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Experimental Evaluation of Mobile IPv6 for Linux

Jesús Calle-Cancho[1], David Cortés-Polo[2], Javier Carmona-Murillo[3] and Jose-Luis González-Sánchez[4]
[1,3]Department of Computing and Telematics System Engineering, University of Extremadura, Spain
[2,4]Research, Technological Innovation and Supercomputing Center of Extremadura (CénitS), Trujillo, Spain

***Abstract*— With the continuous development of mobile communications and Internet technology, one of the major challenges is to achieve efficient mobility management in wireless networks. Internet protocols do not support mobility and wireless networking does not provide reliable connections to mobile users for real-time multimedia communications. For this reason, the Internet Engineering Task Force (IETF) has developed various protocols for IP mobility management such as Mobile IPv6. In this work we analyze the handover process through handover latency. For this, we have developed a real testbed using Universal Mobile IP for Linux implementation, Cisco routers and Cisco access points. We have also conducted throughput tests with real-time communications such as Real-Time Transport Protocol (RTP), analyzing the behavior of the communications when we introduce delays in the access network.**

***Index Terms*— Mobile IPv6, Handover, Latency, Multimedia and Linux**

I. INTRODUCTION

THE exponential growth of Internet applications combined with the extended availability of wireless devices has created an increasing demand for mobility support for moving hosts. The users search the possibility of roaming between different access networks such as 4G Long Term Evolution (LTE), Wireless Local Area Networks (WLAN) or WIMAX. For this reason, one of the main goals in the design of Next Generation Wireless Networks (NGWN) has been the possibility of maintaining the connectivity while a user moves among heterogeneous networks [1].

The IETF has designed Mobile IPv6 [2] protocol to overcome the problems caused by handover in heterogeneous networks and to provide seamless mobility to a node in IPv6 networks with independence of access network technologies. MIPv6 is probably the most widely known IP based protocol, which supports mobility, and it is accepted as the most appropriate protocol for addressing IP mobility management in wireless mobile networks. It is a host-based mobility management protocol [3]. This means that it is necessary to update TCP/IP stack of the Mobile Node (MN) because the MN participates in all aspects of mobility management and it is responsible for handling the signaling messages during the handover process.

The handover or handoff process is one of the most critical phases in MIPv6 [4] and occurs when a MN moves to another IPv6 network. The main objective is to keep active communications of higher levels while a MN moves and changes its point of attachment without changing its IP address.

Furthermore, the combination of the multimedia communications and the mobile networks gives a new dimension to the handover concept from the point of view of the performance, since the handoff leads to packet loss and performance degradation [5]. This implies that real-time applications are affected badly during this process. For this reason, it is necessary to minimize service disruption time during handover all in multimedia communications.

In this paper, we present an analysis of the handover latency in a real testbed. In order to evaluate and quantify the results, we have used an open source implementation environment. Many articles propose analytical evaluations of the MIPv6 but this paper focuses in a real experimentation with a standard implementation of this protocol. We have also carried out a comparison between the different performance tests with multimedia traffic. The behavior of the network is analyzed while its characteristics are changed. In all tests, the protocol used to transmit the multimedia content is Real-Time Transport Protocol (RTP) over UDP.

The rest of the paper is organized as follows. In section II, we present the architecture of the MIPv6 and we explain the most important functional entities of this protocol. In section III, we explain the architecture and configuration of testbed. The results of handover latency and multimedia results are also presented in this section. Finally, section IV contains our concluding remarks.

II. PROTOCOL OVERVIEW

In this section, we describe the MIPv6 protocol architecture [6] and its basic operation such as movement management. Fig. 1 shows the entities involved in this protocol and the operations performed by them.

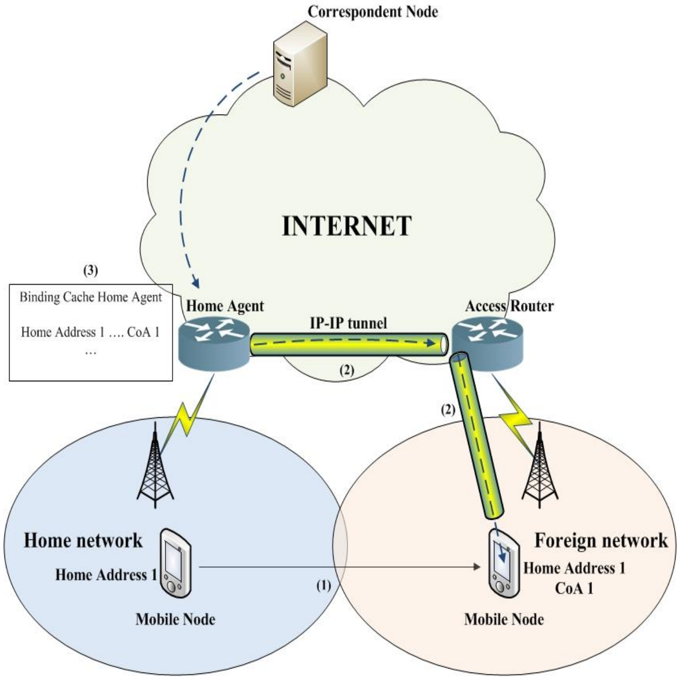

Fig. 1. MIPv6 architecture and its operations.

MIPv6 is a host-based mobility management approach [8]. The MN manages two IPv6 addresses, a Home Address (HoA) that identifies the permanent or static address of a MN and acts as a global identifier; a Care-of-Address (CoA) that represents the temporary address, providing the actual location of the host, and changes when the MN is located in a visited network. For these and other reasons, the MN requires a protocol stack modification in order to support mobility.

Moreover, Home Network (HN) is the network, which prefix network matches with the HoA of the MN. Initially the MN belongs to its Home Network. While a MN is attached to its HN, it is able to receive packets destined to its Home Address, and to forward them by means of conventional IPv6 routing mechanisms. However, when the MN moves to the Foreign Network (1), it acquires the CoA using stateful or stateless address autoconfiguration. Then, the MN performs Duplicate Address Detection (DAD) to check the validity of this address.

In this moment, when the CoA is configured, the mobility signaling process starts. The MN registers it to the HA through Binding Update (BU) message, informing of its current location and establishing a tunnel IP-in-IP between the HA and itself (2). The HA records this binding in its Binding Cache (3) and confirms the registration with a Binding Acknowledgement (BA) message. After this, when the Correspondent Node (CN) needs to communicate to the MN, it sends the packets to the MN's home address. The HA intercepts any packets to the MN's home address and tunnels (using IPv6 encapsulation) them to the MN's CoA, where they are decapsulated. The Home Agent is the critical part of the system since it is on the critical path of both signaling and data for mobile users.

III. EVALUATION AND EXPERIMENTAL RESULTS

This section describes the setup and design of the MIPv6 testbed where we have evaluated experimentally the behavior of the Mobile IPv6 protocol using Ubuntu 12.04 (Debian) and an open source MIPv6 implementation for Linux called Universal Mobile IP for Linux (UMIP) [7]. The testbed setup and design is explained in section III.A and then, in section III.B and III.C, we present and analyze the results obtained in each tests.

A. Mobility Testbed Design

The MIPv6 testbed topology used during the development of the experimental study shown in Fig. 2.

Furthermore, the devices used to develop this mobility testbed have the specifications shown in Table I.

TABLE I. LIST OF COMPONENT AND SOFTWARE

	Home Agent	**Mobile Node**	**Corresp. Node**	**Routers**	**Access Points**
Hardware	Notebook HP G62-b85SS	Sony VAIO TZ31WN/B	HP Proliant ML350 G6	Cisco 1921/K9	Cisco AIR-LAP 1131AG-E-K9
CPU	Intel Core i3-350M 2.26 GHz	Intel Core 2 Duo 1.2 GHz	Intel Xeon 2.4 GHz	ISR G2 with multicore CPUs (15 Mbps)	PowerPC Elvis CPU at 262 MHz
RAM	4 GB	2 GB	12 GB	512 MB	32 MB
Mobility Software	UMIP	UMIP	No Mobility Software	No Mobility Software	No Mobility Software
OS	Ubuntu 12.04 with Kernel 3.8.2	Ubuntu 12.04 with Kernel 3.8.2	Ubuntu 12.04	Cisco IOS 15.2	Cisco IOS 12.4

The experimental testbed consists of two WLAN networks interconnected through an IPv6 cloud. This IPv6 cloud is made up four Cisco 1900 Series Routers, which support IPv6 and IPv6 routing protocols such as RIP next generation (RIPng). Moreover, this IPv6 cloud interconnects the HA, the CN and the Cisco Access Points. The testbed contains two Cisco Aironet 1130AG Series Access Points, which support IEEE 802.11 a/g specifications. Finally, the MN is connected to the IPv6 access network through these access points.

All devices, except Cisco access points and Cisco routers, use an open-source Operative System (OS). Ubuntu 12.04 with Linux mobility-ready kernel is running in the HA and the MN. Linux kernel 3.8.2 has been compiled and installed in the operating system adding mobility characteristics. Moreover, the HA and the MN need mobility software so we have used an open source MIPv6 implementation for Linux called UMIP. Otherwise, the CN use Ubuntu 12.04 but it does not require mobility-ready kernel or specific software to interact with the MN. The other devices (Cisco access points and Cisco routers) use their own operating system called Cisco IOS.

The HA, the CN and each WLAN cell belong to different IPv6 subnets. For this reason, the handover process is carried out between two different IPv6 subnets.

B. Handover Latency Analysis

In this section, we analyze the handover latency in MIPv6 using a real Linux testbed. The results obtained from several tests using the scenario shown in Fig. 2 are presented in this section.

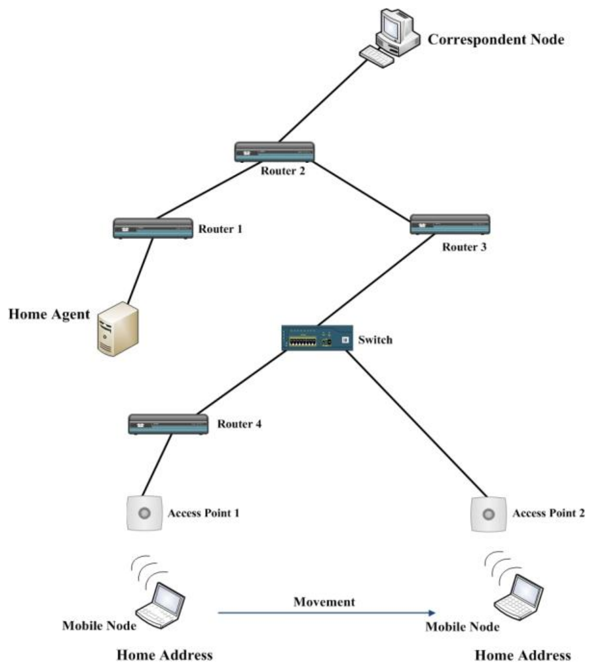

Fig. 2. MIPv6 testbed configuration.

In these tests, we evaluate the handover latency or disruption time in a MN movement, which not receive IPv6 packets until the handover process finishes. The handover latency is the period between the transmission or reception of its last data packet through the old connection and the first data packet through the new connection. This parameter is one of the most important when the handover process is analyzed. This process is one of the most critical phases in MIPv6 and one of the main objectives is to reduce this time. For this reason, the handover process is analyzed through handover latency measurements.

During the development of these tests, we have evaluated the behavior of the handover latency depending on the router advertisement interval. The characteristics of the tests are as follows:

- Several tests have been performed for each router advertisement interval from 0.5 seconds to 4 seconds.
- Traffic has been transmitted with a network traffic generator called Ostinato [9]. It is an open-source implementation, which sends packet of several streams with different protocols and different rates.
- The transmission is realized from the Correspondent Node to Mobile Node. The UDP stream is created with Ostinato and it is transmitted with a constant rate (1000 packets/sec). For this, the type of traffic is Constant Bit Rate (CBR).
- The duration of the tests is 60 seconds and the handover process is performed at second 30 approximately.
- In order to evaluate the handover latency, we have analyzed the network captures with Wireshark on Mobile Node. We measure the time elapsed between the last IPv6 packet received before the handover and the first IPv6 packet received after the process.

The values of the handover latency for each router advertisement interval taken at the MIPv6 testbed are shown in Table II. Moreover, Fig. 3 shows the effect of router advertisement interval in MIPv6 handover.

Two repetitions are performed for each router advertisement interval. In Table II we can observe the average value of the repetitions that we have made.

TABLE II. VALUES OF THE HANDOVER LATENCY

Router Advertisement Interval	Disruption time
0.5 s	1.7310 s
1 s	1.9848 s
1.5 s	2.7232 s
2 s	3.2258 s
2.5 s	3.8776 s
3 s	3.9826 s
3.5 s	4.4414 s
4 s	4.9483 s

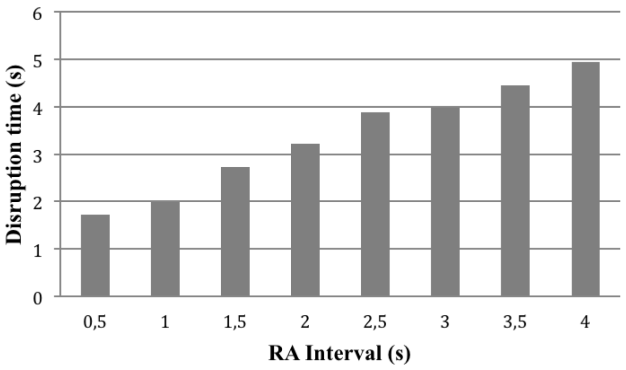

Fig. 3. Router Advertisement Interval effect on MIPv6 disruption time

Fig. 3 shows the direct dependence between the handover latency parameter and the router advertisement interval. The handover delay increases when the router advertisement interval is increased. The minimum value of the handover latency has been obtained with a router advertisement interval of 0.5 seconds; the minimum value is 1.731 seconds.

In MIPv6, the MN uses the router advertisement (RA) messages for the movement management to another network. These messages help the MN to identify that it has changed IPv6 subnet. The Neighbor Discovery protocol establishes a minimum interval of 3 seconds between RA messages. However, MIPv6 relaxes this value determining that the routers should be able to send these messages more frequently establishing a minimum interval of 0.03 seconds. The tests have been conducted with a router advertisement interval from 0.5 seconds to 4 seconds. The Cisco routers do not allow the reduction to the minimum established by the standard. The valid values range goes from 0.5 to 1800 seconds. For this reason, the tests have been performed with values from 0.5 to 4 seconds.

C. Multimedia Traffic Analysis

In this section, we analyze the behavior of the multimedia communications in MIPv6 using a real Linux testbed. Fig. 4 presents the scenario used to develop tests of this section.

Firstly, we explain the design of the testbed on which we have performed tests with real-time traffic. The scenario is similar to that we used in the handover latency analysis shown in Fig. 2. In this multimedia-traffic analysis, we have included a Linux PC in order to introduce the necessary delays in the access network. This Linux computer has replaced a router with respect to previous testbed. This machine has three network interfaces and the Table 3 shows the other specifications of it.

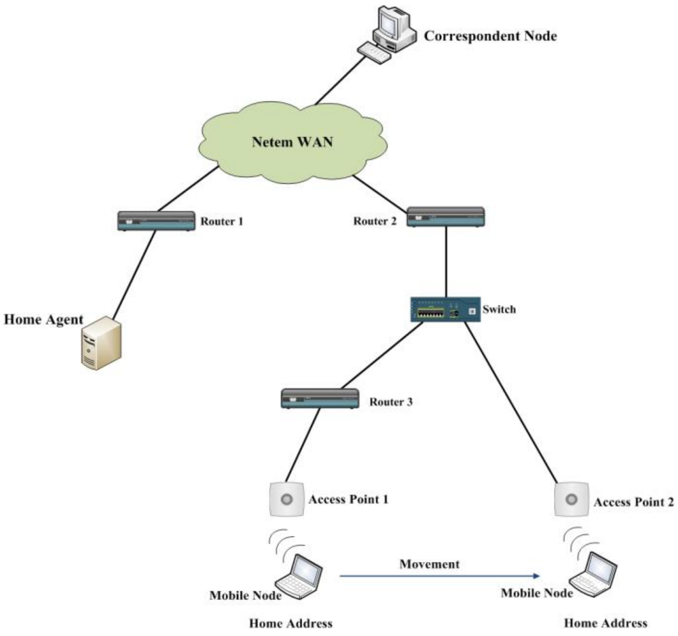

Fig. 4. MIPv6 testbed configuration with Netem.

TABLE III. SPECIFICATIONS OF THE COMPUTER WITH NETEM EMULATOR

	Linux PC (NetEM)
CPU	AMD Athlon 64 X2 Dual Processor 5200+ 2.7 GHz
RAM	2 GB
Routing Software	Quagga Routing Suite
WAN Emulation Software	NetEM
Mobiliy Software	No Mobility Software
Operating System	Ubuntu 12.04

In order to introduce delays in the access network, we have used a WAN emulator called NetEM (Network Emulation), in order to introduce the delays in the access network. NetEM provides network emulation functionality by emulating the properties of Wide Area Networks (WAN). The current version emulates variable delay, packet loss, duplication and re-ordering. It consists of two components: a kernel module for queuing discipline (qdisc) and a command-line utility (tc) to configure it. The kernel module has been integrated in version 2.6.8 or later, and the command is part of the iproute2 package. The default queuing discipline is a FIFO queue. Although NetEM can emulate several features, in these tests we are going to focus on the variation of the delay.

Furthermore we have used Quagga Routing Suite introduced in the new machine so that it has the capability to route packets. Quagga provides the implementation of RIPng for Unix platforms. The Quagga architecture consists of a core daemon, Zebra, which acts as an abstraction layer to the underlying Linux kernel.

Finally, we carry out an explanation of the tests that we have conducted and an analysis of the results that we have obtained.

During the development of these tests, we have conducted throughput tests with real-time traffic, analyzing the behavior of the testbed when we introduce delays in the access network. We have evaluated the throughput in the Mobile Node. Basically this experimentation includes the performance tests with multimedia traffic during the movements of mobile users in our testbed under different conditions. We cause a handover during the traffic transmission.

Fig. 5 presents a comparative between the different behaviors of throughput when delays are introduced in the access network. Within this figure we can see four subplots. The first one shows the behavior of the communication without any additional delay in the access network; simply the delay introduced by the testbed itself. In the other subplots, we will increase the delay in the access network with NetEM considering three different values of the delay: 150 milliseconds, 300 milliseconds and 450 milliseconds.

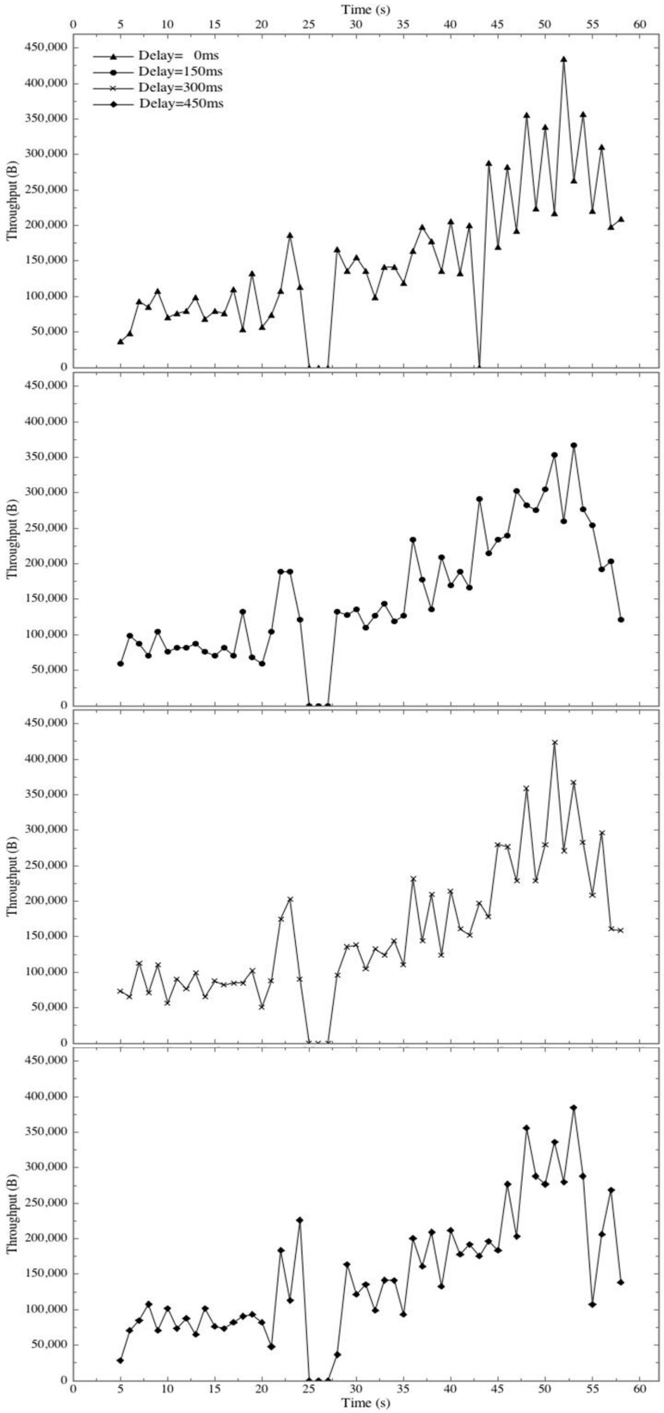

Fig. 5. Throughput tests with real-time traffic and different delays in the access network.

The characteristics of the conducted tests are as follows:

- Several tests have been performed for each value of delay from 0 milliseconds to 450 milliseconds.
- We have used real-time traffic. The protocol used to transmit the multimedia content is RTP over UDP using VLC media player.
- We have worked on the testbed shown in Fig. 4.
- In order to evaluate the throughput, we transmit traffic from the Correspondent Node to the Mobile Node and measure the throughput in the MN. For this, the network captures are analyzed with Wireshark on Mobile Node.
- The video used for transmission has the following characteristics: 50 seconds of duration and 640x344 pixels of resolution. Moreover the transcoding options chosen in video transmission have been: “Video – H.264 + AAC (MP4)”.

We can observe that the packets are not received with a constant throughput. This is typical of multimedia communications. Furthermore, the handover process occurs around the second 25. For this reason, the throughputs of the communications fall down zero in that moment. Also, in the first communication (delay: 0 milliseconds) the throughput is greater than in the other communications. The throughput decreases when we increase the delay in the access network.

Moreover the time of the handover process increases if the value of delay increases. In the Fig. 5 we can observe this fact. When we have conducted tests with the maximum value of delay (delay: 450 milliseconds), the disruption time has increased significantly. When the value of delay introduced in the access network is 150 milliseconds, the disruption time increases by 1%. On the other hand, when the value introduced is 450 milliseconds, the percentage increases up to 14% approximately.

The results obtained allow appreciating the importance of the access network in the multimedia communications. Both MIPv6 data and signaling messages are sent through the access network. For this reason, when the delays are introduced, the handover process is affected. Therefore, the real-time communications are badly affected.

IV. CONCLUDING REMARKS

In this paper we present a deployment and experimental evaluation of a host-based mobility management approach. We have evaluated the behavior of a protocol proposed by IETF (Mobile IPv6) in a real environment. For it, we have used an open source MIPv6 implementation of this protocol called Universal Mobile IP for Linux (UMIP). We have focused on the analysis of the handover process and multimedia communications. This work provides real results, which cannot be obtained through simulation.

From the point of view of the handover process, a detailed analysis of the relation between the handover latency and the router advertisement interval has been carried out through latency measurements. We establish the dependence of these two parameters by the tests performed on the testbed. There is direct dependence between the handover latency parameter and the router advertisement interval. The handover delay increases if we increase the router advertisement interval.

Nowadays, the multimedia communications have taken a great importance. The combination of the multimedia communications and the mobile networks gives a new dimension to the handover concept from the point of view of the performance. For this reason, it is necessary to minimize service disruption during handover above all in multimedia communications. The performance of this multimedia communications has been measured with throughput tests on Mobile IPv6 real testbed changing characteristics of the access network using NetEM. We conclude that the time of the handover process increases if the value of delay increases, quantifying this dependence. Finally, we can say that the handover process of the Mobile IPv6 greatly affects the multimedia communications. For this reason, it is necessary extra mechanisms for improving the handover process in the multimedia transmissions.

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JESÚS CALLE-CANCHO (jesuscalle@unex.es) studied at the University of Extremadura, Spain, where he received his BEng (2011) and MEng (2013) in Computer Science Engineering. During 2012 and 2013 he worked in GITACA Research Group in projects related with mobility management in IPv6.

DAVID CORTÉS-POLO (david.cortes@cenits.es) He got his BS and MS degree in Computer Science at University of Extremadura, 2006. Now, he is a Ph.D. candidate at Telematics Engineering Area (UEx). His areas of interest are IPv6 Mobile Networks, MPLS-TE and QoS support. Currently, he is the Network administrator of the Foundation COMPUTAEX and the Center CénitS

JAVIER CARMONA-MURILLO (jcarmur@unex.es) is a Ph.D. student in the Computing Systems and Telematics Engineering Department at the University of Extremadura, Spain, where he received his BEng (2003) and MEng (2005) in Computer Science Engineering. Now, he is a Ph.D. candidate at Telematics Engineering Area (UEx). He has published many articles in journals and conferences related to computing and networking. His main research topics are broadband networks, QoS provision in mobile networks and IP mobility.

JOSÉ-LUIS GONZÁLEZ-SÁNCHEZ
(joseluis.gonzalez@cenits.es) He received his Engineering degree in Computer Science and his Ph.D. degree in Computer Science (2001) at the Polytechnic University of Cataluña, Barcelona, Spain. He has published many articles and books and directed research projects related to computing and networking. Currently, he is the general manager of the Foundation COMPUTAEX and the Center CénitS.