained in the simulations, the function (figure17) shows the behaviour for different scenarios of simulation. With this functions (Jitter, Lost
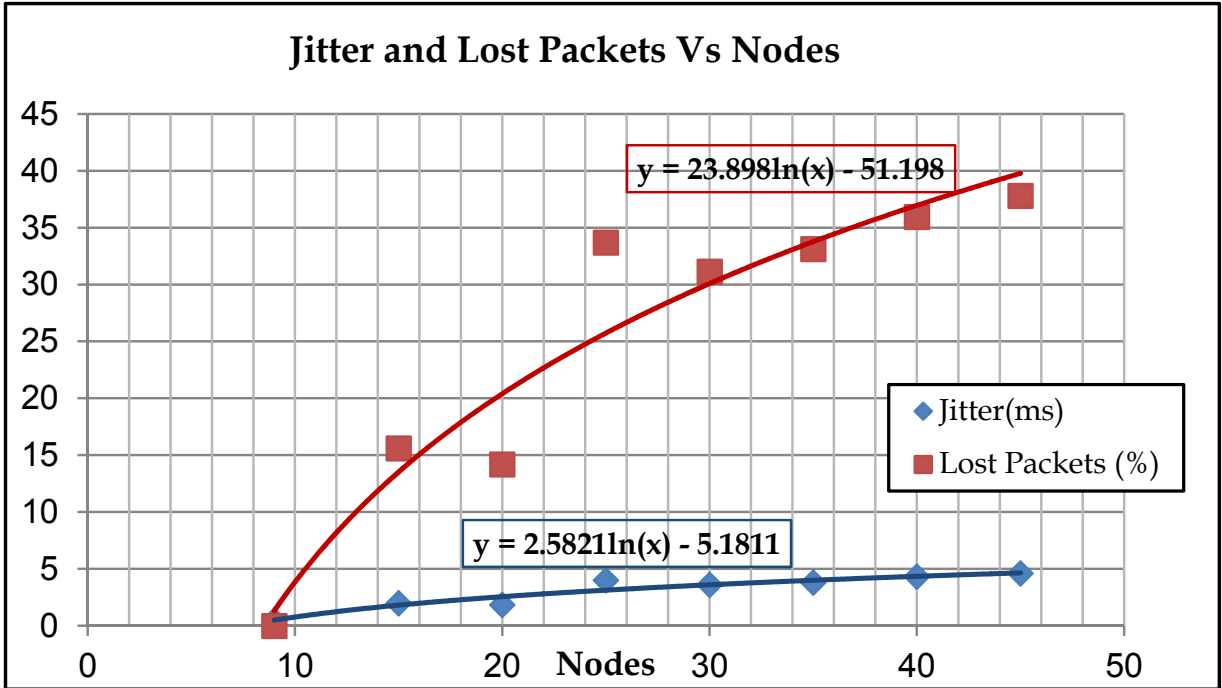


Fig. 17. The functions show the scalability of Jitter and Lost Packets vs. Number nodes

Packets) against the number of nodes. In this manner, we could predict what happen when the number of nodes and flow are traffic is increased.

## 2.3 Conclusions

In this case, we performed the HMIPv6/MPLS scenario simulation using CBR as test traffic. Various QoS metrics were analysed, such as delay, which on average was 66,82 ms; the jitter, which was rather variable, and throughput, which reached 446,0 Kbps on average. On the other hand, in the course of the simulation, 3,74 packets were sent and 207 were lost; that represents 5,54% of all packets. Therefore, we conclude that the simulation scenario showed very good values of delay and throughput, acceptable packet loss and very irregular jitter figures, so that, in order to achieve good levels of QoS, the performance of jitter has to be improved. A similar scenario with FHMIPv6 instead of HMIPv6 could solve this point.

## 3. FHMIPV6/MPLS integration

One of the major problems encountered in the integration HMIPv6/MPLS is the amount of signaling load in Binding Update (BU). Especially in case of a handover. At the time of BU can cause problems of safety and quality of services. With respect to security can be sent or received malicious messages, relative to the quality of services, excessive signaling load can significantly degrade the QoS metrics evaluated.

For this reason, we propose FHMIPv6/MPLS integration as a mechanism that will avoid both these problems. FHMIPv6 has a process of pre and post registration which keeps the communication between the mobile node and access router. FHMIPv6 has a process of pre and post registration which solves the problem observed in HMIPv6/MPLS integration. This we can say based on the work of R. Hsieh. FHMIPv6/MPLS integration has been made in the same manner as HMIPv6/MPLS integration. This integration allows us to compare which is better.

Is important mentioned, Fast Handover for Mobile IPv6 (FMIP) is a mobile IP extension that allows the MN to set up a new CoA before a change of network happens. This is possible because it anticipates the change of the router of access when an imminent change of point of access is detected. This anticipation is important because it minimises the latency during the handover, when the MN is not able to receive packets.

FHMIPv6 had been initially proposed by Robert Hsieh [hsieh03] as a way of integrating Fast Handover and HMIPv6 and shows why this integration is a better option than HMIPv6 alone.

### 3.1 Scenario of simulation

The scenario simulated is shown in figure18. The MN is in the area of HA. Bandwidth configuration and delay of each link are shown below in table3.

The traffic used was CBR, since it allows audio and video simulation in real time. These applications have a high demand of QoS.

Figure18 shows the topology of the simulated network. MPLS is the core of the network and is constituted by the following nodes: 1 (MAP), 2 (LSR1), 3 (LSR2), 4 (LSR3), 7 (LER1 for

| Link | Delay | Bandwidth |
|------|-------|-----------|
| CN-LSR1 | 2ms | 100Mb |
| LSR1-HA | 2ms | 100Mb |
| LSR1-MAP | 50ms | 100Mb |
| MAP-LSR2 | 2ms | 10Mb |
| MAP-LSR3 | 2ms | 10Mb |
| LSR2-PAR | 2ms | 1Mb |
| LSR3-NAR | 2ms | 1Mb |

Table 3. Bandwidth and delay configuration

MPLS and PAR for F-HMIPv6) and 8 (LER2 for MPLS and NAR for F-HMIPv6); the tag distribution protocol used by MPLS is RSVP.
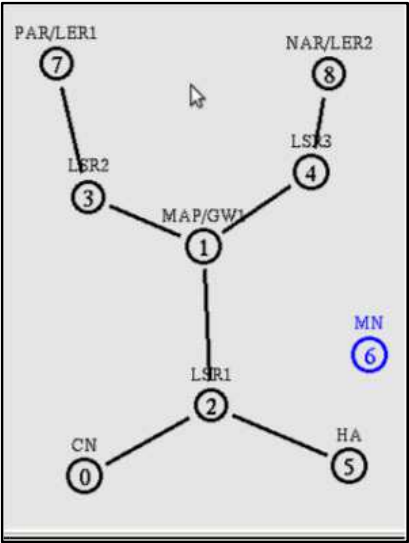


Fig. 18. Scenario FHMIPv6/MPLS Integration

Every link shows two of their characteristics: bandwidth (in megabits or kilobits) and delay (in milliseconds). A few seconds later, the MN moves towards the area of PAR, as figure 19 proves.

Finally, the MN moves to the area of NAR (figure20).

### 3.2 Description of simulation

Initially, the MN is located in the area of the HA. 2 seconds after the start of the simulation, the HA moves towards the area of the PAR at 100 m/s, arriving at t=3,5 s approximately. At t=5 s, the CN begins sending CBR traffic to the MN following the route CN→LSR1→HA→LSR1→MAP→LSR2→PAR→MN as shown in figure 19. Then, at t=10 s, the MN starts moving to the area of the NAR at 10 m/s. At the same time, the handover takes places at around t=13,12 s and the MN receives one of the first packets from the NAR at t=13,14 s approximately. Afterwards, the MN places in the area of the NAR at around t=17 s. Finally, at t=19 s, the CN stops sending traffic flow towards the MN.
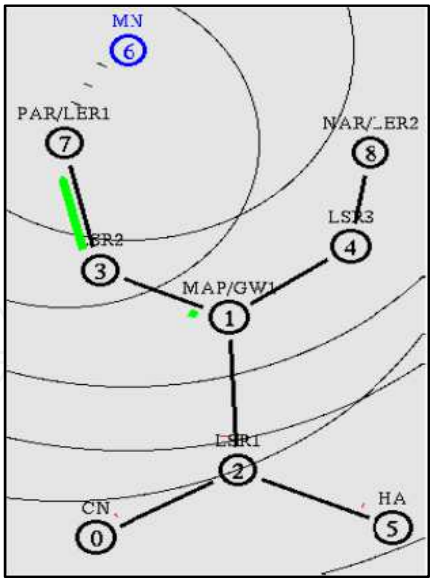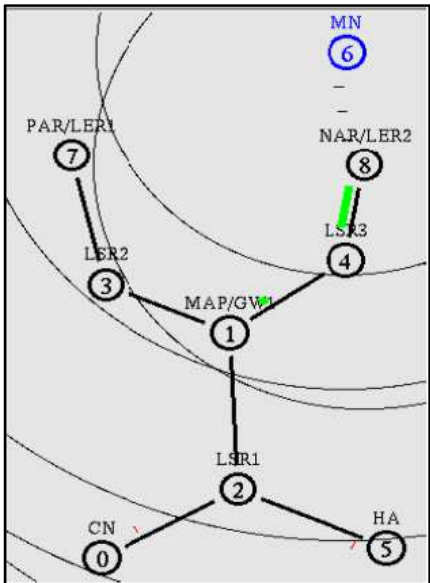
Fig. 19. The MN moves towards the area of PAR



Fig. 20. The MN moves to the area of NAR

### 3.3 Scalability

The objective of this simulation with different scenarios was to analyse QoS metrics in HMIPv6/MPLS integration with CBR traffic and the scalability. The table4 show the different scenarios simulated. The first scenario was proposal by R.Hsieh, the other scenarios were increasing the number nodes in order to test the scalability, the table show the results of different metrics analysed.

The table4 shows that the delay, jitter, throughput and packet loss rate vary slightly as the topology and the network flow increase. Therefore, we can conclude that the FHMIPv6/MPLS integration keeps the quality of service (QoS) high, despite the growth of the network and the traffic flow.

| Nodes | Delay(ms) | Jitter(ms) | Throuhgput (Kbps) | Send Packets | Received Packets | Lost Packets (%) |
|---|---|---|---|---|---|---|
| 9 | 67,16 | 0,47 | 446,05 | 3734 | 0 | 0 |
| 15 | 278,82 | 2,41 | 334,37 | 3734 | 2871 | 23,11 |
| 20 | 255,9 | 2,03 | 372,54 | 3734 | 3158 | 15,43 |
| 25 | 314,41 | 4 | 286,64 | 3734 | 2435 | 34,8 |
| 30 | 315,12 | 3,6 | 303,89 | 3734 | 2582 | 30,85 |
| 35 | 313,62 | 4,04 | 286,96 | 3734 | 2437 | 34,73 |
| 40 | 305,83 | 4,03 | 281,91 | 3734 | 2395 | 35,86 |
| 45 | 309,3 | 4,28 | 274,85 | 3467 | 2168 | 31,96 |

Table 4. FHMIPv6/MPLS Integration

The (figure 21) shows the results of the following metrics obtained of the table 2. In this manner can visualize the behavior of: delay, throughput, send and received packets against the quantity of number of nodes.
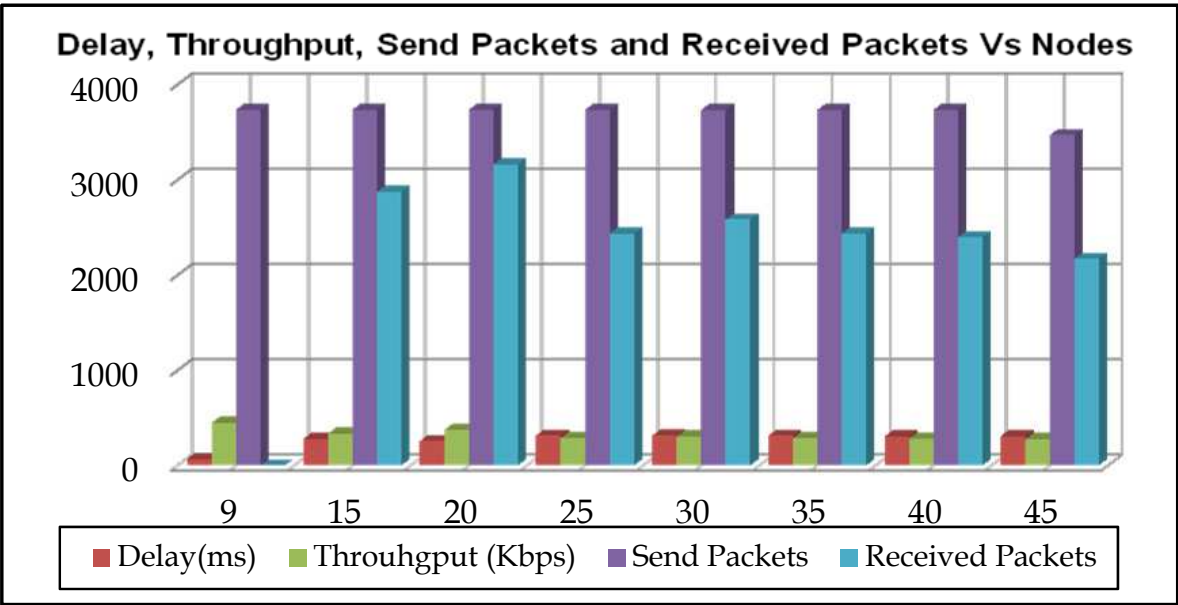


Fig. 21. Delay, Throughput, Send and Received Packets vs. number nodes

In order to extend the different results obtained in the simulations, the function (figure22) shows the behavior for different scenarios of simulation. With this functions can know what happened with the metrics (Delay, Throughput, Send and Received Packets) and the number nodes. In this manner we could predict what happens when the number of nodes and flow of the traffic are increased.
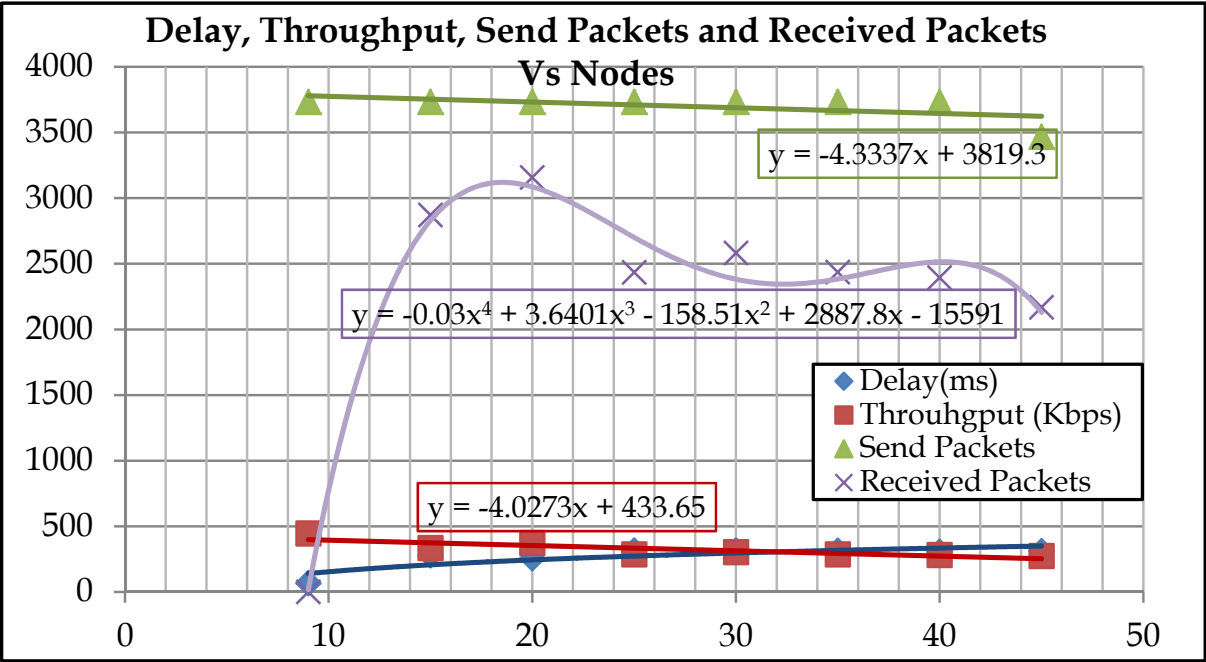


Fig. 22. The functions shows the delay, throughput, send and received packets vs. number nodes

The (figure23) shows the results of the following metrics obtained of the table 2. In this manner can visualize the behavior of jitter and lost packets nodes and the number nodes.
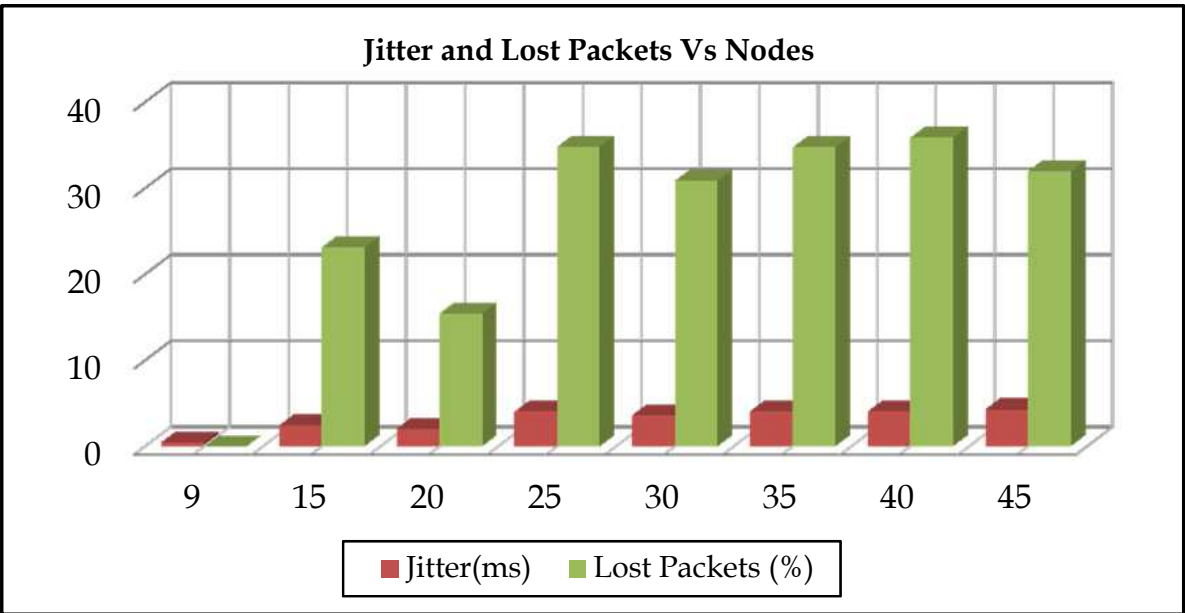


Fig. 23. The functions shows the jitter and lost packets vs. number nodes

**Jitter and Lost Packets Vs Nodes**

$y = 0.0005x^3 - 0.0849x^2 + 4.1635x - 29.116$

$y = 2.3349\ln(x) - 4.3559$
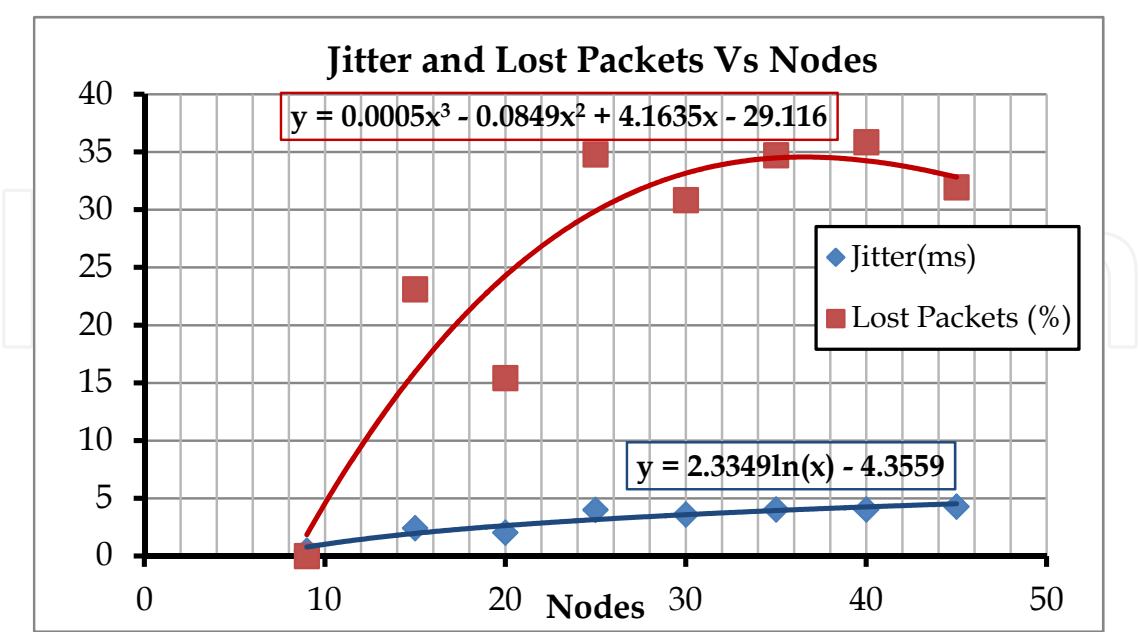
♦ Jitter(ms)

■ Lost Packets (%)

**Nodes**

Fig. 24. The functions shows the jitter and Lost packets vs number nodes

In order to extend the different results obtained in the simulations, the function (figure24) shows the behavior for different scenarios of simulation. With this functions can know what happened with the metrics (Delay, Throughput, Send and Received Packets) and the number nodes. In this manner we could predict what happens when the number of nodes and flow of the traffic is increased.

## 4. FHAMIPv6/AODV integration

FHAMIPv6/AODV present the integration of protocol Fast Hierarchical Ad-Hoc Mobile IPv6 (FHAMIPv6) and the Ad hoc On Demand Distance Vector (AODV). The integration shows the effects of FHAMIPv6/AODV about the QoS. The simulation was realized in NS-2 version 2.32. The traffic used is TCP. We analyze the delay, jitter and throughput in an end to end communication. The metrics from the ACN perspective are presented. The integration FHAMIPv6/AODV is a work advance of the integration FHAMIPv6/ MPLS/ AODV in order to provide quality of service in MANET networks. We can consider FHAMIPv6/AODV and the following integration FHAMIPv6/MPLS as part of the development of LTE standard included in the all-IP concept that allows us to meet some requirements of LTE.

From the table 5 highlight the link AN1 - MAP/GW1 has a bandwidth and delay than the rest, because it represents a connection to the Internet.

The (figure25). Shows that initially (6) AMN is in the area of the (5) AHA in communication with the (0) ACN, also we can see that the core consists of MPLS nodes MAP/GW1, LSR2, LSR3, PAR/LER1, NAR/LER2.

Where MAP/GW1 node performs the functions of default gateway, nodes and LSR3 LSR2 are used simultaneously as routers, LSPs and FHAMIPv6 intermediate nodes.

| Link | Bandwith(Mbps) | Delay(ms) |
|------|----------------|-----------|
| AN1-- MAP/GW1 | 100 | 50 |
| MAP/GW1 – LSR2 | 10 | 2 |
| MAP/GW1 – LSR3 | 10 | 2 |
| LSR2 -- PAR/LER1 | 1 | 2 |
| LSR3 -- NAR/LER2 | 1 | 2 |

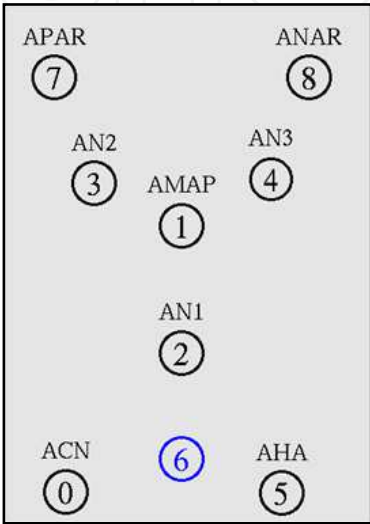Table 5. Characteristics of the links FHAMIPv6/AODV



Fig. 25. Illustrates the simulation scenario (base)

Nodes can also be NAR/LER2 PAR/LER1 and have functions MPLS edge router and access router FHAMIPv6.

On the other hand, operates as a node AN1 intermediate FHAMIPv6 but no MPLS features, while ACN and AHA are the CN and HA, respectively, at last, and AMN is the mobile node MN.

## 4.1 Description of simulation

The AMN (blue node in (figure23) is initially located in the area of the ACN. Here, communication between these nodes occurs with no intermediary elements.

In the 1,3th s, ACN starts to transmit TCP packets towards the AMN. They are transmitted with an average delay of 4,99s. Until the 5th s, communication flows normally. After the 5th s, the AMN starts to move towards the APAR. While this is happening, communication with the ACN is not affected until the 5,43th s, when it is out of the ACN rank. From that mentioned instant until the 6,53th s, the AMN does not receive any packets from the ACN. In the 6,27th s, the AMN locates next to APAR. Around this time (and in many other moments) certain UDP signalling is shown in the network. This signalling corresponds to the AODV signalling packets. That routing protocol takes almost 250 ms to learn the new AMN position. It is only in the 6,53rd s that the AMN resumes the session with the ACN. From that instant until the 14,6th s, communication results as follows:

$$ACN \rightarrow AN1 \rightarrow AMAP \rightarrow AN2 \rightarrow APAR \rightarrow AMN$$

In that moment, the AMN begins moving towards the ANAR and finishes in the 15,0th s. In the 15,08rd s the AMN receives the first packet from the ANAR. From then on, this will be the route that will allow the AMN access to the FHAMIP network. Simulation ends after 20 seconds of starting.

### 4.2 Scalability

The figure26 shows the results of the following metrics obtained of the table6. In this manner can visualize the behavior of: delay, throughput, send and received packets against quantity of number nodes.

| Nodes | Delay(ms) | Jitter(ms) | Throughput(Kbps) | Send Packets | Received Packets | Lost Packets (%) |
|---|---|---|---|---|---|---|
| 15 | 320,93 | 52,76 | 136,32 | 655 | 615 | 6,11 |
| 20 | 308,03 | 46,92 | 136,9 | 658 | 617 | 6,23 |
| 25 | 330,34 | 58,05 | 126,04 | 608 | 571 | 6,09 |
| 30 | 314,55 | 59,67 | 99,5 | 460 | 450 | 2,17 |
| 35 | 263,93 | 50,65 | 111,7 | 539 | 505 | 6,31 |
| 40 | 214,36 | 62,8 | 75,71 | 354 | 332 | 6,21 |
| 45 | 309,0 | 104,53 | 56,23 | 267 | 255 | 4,5 |

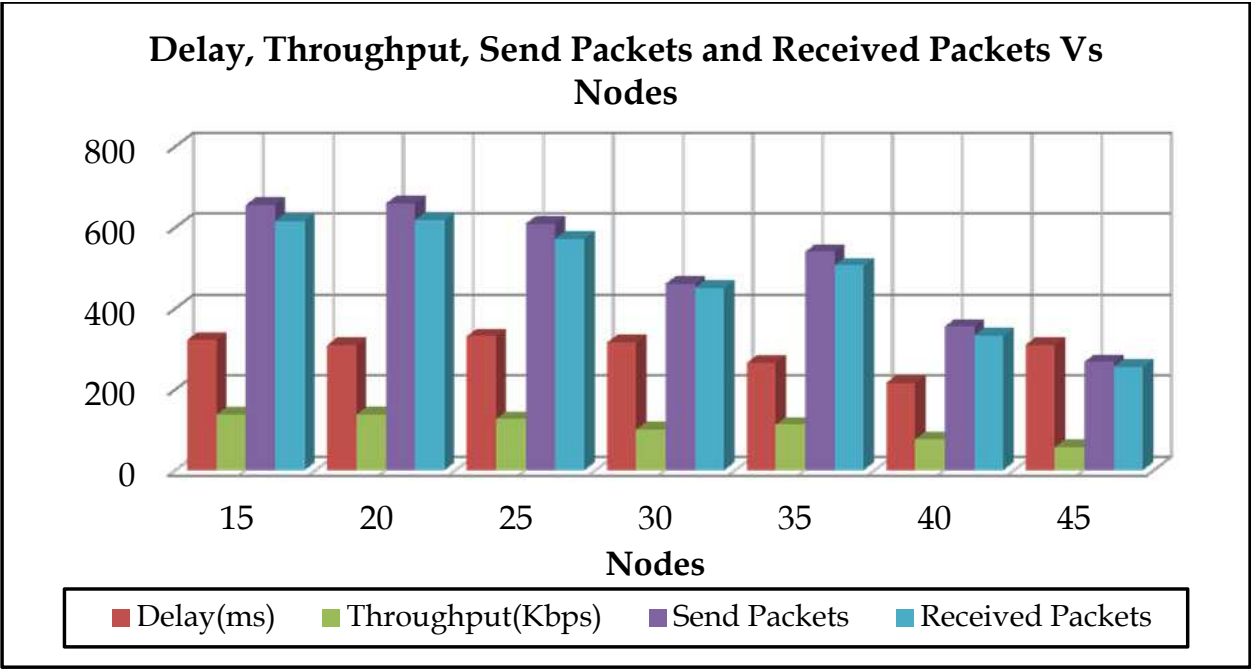Table 6. Shows FHAMIPv6/AODV



Fig. 26. Delay, Throughput, Send and Received Packets vs. Number nodes

In order to extend the different results obtained in the simulations, the function (figure27) shows the behavior for different scenarios of simulation. With this functions could predict what happens with the metrics (Delay, Throughput, Send and Received Packets) against quantity of number of nodes. In this manner we could predict what happen when the number of nodes and the flow are traffic is increased.
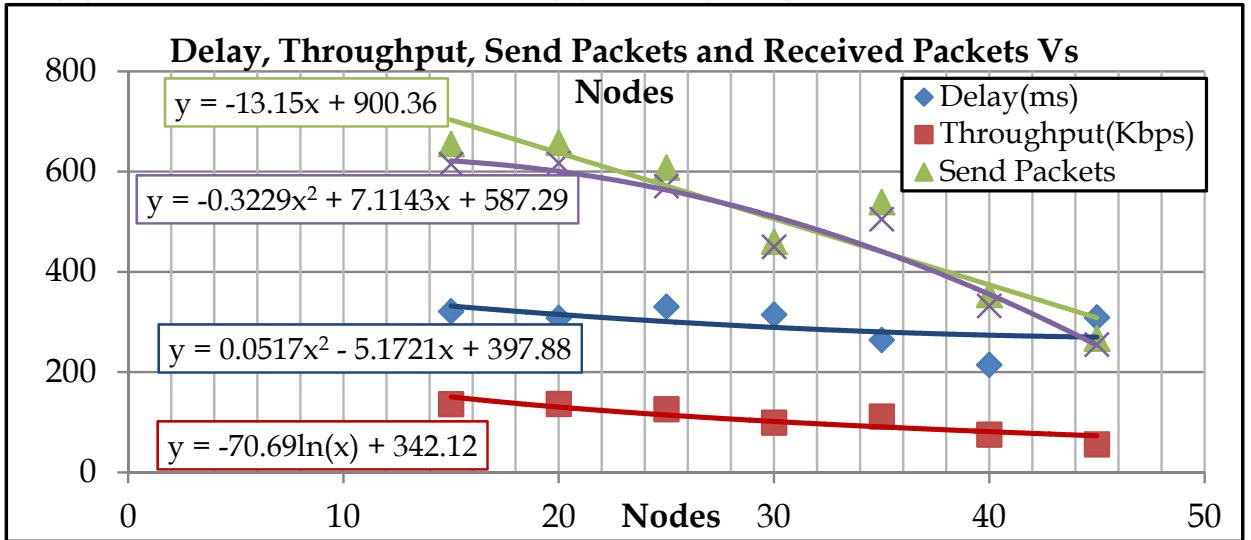


Fig. 27. The figure show the functions Delay, Throughput, Send and Received Packets an Number nodes

The figure 28 shows the results of the following metrics obtained of the table 2. In this manner can visualize the behavior of delay, throughput, send and received packets with different number nodes.
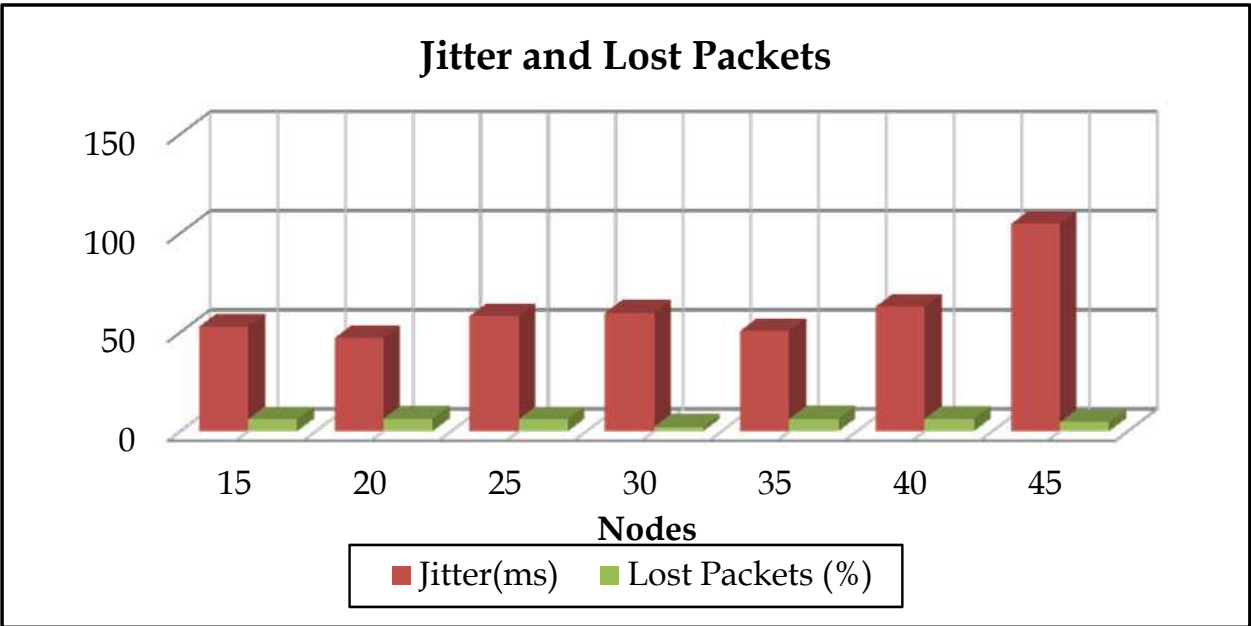


Fig. 28. Jitter and Lost Packets vs Number nodes

In order to extend the different results obtained in the simulations, the function (figure29) shows the behavior of the different simulation scenarios. With this functions could predict what will happen with the metrics (Delay, Throughput, Send and Received Packets) and the number nodes. In this manner, we could predict what happens when the number of nodes and flow of the traffic is increased.
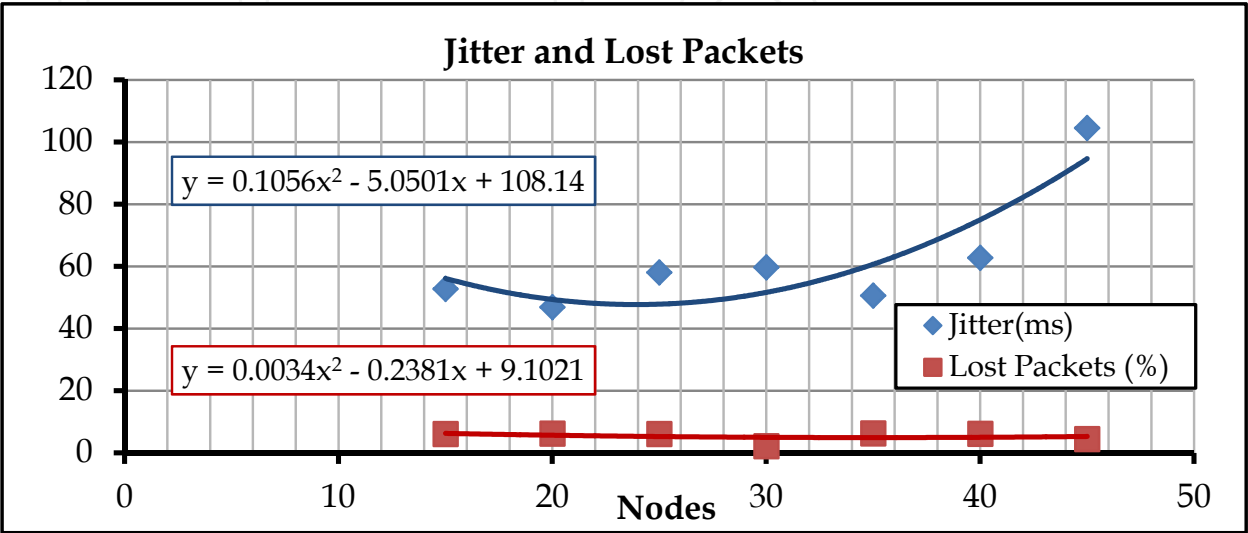


Fig. 29. The figure show the functions Jitter and Lost Packets vs. Number nodes

### 4.3 Conclusions

This research shows the effects of the FHAMIP/AODV integration over the QoS metrics. The simulation proved that the average delay was approximately 112,27 ms and was penalized by the AODV signalling, so it was necessary to update the status of the routes. On the other hand, the average jitter analysed reached 38 ms.

Regarding the loss of packets, a total of 86 did not reach the destination. Most of them were lost when the AMN moved either towards the APAR or to the ANAR.

The jitter was quite satisfactory given the fact that it exceeds 176 Kbps. In general, the delay and the jitter suffer the strong effects of the AODV routing updates. Some nodes stop sending TCP packets to transmit useful AODV signalling to recalculate routes, increasing the delay in a TCP session significantly. A possible solution (assuming that only a node moves on) would be to modify AODV in order to stop routes updating until the APAR and the ANAR receive a MAP_REG_REQUEST from the AMN. This would indicate that the AMN is in its own area.

## 5. FHAMIPv6/MPLS integration

FHAMIPv6 protocol was created as an extension to support FHMIPv6 hierarchical addresses in MANET networks, but FHAMIPv6, is not an protocol to provide quality services in such networks. For this reason, it was necessary to integrate MPLS and FHAMIPv6 in order to provide QoS in MANET networks.

To achieve the integration was necessary to modify the source codes of MPLS and FHAMIP. In this section the same way as in the other sections, we used the base scenario proposed by R. Hsieh and then the number of nodes and traffic flow was increased in order to analyze the scalability of the integration. The Tests were realized with: 9, 20 and 30 nodes. The QoS metrics analyzed were: Delay, jitter, throughput, send and received packets and lost packets.

The figure 30 Shows that initially the AMN is in the area of the AHA in communication with the ACN, it can also be observed that the core MPLS is formed by MAP/GW1, LSR2, LSR3, PAR/LER1, NAR/LER2 nodes. Where the MAP/GW1 node performs the functions of default gateway, the nodes LSR3 and LSR2 are used simultaneously as Label Switching Routers and intermediate nodes FHAMIPv6; it can also be observed that the nodes PAR/LER1 and NAR/LER2 have functions of MPLS edge router and access router for FHAMIPv6. Furthermore, the node AN1 only functions as an intermediate FHAMIPv6 node and has no has no MPLS functions, while ACN and AHA nodes correspond to the corresponding node and base agent respectively, lastly the AMN node represents the mobile node. With regards to the characteristics of the wired links, table7 presents details. From the table above, we can highlight the fact that the link AN1 - MAP/GW1 has a superior bandwidth and delay than the rest, because it represents a connection with Internet.
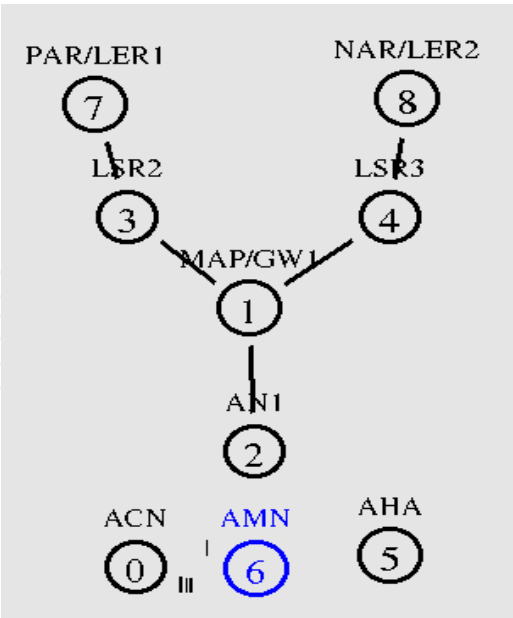


Fig. 30. Scenario of simulation

| Link | Bandwith(Mbps) | Delay(ms) |
|---|---|---|
| AN1-- MAP/GW1 | 100 | 50 |
| MAP/GW1 – LSR2 | 10 | 2 |
| MAP/GW1 – LSR3 | 10 | 2 |
| LSR2 -- PAR/LER1 | 1 | 2 |
| LSR3 -- NAR/LER2 | 1 | 2 |

Table 7. Presents the characteristics of the wired wireless links.

## 5.1 Description of simulation

This section will describe in detail, and scenario by scenario, all relevant events in each simulation, details on the movement of the AMN will be presented, the moments of reserve of resources through RSVP and some comments on the transfer; not without mentioning that for all scenarios a FTP traffic type was used and the following metrics of QoS were defined:

Delay, jitter, throughput, TCP congestion window and lost packets. The choice of the afore mentioned metrics is because they are the most affected when the amount of network traffic is very high, in addition these are the metrics that affect more significantly the traffics that have high QoS requirements such as video, audio and real-time applications.

It is noted once again that scenarios with different number of nodes were simulated to study the impact of this change in the behavior of the proposed integration compared to the QoS metrics and to evaluate the functionality of the proposed integration to such scenarios.
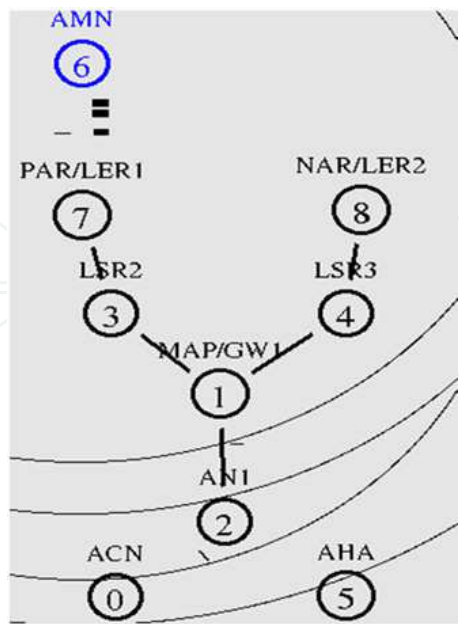


Fig. 31. AMN in PAR/LER zone

At the initial instant the mobile node (AMN) is in the area of its home agent (AHA) as shown in Figure 29, then at t = 1.2s the AMN starts transferring FTP traffic with the ACN, there upon between t = 3.5s and t = 4.5s MPLS / RSVP resource reservation takes place on the path MAP/GW1 - LSR2 - PAR/LER1. Then at time t = 10s the AMN begins its displacement towards the PAR/LER1, at a speed of 100m / s arriving shortly to this area from which it will use the PAR/LER1 - LSR2 - MAP / GW1 - AN1 route to communicate.

A few seconds later between t = 14.5s and t = 15.5s resource reservation along the route MAP/GW1 - LSR3 - NAR/LER2 takes place anticipating the subsequent transfer made by the AMN which moves at 10m / s from PAR/LER1 toward the NAR/LER2 at t = 16s. From there on, the traffic will follow the NAR/LER2 - LSR3 - MAP/GW1 - AN1 route to communicate with the ACN and the AHA. This is illustrated in the figure 32.
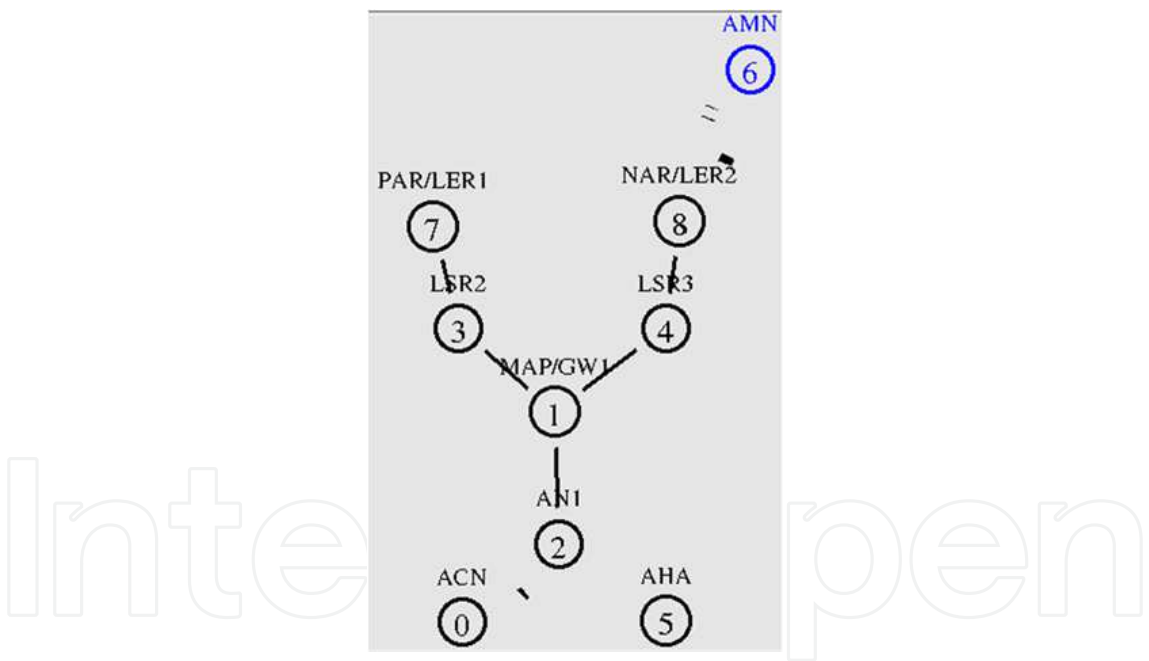


Fig. 32. AMN in NAR/LER zone

## 5.2 Scalability

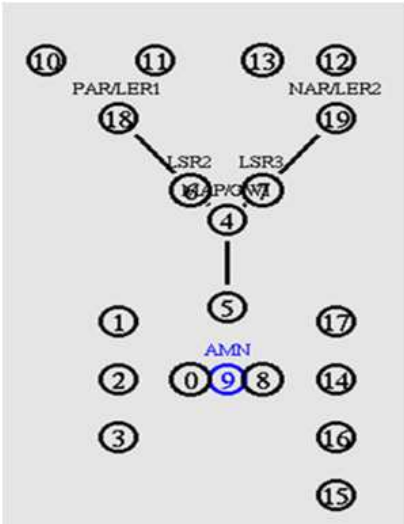In the same way, we simulated with 20 and 30 nodes. See figures 33 and 34.
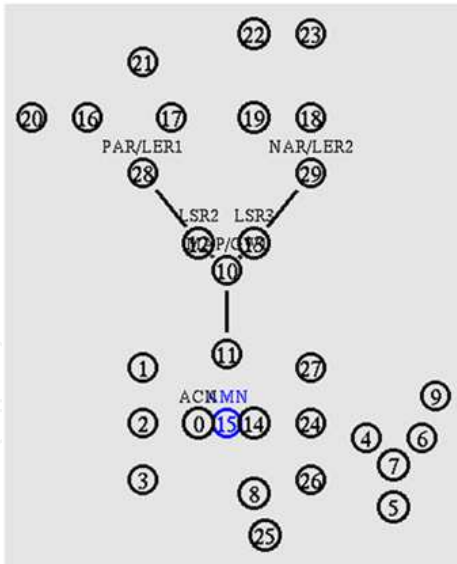
Fig. 33. Scenario with 20 nodes



Fig. 34. Scenario with 30 nodes

### 5.2.1 Analysis of delay

As shown in the (figure 35), in the time that the AMN is in the AHA zone (between t = 1.2s and t = 10s), the traffic experiences a delay below 250ms, this is due mainly to the fact that

the AMN communicates directly with the ACN, that is to say, traffic does not pass through the intermediate nodes. Then we can see a blank space, which corresponds to the time when the AMN moves towards the PAR/LER1 and does not send traffic to the ACN. Beyond the time t = 10s we can observe that the experienced delay increases, at this time the AMN is fully in PAR/LER1 zone. A few seconds later we see a growing tendency of the delay until reaching a blank space, this behavior corresponds to the time when the AMN performs the transfer from the PAR/LER1 to the NAR/LER2 between times t = 16s and t = 20s . Finally the delay adopts a regular behavior close to the 350ms, which is maintained until the end of the simulation. The average delay was 224.521ms.
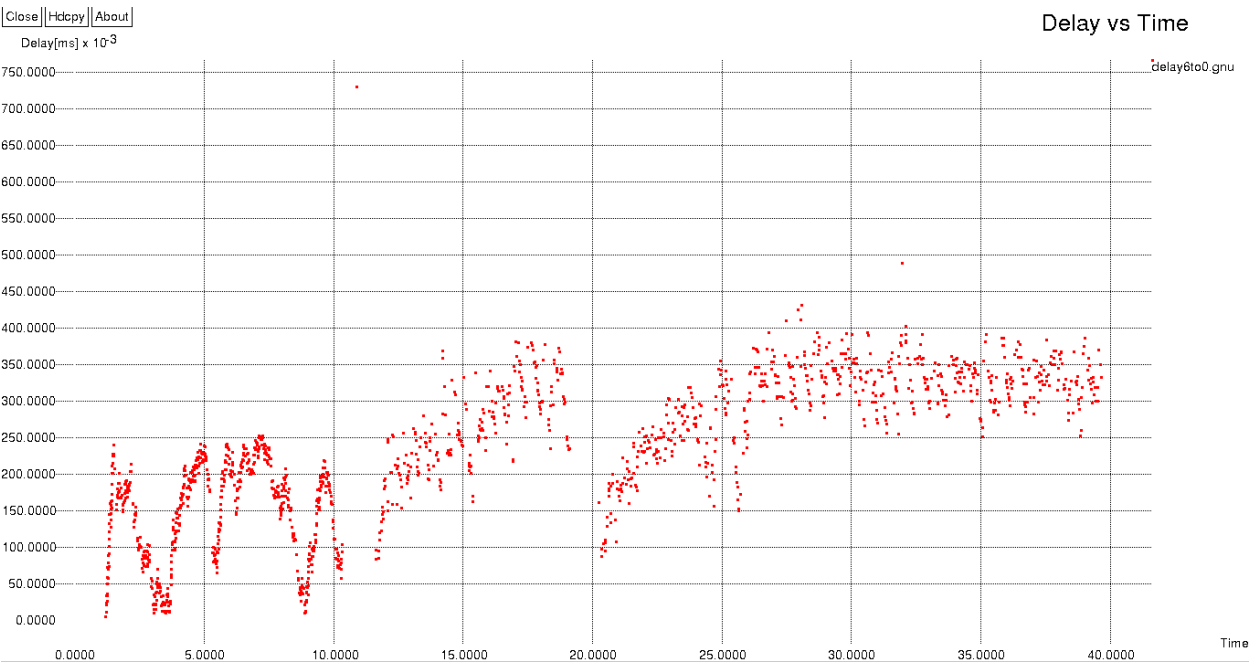


Fig. 35. Illustrates the behaviour of the delay vs. time in the simulation

### 5.2.2 Analysis of jitter

The (figure36) illustrates the jitter behavior as time in the simulation.

As it can be seen in figure 36, the jitter has a similar behavior to the delay during the first 10s of simulation, in the sense that both present the lowest values throughout the simulation in this range, but after the AMN moves towards the PAR/LER1 a huge peak of about 650ms is registered, this corresponds with the packet that experiences more than 700ms in delay in figure 80. After this, the jitter is stabilized below 50ms when the AMN is in the ANAR/LER2 zone (after t = 20s) and below 100ms when the AMN is in the APAR/LER1 zone (between the 11s and 18s or so). Additionally it is noted that the transfer that takes place near the instant t = 16s has no significant effects on the experienced fluctuation. Finally the average jitter during the simulation was 15.84ms.
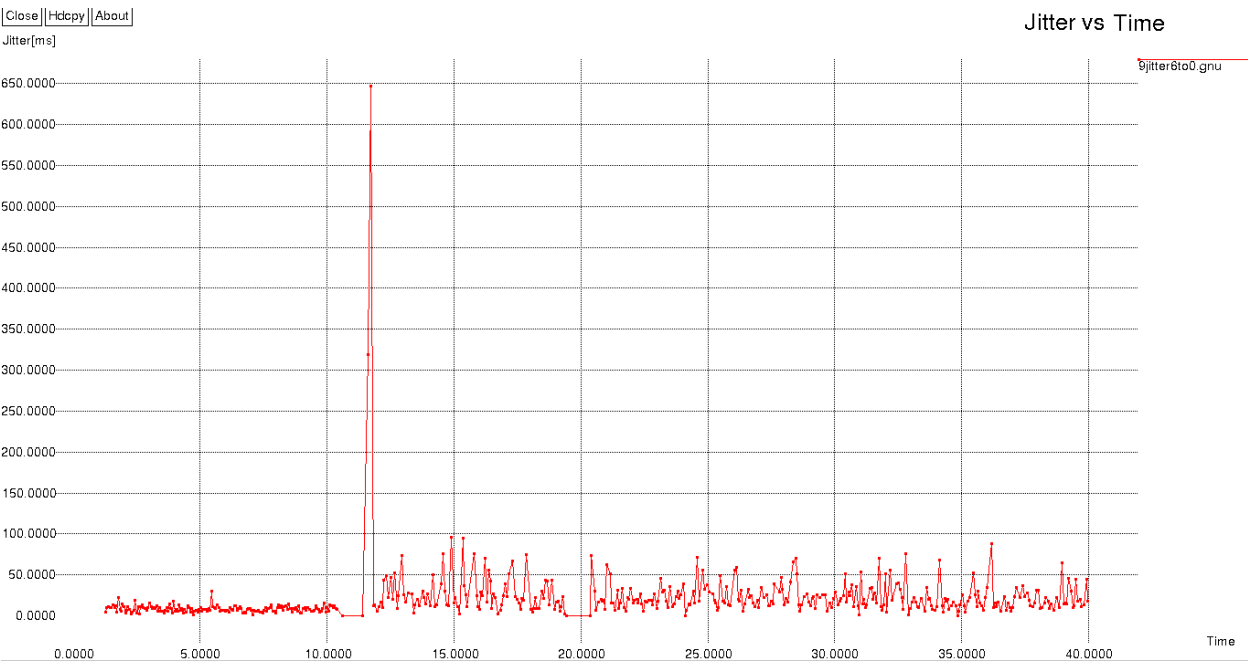
Fig. 36. Jitter vs. time

### 5.2.3 Analysis of throughput

The figure 37 shows the same trend that is reflected in the previous metrics, related to the fact that while the AMN is located in the AHA zone the metric performs better than in the rest of the simulation. In this occasion the throughput obtains values close to the 800Kbps before the 10s after the start of the simulation. Subsequently when the AMN moves to the PAR/LER1 zone performance drops to 0Kbps which is due to the absence of traffic at that moment and the loss of some packets while the displacement occurs. Then when the AMN reaches the area in question an irregular behavior of the performance is registered, which sometimes comes close to the 800Kbps which is close to the maximum possible limit of 1Mbps due to the LSR2 – PAR/LER1 link, while on the other hand also reaches values of about 50Kbps. Moments later, after the AMN moves towards the ANAR/LER2 the performance drops once again to 0Kbps due to decreasing traffic and the lost of some packets during the transfer. Finally, once the AMN arrives to the above-mentioned area, throughput shows a behavior similar to that reported in the PAR/LER1 zone. The average throughput of the simulation was 343.649Kbps.

### 5.2.4 TCP windows

This is also supported by the behavior of the TCP congestion window presented in the figure 38 as it can be seen, the instants near t = 11s and t = 20s show the drop in the TCP congestion window which indicates the loss of packets, as was mentioned above.
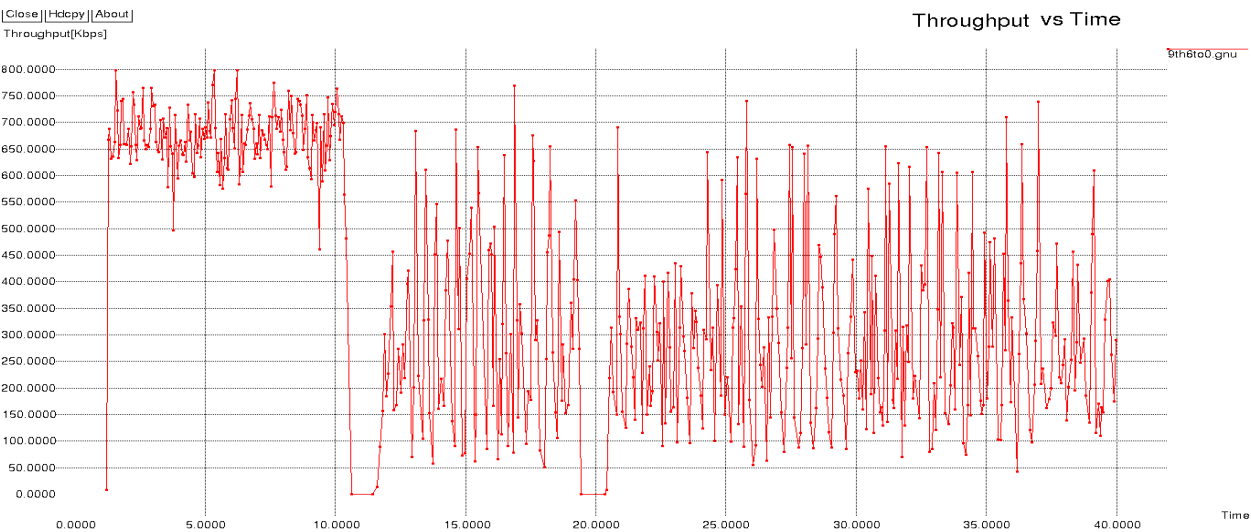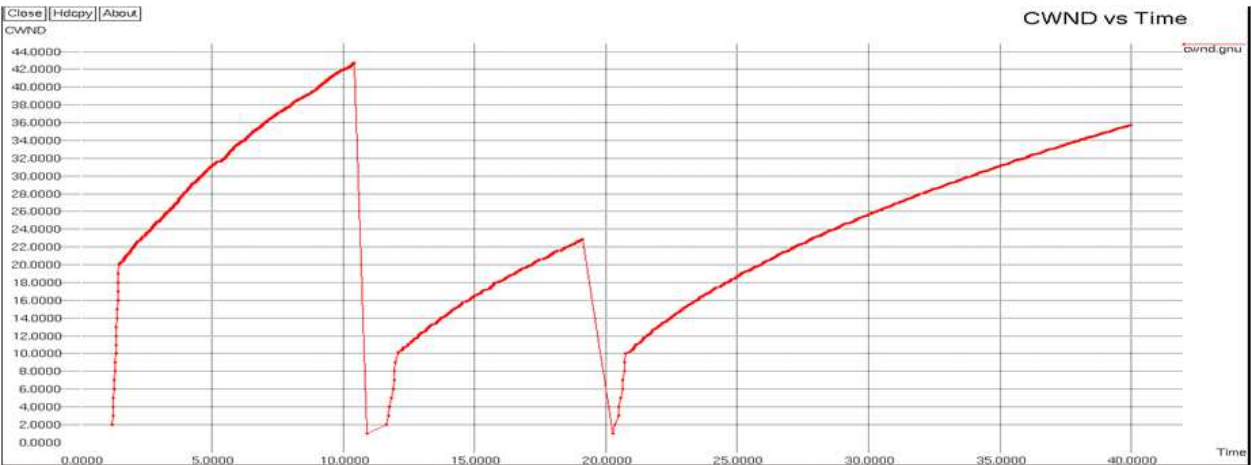
Fig. 37. Illustrate throughput vs. time



Fig. 38. TCP congestion window vs. time

### 5.2.5 Analysis of lost packets

During the simulation 1610 packets were sent from the AMN to the ACN, out of which 1586 reached their destination, leading to the loss of 24 packets, which corresponds to 1.49% of the total packets.

### 5.2.6 Analysis of results

The table 11 presents various facts to highlight: first, both the delay and the fluctuation do not exhibit increasing tendency as the number of nodes increases, this is important because

it shows that the proposed integration is functional in the presence of more than 9 nodes and also that the metrics in question do not deteriorate significantly in scenarios of large volumes of nodes. Another important fact to highlight is that performance observes a relationship of inverse proportion to the number of nodes that make up the simulation scenario that is to say, that with more nodes the performance decreases, however this decrease is not linear but it is less affected with the presence of new nodes. As the tendency is presented, it could be said that it is possible that for scenarios of more nodes performance will be stabilized around a certain value, which means that the decrease has a limit. The last fact to note is that the proportion of lost packets does not increase as the number of nodes increases, but stabilizes after some growth in the network. Therefore we can conclude that the proposed integration is useful for providing QoS in scenarios with large volumes of nodes.

| Scenario\Metric | Delay(ms) | Jitter(ms) | Throughput(Kbps) | Send Packets | Lost Packets |
|---|---|---|---|---|---|
| 9 nodes | 224.52 | 15.84 | 343.65 | 1610 | 24 |
| 20 nodes | 275.20 | 27.87 | 241.60 | 1168 | 53 |
| 30 nodes | 225.52 | 21.99 | 206.87 | 989 | 34 |

Table 8. Nodes vs. Different metrics

In this figure 39 we can visualize the following metrics (Delay, Jitter, Throughput, Send and Lost Packets vs. Number nodes). The Delay, Jitter and Throughput have slight variation. The throughput decreases when increasing the number nodes, likewise the send packets decreases when increased the number nodes and traffic flow. This behavior of these metrics is logical, we did not test with more nodes, because we believe that these tests is enough to make an analysis
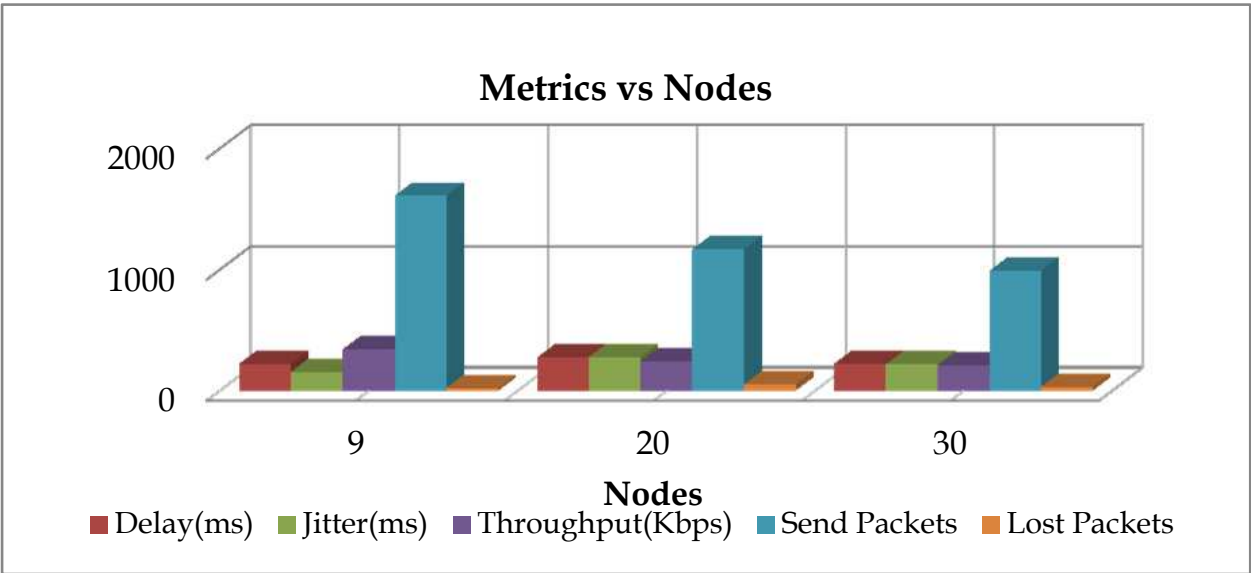


Fig. 39. Metrics vs. number nodes in FHAMIPv6/MPLS integration

### 5.3 Conclusions

This chapter released the results of the integration FHAMIPv6/MPLS and features to provide QoS. This study is of considerable importance because it is the first to bring mobile capabilities, fast handover and hierarchical IP extensions to MPLS hybrid environments. Thus provides the basis for future research that want to implement prototypes in real environments.

## 6. General conclusions

This chapter is focused on all IPv6/MPLS scheme for wireless mobile networks. We presented different integrations of mobility protocols (versions6 IP protocol extensions) with quality of service (QoS) protocols (MLPS, RSVP). The initial integrations were performed in infrastructure networks. The results delivered valuable information on how the protocols operated as well as the different coupling options available. This shows that the best coupling option was that where it is necessary to modify the protocols in a way that all could work as one single protocol. Other options were discarded, since protocols operating independently or even synchronised did not deliver satisfactory results. Among the quality of service protocols, we managed to prove that the RSVP was valid as a signalling protocol. This was also confirmed at the IETF when protocol CR-LPD was discarded as a signalling protocol when it was used together with MPLS.

On the other hand, in order to integrate IP protocol extensions (IP mobile, HMIPv6, F-HMIPv6 and FHAMIPv6) and MPLS protocol, it was necessary to modify MPLS nodes to turn them into mobile MPLS nodes. It was proved that IP mobile protocol, when integrated with MPLS, works better in macromobility scenarios. For micromobility scenarios, it is more convenient to use hierarchical IP mobile extensions since the signalling load is higher. The integration MPLS and HMIPv6 protocol extensions formed a good coupling for infrastructure networks in order to provide QoS. On the contrary, in total ad-hoc networks it is almost impossible because MPLS/Diffserv provides end-to-end quality of service, and when integrated with HMIPv6, the signalling load was so high that the network resulted overloaded.

Another problem was the compatibility of the source codes to perform the simulation to migrate from one version to another. The protocols did not work correctly. For this reason, we tested the F-HMIPv6 and MPLS protocols to verify if this was the best option to provide QoS to the next generation of mobile networks. In full ad-hoc mobile networks, FHMIPv6 showed diverse inconveniences, so it had to be modified to assume a new agent. This new agent was in the origin of the FHAMIPv6 protocol and the AHRA routing protocol. In order to solve the problem of the routing protocol AHRA, FHAMIPv6 was integrate with AODV and the result was successful. Similarly, we integrate FHAMIPv6 and MPLS and the result was satisfactory. With this result, we have achieved to propose an alternative to one of the great challenges of ad hoc networks. Because to provide QoS in ad hoc networks is a big challenge.

The quality of service values were obtained when a handover occurred and the results were satisfactory. In general, we can affirm that during a handover, not only metrics such as delay jitter and throughput improved, but also the default quality level was maintained in the integrations performed. The results obtained allowed us to identify which integration

protocols were the most suitable to ensure QoS in all IPv6/MPLS network. A series of architectures for next generation hybrid networks were proposed, including several important applications for universities, industry and the government. In general, the coupling between the quality of service and mobility protocols mentioned before is an excellent option to provide QoS in mobile networks and, especially, in the ad-hoc mobile ones. An interesting topic that we are currently evaluating is the different security issues that are generated in coupling protocols, which can actually degrade the quality of service by the action of malware or malicious users. On the other hand, we can say that, in next generation networks (4G), an all IPv6/MPLS architecture will be critical in next generation wireless mobile networks, compatible with the standards proposed so far (WIMAX, advanced LTE/SAE, LTE/IMT, WiMAX/IMT).

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The growth in the use of mobile networks has come mainly with the third generation systems and voice traffic. With the current third generation and the arrival of the 4G, the number of mobile users in the world will exceed the number of landlines users. Audio and video streaming have had a significant increase, parallel to the requirements of bandwidth and quality of service demanded by those applications. Mobile networks require that the applications and protocols that have worked successfully in fixed networks can be used with the same level of quality in mobile scenarios. Until the third generation of mobile networks, the need to ensure reliable handovers was still an important issue. On the eve of a new generation of access networks (4G) and increased connectivity between networks of different characteristics commonly called hybrid (satellite, ad-hoc, sensors, wired, WIMAX, LAN, etc.), it is necessary to transfer mechanisms of mobility to future generations of networks. In order to achieve this, it is essential to carry out a comprehensive evaluation of the performance of current protocols and the diverse topologies to suit the new mobility conditions.

## How to reference

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