Universidade de Aveiro

Departamento de Electrónica, Telecomunicações e Informática

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Suporte de Mobilidade em Redes WiMAX

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia Electrónica e de Telecomunicações (Mestrado Integrado), realizada sob a orientação científica da Professora Dra. Susana Sargento, Professora auxiliar convidada do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro, e do Professor Francisco Fontes, Professor auxiliar convidado do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro.

o júri

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agradecimentos

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palavras-chave

IEEE 802.16, IEEE 802.21, WiMAX, Mobilidade, Qualidade de serviço, VoIP, IPTV, MIHF, handovers entre redes heterogéneas.

resumo

O desenvolvimento crescente da Internet, com novos serviços e aplicações que requerem elevadas exigências a nível de qualidade de serviço, como por exemplo, o VoIP e IPTV, a crescente necessidade de um utilizador estar sempre contactável em qualquer sítio e a qualquer momento, torna necessária a integração actual da Internet com as redes móveis da próxima geração.

A tecnologia IEEE 802.16 surge como uma tecnologia de banda larga sem fios que pode ter um papel fundamental num ambiente de próxima geração. Devido aos seus baixos custos de instalação e à possibilidade de chegar facilmente a zonas rurais ou a zonas de difícil acesso, torna-se um sério candidato para suprir as necessidades dos utilizadores.

A necessidade de mobilidade pelo utilizador, para aceder a diversos serviços em diferentes sítios ou ser identificado remotamente para a posterior recepção de informação também é um desejo futuro.

O protocolo IEEE 802.21 surge como um meio que providencia a optimização de handover entre diferentes tecnologias de acesso, quer sejam elas WiFi, WiMAX, 3GGP ou 3GPP2, no sentido de proporcionar ao utilizador a utilização de diferentes serviços de uma forma transparente à tecnologia de acesso, quando em situações de mobilidade.

Esta dissertação apresenta a arquitectura desenvolvida para proporcionar a correcta avaliação da atribuição de QoS e mobilidade transparente, num ambiente real de próxima geração. Serão também efectuados testes com o equipamento WiMAX disponível, no sentido de mostrar o seu correcto comportamento na atribuição de QoS fim-a-fim em cenários ponto-a-ponto e ponto-a-multiponto com serviços com características de tempo real. A integração do software da primeira fase do projecto WEIRD e o seu correcto comportamento em ambientes de atribuição de QoS também vai ser estudado. A implementação dos diferentes módulos, em especial a implementação da unidade central da arquitectura de IEEE 802.21 (MIHF), vai ser descrita, no sentido de avaliar o desempenho do WiMAX e do protocolo IEEE 802.21 numa rede real no âmbito da segunda fase do projecto WEIRD. Os resultados obtidos demonstram que a arquitectura desenvolvida consegue fornecer QoS fim-a-fim com suporte de mobilidade entre redes heterogéneas.

keywords

IEEE 802.16, IEEE 802.21, WiMAX, Mobility, Quality of Service, VoIP, IPTV, MIHF, handovers between heterogeneous networks.

abstract

The growing development of the Internet, with new services and applications that require a high level of quality of service, such as, VoIP and IPTV, the increasing need for a user to be always reachable anywhere and at anytime, motivates the integration of current Internet with the next generation of mobile networks.

The IEEE 802.16 technology emerges as a technology for broadband wireless access that may have a key role in a next generation environment. Due to its low costs of installation and its ability to easily reach rural areas or areas with difficult access, it becomes a serious candidate to supply the needs of users.

The mobility's necessity by the user, to access to several services in different locations or be identified remotely for subsequent receipt of information, is also a future desire.

The IEEE 802.21 protocol provides the optimization of handover between heterogeneous networks, such as WiFi, WiMAX, 3GGP or 3GPP2, to offer the user different services in a transparent manner to his access technology, when in situations of mobility.

This Thesis presents the architecture developed to provide the correct integration of QoS and seamless mobility, in a real next generation environment. It will also present tests carries out with the available WiMAX equipment, to show its correct behaviour in the allocation of end-to-end QoS in point-to-point and point-to-multipoint scenarios with real-time services. The integration of software from the first phase of the WEIRD project and its correct behaviour in environments of QoS allocation will also be studied. The implementation of the various modules, in particular the implementation of the central unit of IEEE 802.21 architecture (MIHF), will be described, to evaluate the performance of WiMAX and IEEE 802.21 protocol in a real network provided by the second phase of the WEIRD project. The obtained results show that the developed architecture is able to provide end-to-end QoS with seamless mobility support over heterogeneous networks.

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Acronyms

	Acronym	Description
	3GPP	Third Generation Partnership Project
	3GPP2	Third Generation Partnership Project 2
A		
	ASN	Access Service Network
	ASN-GW	Access Service Network - Gateway
	ACK	Acknowledge
	AID	Action Identifier
	AC	Admission Control
	AVC	Advanced Video Coding
	API	Application Program Interface
	ADSL	Asymmetric Digital Subscriber Line
	ATM	Asynchronous Transfer Mode
	AAA	Authentication, Authorization and Accounting
B		
	BS	Base Station
	BE	Best Effort
	BWA	Broadband Wireless Access
C		
	CoA	Care of Address
	CPS	Common Part Sublayer
	CID	Connection Identifier
	CSC	Connectivity Service Controller
	CSN	Connectivity Service Network
	CBR	Constant Bit Rate
	CPl	Control Plane
	CS	Convergence Sublayer
	CN	Correspondent Node
	CPE	Customer Premises Equipment
D		
	DB	Database
	DPl	Data Plane
	DSL	Digital Subscriber Line
E		
	ETH	Ethernet
	ertPS	extended real-time Polling Service
F		
	FBSS	Fast Base Station Switching
	FCAPS	Fault, Configuration, Accounting, Performance, Security management
	FTP	File Transfer Protocol
	FIFO	First In First Out
	FA	Foreign Agent

	FDD	Frequency Division Duplexing
	FDM	Frequency Division Multiplexing
G		
	GIST	General Internet Signaling Protocol
	GPS	Global Positioning System
	GUI	Graphical User Interface
H		
	HO	Handoff/Handover
	HTTP	Hypertext Transfer Protocol
	HA	Home Agent
	HIP	Host Identity Protocol
I		
	ID	Identifier
	IETF	Internet Engineering Task Force
	IP	Internet Protocol
	IPTV	Internet Protocol Television
	IPv4	Internet Protocol version 4
	IPv6	Internet Protocol version 6
	IEEE	Institute of Electrical and Electronics Engineers
J		
	JTG	Jugi's Traffic Generator
K		
L		
	L2	Layer 2
	L3	Layer 3
	LOS	Line of Sight
	LLA	Lower Level Agent
	LLC	Lower Layer Controller
M		
	MDHO	Macro Diversity Handover
	MPl	Management Plane
	MTU	Maximum Transfer Unit
	MOS	Mean Opinion Score
	MICS	Media Independent Command Service
	MIES	Media Independent Event Service
	MIIS	Media Independent Information Service
	MIH	Media Independent Handover
	MIHF	Media Independent Handover Function
	MIHU	Media Independent Handover User
	MAC	Medium Access Control
	MAN	Metropolitan-Area Networks
	MAHO	Mobile Assisted Handover
	MCHO	Mobile Controlled Handover
	MIHO	Mobile Initiated Handover
	MIP	Mobile IP
	MIPv4	Mobile IP version 4

	MIPv6	Mobile IP version 6
	MN	Mobile Node
	MS	Mobile Station
	MT	Mobile Terminal
	MM	Mobility Manager
	MPEG	Moving Picture Experts Group
	MIMO	Multiple Input Multiple Output
N		
	NCHO	Network Controlled Handover
	NIHO	Network Initiated Handover
	NSIS	Next Step In Signaling
	NSLP	NSIS Signaling Layer Protocol
	NLOS	Non Line of Sight
	nrtPS	non-real-time Polling Services
O		
	OPCODE	Operation Code
	OFDM	Orthogonal Frequency Division Multiple
	OFDMA	Orthogonal Frequency Division Multiple Access
P		
	PC	Personal Computer
	PHY	Physical
	PHP	Hypertext Preprocessor
	PoA	Point of Attachment
	PTP	Point-to-Point
	PMP	Point-to-Multipoint
	PTPd	Precision Time Protocol daemon
	PDU	Protocol Data Unit
	PSTN	Public Switched Telephone Network
Q		
	QoS	Quality of Service
	QoSNSLP	Quality of Service NSIS Signaling Layer Protocol
R		
	rtPS	real-time Polling Services
	RTPS	Real Time Streaming Protocol
	RTP	Real Time Transport Protocol
	Rx	Reception
	RC	Resource Controller
	RM	Resource Manager
S		
	SAP	Service Access Point
	SDU	Service Data Unit
	SF	Service Flow
	SID	Service Identifier
	SIP	Session Initiation Protocol
	SID	Silence Insertion Descriptor
	SNMP	Simple Network Management Protocol

	SS	Subscriber Station
T		
	TV	Television
	TDD	Time Division Duplexing
	Tx	Transmission
	TCP	Transmission Control Protocol
	TLV	Type Length Value
	ToS	Type of Service
U		
	URL	Uniform Resource Locator
	UGS	Unsolicited Grant Services
	UDP	User Datagram Protocol
V		
	VBR	Variable Bit Rate
	VLC	Video Lan Client
	VLAN	Virtual Local Area Network
	VoIP	Voice over IP
W		
	WA	Weird Agent
	WLAN	Wireless Local Area Network
	Wi-Fi	Wireless Fidelity, refers to 802.11 standards, including 802.11b, 802.11a, and 802.11g
	WiMAX	Worldwide Interoperability for Microwave Access
	WEIRD	WiMAX Extension to Isolated Research Data networks
X		
Y		
Z		

1.Introduction

1.1.Motivation

One area of research in telecommunications, with increasing interest, relates to the next generation of mobile communications systems. These systems, with support for multiple - technologies without wires, will provide high bandwidth and transparent communication capabilities to the user.

The growing need of users to be 'linked' at anytime and anywhere has led to the integration of the Internet with the mobile networks. However, there are always areas of difficult access where Internet access is difficult to achieve [10].

The rapid growth of high-speed Internet generated a huge demand in the residential and business markets. Despite a large percentage of that connectivity is provided by Asymmetric Digital Subscriber Line (ADSL) system, the future is not in ADSL, as the cable connection is not available in all areas [43].

The ability to have a Broadband Wireless Access (BWA) to Internet anywhere and at anytime has become a near dream for most users and mobile devices. The technology for metropolitan access IEEE 802.16 (commonly called Worldwide Interoperability for Microwave Access - WiMAX) is a technology for BWA with low cost compared to solutions of fibre, cable or copper, which is a very important factor in developing countries or rural areas [10].

The IEEE 802.16 group provides support for mobile access, by defining the IEEE 802.16e standard, placing mobility in this scenario of metropolitan networks. Thus, this technology becomes very promising for use in environments of next generation. In environments of next generation networks, users want access to all possible services, including multimedia in its various topological aspects (point-to-point (PTP), point-to-multipoint (PMP), mesh), and operators need to support their requirements: support new services in real time with high quality, independent of the users mobility.

The IEEE 802.16 will soon become one of the most powerful wireless technologies in the market. It is a standards-based technology provides fixed and mobile wireless broadband connectivity with a lot of possible applications as shown in Figure 1.

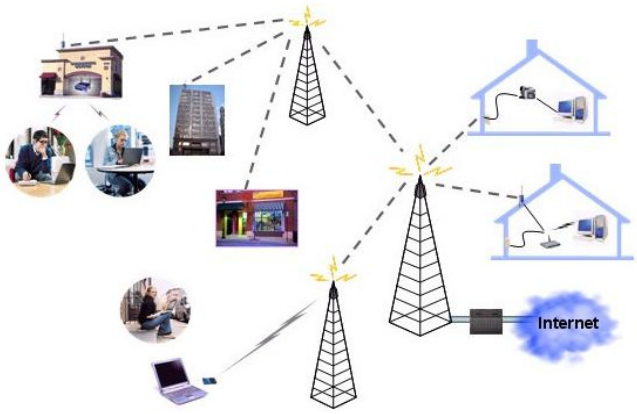


Figure 1 - WiMAX applications for near future

Another open issue in the near future is the seamless handover (HO) procedure in the next generation of networks. For mobile users, handovers may occur due to changes in wireless link conditions. For the stationary user, handovers may become imminent when the surrounding network environment changes, making one network more attractive than another. Another possibility is that the user may choose an application which may require a higher data rate channel, for example during download of a large data file. In all such cases service continuity should be maintained to the extent possible during handover. As an example, when making a network transition during a phone call, the handover procedures should be executed in such a way that any perceptible interruption to the conversation will be minimized [3].

The IEEE 802.21 (Media Independent Handover Services) standard provides link layer intelligence and other related network information to upper layers to optimize handovers between heterogeneous networks, as we can see in Figure 2. It provides the definition of algorithms to facilitate seamless handover between networks of the same (HO Horizontal) or of different technologies (HO Vertical) [3].

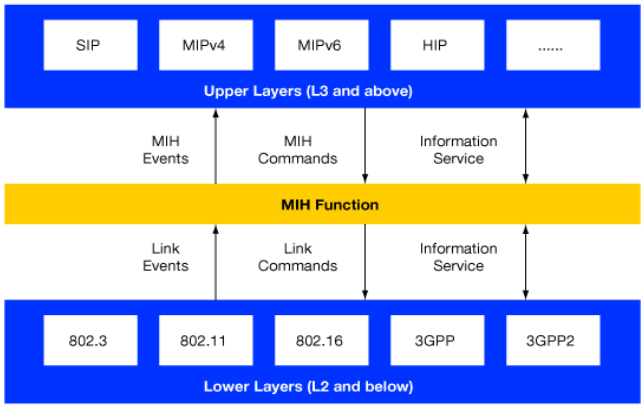


Figure 2 - Main function of IEEE 802.21 protocol

In the one hand, IEEE 802.16 helps on the process of ubiquitous Internet access allowing users to be connected to the Internet in remote locations. In other hand, users require seamless handover maintaining its Quality of Service (QoS) requirements.

In order to successful integrate these two point of views, which are indeed important to the near future, WEIRD (WiMAX Extension to Isolated Research Data networks) project [4][5] aims to develop the QoS and mobility aspects of the IEEE 802.16 technology integrating IEEE 802.21 protocol.

WEIRD is an European IST project which aims to demonstrate the effectiveness of IEEE 802.16 equipment in real-scenarios such as fire prevention, telemedicine, video surveillance, real time services such IPTV (Internet Protocol Television) and VoIP (Voice over IP), and mobility questions [30][32][33]. For this purpose, it was defined an end-to-end QoS architecture with mobility support and real time services support in a heterogeneous environment.

1.2.Objectives

This Thesis aims to assist in the integration of the IEEE 802.16 network technology in a heterogeneous network with support for mobility. This work requires a familiarity with technology and testing of IEEE 802.16 equipment.

It also studies the mechanisms to support mobility in the IEEE 802.16 technology and in its integration with heterogeneous environments, implementing Media Independent Handover Function (MIHF) and integrating them with IEEE 802.16 and mobility schemes.

For the development of mobility mechanisms, the architecture will use the concepts of local and global mobility, and concepts of independent technology mobility (Media Independent Handovers, IEEE 802.21) applied to 802.16e networks with intrinsic mobility.

The following activities will be developed:

- Study of BWA Technologies, giving special emphasis on IEEE 802.16d and IEEE 802.16e.
- Revision of QoS support (in PTP and PMP scenarios).
- Learning of technology IEEE 802.16e features for mobility.
- Study of mechanisms for management the local and global mobility.
- Study of technology IEEE 802.21 for Media Independent Handover (MIH).

- Carrying out tests of operation and performance with the 802.16 equipment available. This includes the evaluation of real-time services, such as VoIP and IPTV, over WiMAX which is able to provide end-to-end QoS. We will also evaluate several mechanisms of VoIP aggregation.

- Development of a mobility mechanism with support for QoS, which includes the implementation of the MIHF (the central unit of the IEEE 802.21 architecture).

- Realization of experiences with real equipment and evaluation of performance.

1.3.Contributions of the Thesis

As result of the accomplishment of the majority part of the proposed objectives, this work provides the following set of contributions:

- The development of a MIHF module and its integration in a real testbed of the WEIRD European IST Project [4][5].

- The evaluation of real time services (VoIP and IPTV) over WiMAX, being valuable to the WiMAX development and its establishment in the next generation networks.

- The work developed in this Thesis, particularly the evaluation of the effectiveness of the WEIRD project in terms of resource allocation and QoS performance with real-time services, is the purpose of one chapter of a WiMAX book:

    - Pedro Neves, Susana Sargento, Kostas Pentikousis, Ricardo Matos, Giada Landi, Marília Curado, Francisco Fontes, "A WiMAX Cross Layer Framework for Next Generation Networks", WiMAX Book, Wiley, accepted for publication, 2008.

1.4.Organization of the Thesis

The present thesis is organized as follows:

- Chapter 2 provides an overview of the IEEE 802.16 standard, including the Medium Access Control (MAC) and Physical (PHY) layers. It will be made a short comparison between the fixed and mobile IEEE 802.16 standards, and the main characteristics of the equipment used for the thesis. At this chapter we will also depict the mobility mechanisms that exist, giving special emphasis on IEEE 802.21.

- Chapter 3 provides some experiences with real time traffic (VoIP and IPTV) under the WiMAX equipment. We will evaluate the QoS performance of the equipment used.

- Chapter 4 provides a brief description of the WEIRD's phase 1 architecture, as well as the network modules that have been defined. We will evaluate the effectiveness of the WEIRD's phase 1 architecture in terms of its resource allocation capabilities.

- Chapter 5 describes the WEIRD's phase 2 architecture, giving special emphasis on mobility requirements of the project. At this chapter it will be detailed the implementation of the MIHF, including its functions and functionalities.

- Chapter 6 discusses the measurement results obtained for the implemented module (MIHF) in a real mobility scenario provided by WEIRD's phase 2 architecture and depicts a scenario for advanced mobility features.

- Chapter 7 presents the conclusions of this work, as well as the possible future work.

2.Background

At this chapter will be explained all the background necessary to the Thesis. At Section 2.1 will be depicted the rise of the Broadband Wireless Access (BWA) technologies in which is included the IEEE 802.16 standard (commonly named Worldwide interoperability for Microwave Access - WiMAX), which will be described along this section, more specifically its Medium Access Control (MAC) and Physical (PHY) layers, the two modes of operation: fixed and mobile, and the WiMAX equipment used to perform real measurements. Section 2.2 provides the introduction of mobility mechanisms, giving special emphasis to IEEE 802.21 standard and its main goals to promote a seamless handover (HO) in a next-generation environment. Section 2.3 provides a brief summary of the chapter.

2.1.Broadband Wireless Access

Broadband Wireless Access (BWA) is an emerging wireless technology that allows simultaneous wireless delivery of voice, data, and video. This technology provides an alternative solution for the last mile delivery of high-speed internet and other data services to business and homes. They are less expensive and more rapidly deployed than traditional optical fibre or wired telephone solutions. The goal of this new technology is to enable worldwide deployment of affordable, ubiquitous, always-on and interoperable multi-vendor mobile broadband wireless access networks that meet the needs of business and residential end user markets.

There are two different types of broadband wireless services, the fixed wireless broadband, which provides traditional fixed-line broadband services, and the mobile wireless broadband, which provides more features to the user such as the mobility, nomadicity and portability [7].

One of the most promising technology for BWA is the WiMAX [40], which offers both fixed and mobile access over the same infrastructure, opening the way for a new personal broadband service that gives users continuous broadband Internet access at home, at work, and while they are on the move. The WiMAX can be used on a variety of wireless broadband connections and solutions:

- "Last Mile" Broadband Access Solution to Metropolitan-Area Networks (MAN) connections to home and business office, specially in those areas that were not served by cable or DSL (Digital Subscriber Line) or in areas where the local telephone company may need a long time to deploy broadband service.
- Backhaul networks for cellular base stations, bypassing the Public Switched Telephone Network (PSTN); the cellular service providers can look to wireless backhaul as a more cost-effective alternative. The robust WiMAX technology

makes it a nice choice for backhaul for enterprises such as hotspots as well as point-to-point backhaul solutions.

- Backhaul enterprise connections to the Internet for WiFi hotspots. It will allow users to connect to a wireless Internet service provider even when they roam outside their home or business office.
- A variety of new business services by wireless Internet service provider.

2.1.1.IEEE 802.16

WiMAX technology is presently one of the most promising global telecommunication systems.

Great hopes and important investments have been made for WiMAX, which is a BWA system having many applications.

WiMAX is based on the IEEE 802.16 standard (802.16-2004 [1] for fixed and 802.16e-2005 [2] for mobile), having a rich set of features. These standards define the MAC and the PHY Layes of a fixed and mobile BWA System. The architecture of WiMAX System is defined by the WiMAX Forum [40].

More technically WiMAX is a layer 1 (PHY) and layer 2 (MAC) technology. It uses Orthogonal Frequency Division Multiple (OFDM) transmission and presents a sophisticated MAC Layer which provides efficient use of the frequency and Quality of Service (QoS) Management in order to obtain high data rates and different types of transmission services: voice, video, games, real-time, Best Effort … Two topologies (modes) can be used: PMP and Mesh.

2.1.1.1.IEEE 802.16-2004 MAC Layer

Figure 3 describes the IEEE 802.16-2004 MAC and PHY layers.

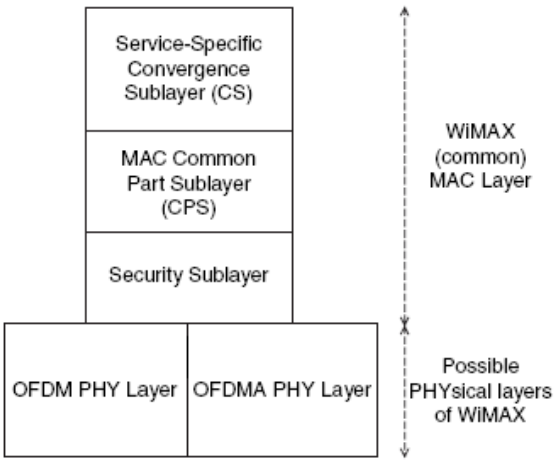


Figure 3 - IEEE 802.16 – 2004 layers (MAC and PHY)

The MAC Layer provides the interface with higher layers through the Service Specific Convergence Sublayer. Below the Service Specific Convergence Sublayer (CS) we find the Common Part Sublayer (CPS) that is the responsible for the most important MAC functions. Finally there is the Security Sublayer [1].

- **Service Specific Convergence Sublayer**

As the name implies, the convergence sublayer handles the convergence of different services supporting both ATM services and packet services, such as IPv4, IPv6, Ethernet, and VLAN services.

This specific layer have several functions such as: accepting higher-layer Service Data Units (SDUs) from the higher layers; classifying and mapping the SDUs into appropriate Connection Identifiers (CIDs), which is a basic function of the QoS management mechanism of 802.16 BWA; processing (if required) the higher-layer SDUs based on the classification; suppressing repetitive parts of payload headers at the sender and restoring these headers at the receiver (optional); delivering CS Protocol Data Units (PDUs) to the appropriate MAC Service Access Point (SAP) and receiving CS PDUs from the peer-entity.

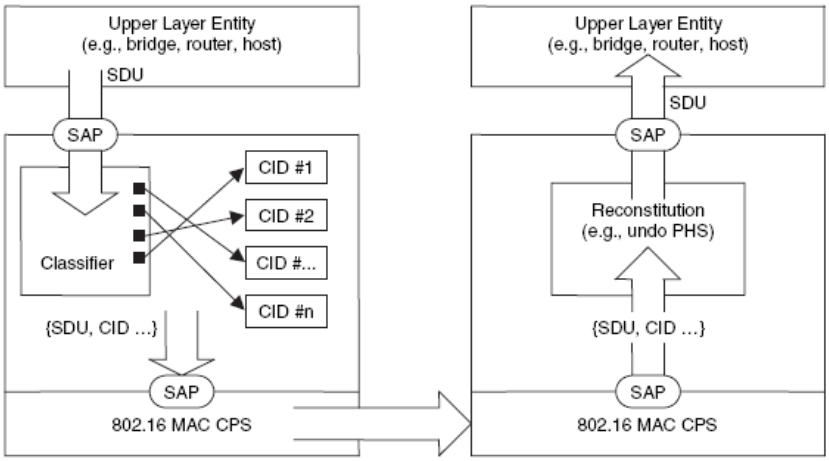


Figure 4 - Classification and CID Mapping

IEEE 802.16 MAC is connection oriented. Firstly assigns traffic to a service flow and then maps it to MAC connection using a CID, so, both IP and UDP protocols are transformed into connection-oriented service flows.

A service flow is described by a set of QoS parameters responsible for latency, jitter and throughput. Then it is time to associate this service flow with a CID and forward it to the appropriate queue. After this it was time for scheduling which is done in downlink case by Base Station (BS) and in uplink case by Subscriber Station (SS). This principle is depicted in Figure 4.

- **Common Part Sublayer**

The CPS resides in the middle of the MAC layer. The CPS represents the core of the MAC protocol and is responsible for:

  - Fragmentation and segmentation of the SDUs into MAC protocol data units (PDUs).
  - Bandwidth allocation.
  - Connection establishment.
  - Maintenance of the connection between the two sides: BS and SS.

The IEEE 802.16-2004 standard [1] defines a set of management and transfer messages. The management messages are exchanged between the SS and the BS before and during the establishment of the connection. When the connection is realised, the transfer messages can be exchanged to allow the data transmission. The CPS receives data from the various CSs, through the MAC SAP, classified to particular MAC connections. The QoS is taken into account for the transmission and scheduling of data over the PHY Layer. Different types of QoS are defined:

  - BE (Best Effort): Used for lowest priority time-constraint services such as email or web-browsing.
  - nrtPS (non-real-time Polling Services): Used for non-real-time services having some time constraints (FTP for example).
  - rtPS (real-time Polling Services): Used for variable data rate real-time services. Example is the MPEG video.
  - UGS (Unsolicited Grant Services): Dedicated to Constant Bit Rate (CBR) services, UGS guarantees fixed-size data packets issued at periodic intervals. Example of use is T1/E1 transmissions.

The CPS includes many procedures of different types: frame construction, multiple access, bandwidth demands and allocation, scheduling, radio resource management, QoS management, etc.

- **Security Sublayer**

This sublayer is the third and last sublayer from the MAC layer. It provides authentication and data encryption functions.

2.1.1.2.IEEE 802.16-2004 PHY Layer

The PHY layer is also defined in the 802.16-2004 standard. There was established that Frequency and Time Division Duplex were used (FDD and TDD). Several PHY Layers are supported [6]. They can be divided in two different frequency bands:

- 10 - 66 GHz licensed bands (WirelessMAN-SC), provide a physical environment with single carrier air interface, in which, due to the short wavelength, LOS environment is required.

- 2 - 11 GHz licensed bands (WirelessMAN-SCa, WirelessMAN-OFDM and WirelessMAN-OFDMA). The 2 - 11 GHz licensed bands provide a physical environment where, due to the longer wavelength, LOS environment is not necessary. Three air interfaces are defined in this frequency band: WirelessMAN-SCa, single carrier air interface; WirelessMAN-OFDM, multi-carrier air interface using Orthogonal Frequency Division Multiplexing (OFDM) with 256 carriers; WirelessMAN-OFDMA, multi-carrier air interface using Orthogonal Frequency Division Multiple Access (OFDMA) with 2048 carriers.

The WiMAX is therefore based OFDM. It is a technique of transmitting multi-carrier which is recognized as an excellent method for high-speed bidirectional communication of data through wireless technology and provides efficient means to overcome the challenges of Non Line of Sight (NLOS) communication.

OFDM is a frequency-division multiplexing (FDM) scheme utilized as a digital multi-carrier modulation method. A large number of closely-spaced orthogonal sub-carriers are used to carry data. The data are divided into several parallel data streams or channels, one for each sub-carrier. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase shift keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions - for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath - without complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly-modulated narrowband signals rather than one rapidly-modulated wideband signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to handle time-spreading and eliminate intersymbol interference (ISI). This mechanism also facilitates the design of single-frequency networks, where several adjacent transmitters send the same signal simultaneously at the same frequency, as the signals from multiple distant transmitters may be combined constructively, rather than interfering as would typically occur in a traditional single-carrier [7].

2.1.1.3.IEEE 802.16e-2005

IEEE 802.16e-2005 standard [2] provides an optimized solution for fixed and mobile BWA. It main enhancements, compared with the IEEE 802.16-2004 standard, are:

- It can serve all usage models from fixed to mobile with the same infrastructure, offering fixed, nomadic, portable and mobile capabilities.

- Kept the fixed PHYs but added "Scalable OFDMA" to adapt to capacity and coverage needs.

- Handover Support: Make-Before-Break, Break-Before-Make and Macro-Diversity Handover.

- Provides enhanced performance, even in fixed and nomadic environments.

- 802.16e added a fifth scheduling service: ertPS (extended real-time Polling Service). Intermediary between rtPS and UGS, used for VoIP.

- Better Non Line of Sight (NLOS) performance, frequency reuse and power management functions (sleep and idle modes are implemented).

However 802.16e-2005 is not backward compatible with 802.16-2004 and it presents some losses when we attempt at frequency of operation (2-11 GHz for fixed WiMAX and 2-6 GHz for mobile) and at the data rate (fixed WiMAX reaches the maximum of 75 Mbps using a 20 MHz channel bandwidth whereas mobile can only reach 15 Mbps with a 5 MHz channel bandwidth) [6].

2.1.2.IEEE 802.16 Hardware – Redline Communications AN-100U

The IEEE 802.16 equipment (Redline Communications AN-100U) [41] used for this work is compliant with the IEEE 802.16-2004 version and has been acquired from Redline Communications for deployment of point-to-multipoint (PMP) and point-to-point (PTP) systems. It is composed by an indoor terminal (IDU) and outdoor transceiver and antenna (ODU). The WiMAX system is comprised of a RedMAX AN-100U and two WiMAX Forum [40] certified subscriber stations. Each subscriber station registers and establishes a bi-directional data link with the AN-100U sector controller. The antennas used for the tests were mounted on the roof of our premises.

- **PHY Layer features**

The AN-100U operates in the frequency 3.4480GHz. The maximum channel size is 7 MHz which allows up to 35 Mbps over the air rate and up to 23 Mbps data rate. The AN-100U system uses time division duplexing (TDD) to transmit and receive on the same RF

channel, or using separate RF channels using half-duplex FDD (HDFDD). It supports coding rates of 1/2, 2/3, and 3/4 and BPSK, QPSK, 16 Quadrature Amplitude Modulation (QAM), and 64 QAM modulation. The maximum range is 20 Km LOS or 3 Km NLOS [7].

- **Service Flows**

Service flows are a key feature of the 802.16 standard. A service flow represents a unidirectional data flow. Transmitting bidirectional traffic requires that two service flows be defined: one for the uplink, and another for the downlink.

These service flows can have different QoS settings. A service flow may be pre-provisioned or can be dynamically created and deleted without service outage. This is useful for supporting multiple subscribers in a single sector.

- **Service Flow Classification**

The 802.16 equipment is restricted in terms of available classification methods (Convergence Sublayers).

Only two distinct methods are available for traffic classification in the equipment: classification based on the IPv4 protocol (IPv4 CS), or classification based on the MAC address of the MN (Ethernet CS), either the source (for the uplink traffic) or the destination (for the downlink traffic).

- **Scheduling**

The RedMAX AN-100U base station enforces the QoS settings in the WiMAX segment by controlling all uplink and downlink traffic scheduling providing non-contention based traffic with predictable transmission characteristics.

The 802.16 equipment is restricted in terms of service classes that support. Only two classes are supported. They are real-time Polling Service (rtPS) (typical applications include streaming MPEG video or VoIP with silence suppression) and Best Effort (BE) (typical applications may include Internet access and email)

- **Management Interface**

There are several interfaces supported by the equipment such as: HTTP, FTP, Telnet/CLI interfaces and SNMP.

2.2.Mobility

Mobility is an user desire! He needs to access information at anytime and anywhere, needs to be able to contact and be always reachable, because of the increasing transmission capacity of the networks and number of portable terminals, emerging new applications.

A user may want access to several services in different locations or can be identified remotely for subsequent receipt of information. The flow of information of a particular application may be redirected to different places or even the equipments, due its increasingly portable, can suffer mobility maintaining the connection over a large area. All of this is mobility!

2.2.1.Mobility Concepts

Handovers

A handover is basically the transition from a mobile unit from one cell to another in a transparent way to the user, or in the same manner, the transfer of the flow of information between different access points.

Handovers can be classified by several ways:

- Purpose – Link Layer Handover if only the access point changes, Intra-cell if after the handover the mobile terminal change the cell interface, Inter-cell if it happens between two different cells or Inter-network if the network of mobile terminal changes (Layer 3 handover).

- Technology – Horizontal handover when the two access points of the network are based on the same link wireless technology (intra-technology handover) or Vertical handover when the two access points of the network are based on different wireless technologies (inter-technology handover).

- Connectivity – Soft handover (Make-before-break) or Hard handover (Break-before-make). The first one is designed when there is simultaneously connectivity to the two access points and before finishing the old link is established the new. The second one is designed when there isn't simultaneously connectivity to both access points and the old link is broken before the establishing of the new. The advantages of the soft handover are: the connection is always guaranteed without delay, low probability of the call's falling, increasing of the capacity/coverage, which promotes the satisfaction of the user. The advantage of the hard handover is that it requires little network processing.

- Management – Handover can be classified by which entity detects it (mobile terminal - Mobile initiated handover (MIHO) or network - Network controlled handover (NIHO)), which entity manages it (mobile terminal - Mobile controlled handover (MCHO), network - Network controlled handover (NCHO), or both of them - Mobile assisted handover (MAHO)), which entity helps it (mobile terminal or network), if it is done by the new access point or by the old one, if it is proactive or unexpected.

- Performance – Smooth handover if the loss of the packets is minimized, Fast handover if the communication delay is minimized, Seamless handover which minimizes the delay and the loss of the packets, and a Context-aware handover if the mobile terminal context is guaranteed during the handover.

Link Layer Mobility – IEEE 802.16e

The IEEE 802.16e-2005 standard [2] defines a framework for supporting mobility management which includes handover support and power management. IEEE 802.16e supports Link Layer mobility and IP mobility using Mobile IP. For this both PHY and MAC were enhanced, with advanced error correction decode, different MIMO techniques, different modulation schemes.

Attempting to the IEEE 802.16e standard an handover may occur when a Mobile Station (MS) migrates from the air-interface provided by one Base Station (serving BS) to the air interface provided by another Base Station (target BS). The handover decision can be made by MS (Mobile Station), BS or another entity. The handover initially may be originated in the MS, in the BS or on the network. The MS does periodically a radio frequency scan and measures the quality of signal of neighbouring Base Stations and can perform a Mobile Initiated Handover (MIHO).

IEEE 802.16e supports both hard and soft handover. The first implies an abruptly transfer of the connection from one BS to another. The two soft handover methods supported by the standard are:

- Fast Base Station Switching (FBSS), in which, the MS and BS maintain a list of BSs that are involved in FBSS with the MS. The MS continuously monitor the signal strength of the possible BSs to move and select the best one to be its Anchor BS, this is, the one that supports mobile station (is designated to transmit/receive data to/from MS), where the MS is registered, synchronized, performs ranging and monitors the downlink channel for control information.

- Macro Diversity Handover (MDHO), in which, the MS migrates from the air-interface provided by one or more base stations to the air-interface provided by one or more BSs, and it begins when a MS decides to transmit or receive unicast messages and traffic from multiple BSs in the same interval.

The power management advances are commonly named “sleep mode” and “idle mode”, which let the mobile system be at rest.

IP Mobility

- **MIPv4**

Mobile IP [8] is an Internet Engineering Task Force (IETF) standard communications protocol that is designed to allow mobile device users to move from one network to another while maintaining a permanent IP address.

There main entities and addresses are: Mobile Node (MN), Home Agent (HA), Foreign Agent (FA), CN (Correspondent Node), Home Address and Care-of-Address (CoA) (see Figure 5).

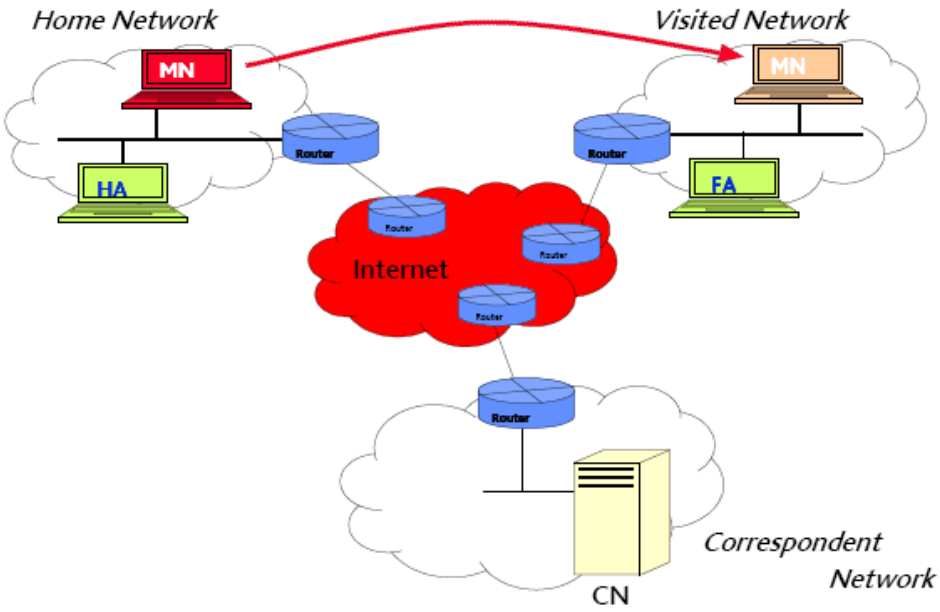


Figure 5 - MIPv4 main elements

- MN is a host or router that changes its point of attachment from one network to another.
- HA is a router on a mobile node’s home network which tunnels datagrams for delivery to the mobile node when it is away from home, and maintains current location information for the mobile node.
- FA is a router on a mobile node’s visited network which provides routing services to the mobile node while registered. The foreign agent detunnels and delivers datagrams to the mobile node that were tunneled by the mobile

node's home agent. For datagrams sent by a mobile node, the foreign agent may serve as a default router for registered mobile nodes.

- CN is the terminal that wants to connect to Mobile Node, even it is on the Home Network or Foreign Network.
- Home Address is a permanent address assigned to the MN in the home network.
- CoA is the temporary address that permits to identify the position of the MN in a foreign network.

HA and FA advertise their presence on the networks where they are located by using Agent Advertisement messages. A mobile node may optionally solicit an Agent Advertisement Message through an Agent Solicitation message. A MN receives this Agent Advertisements and determines whether it is on its home network or a foreign network.

When a MN detects that it is located in its home network, it operates without mobility services. When a MN detects that it has moved to a foreign network, it obtains a care-of-address. A MN operating away from home then registers its new care-of-address with the HA through exchange of a Registration Request and Registration Reply message with it, possibly via a FA.

The datagrams sent to the MN's home address are intercepted by its HA, tunnelled by the HA to the MN's care-of-address, received at the tunnel endpoint (either at a FA or at the MN itself), and finally delivered to the MN. In the reverse direction, the datagrams sent by the MN are generally delivered to their destination using standard IP routing mechanisms, but they can pass through the HA too.

- **MIPv6**

MIPv6 [20] is a mobility enabled version of the IPv6. As IPv6 was designed with mobility in mind from the beginning, MIPv6 is able to use basic IPv6 functionalities in its operation. This means that considerably less modification is required to an IPv6 network than what is needed when MIPv4 is implemented over an IPv4 network. In the MIPv6 design, the shortcomings of MIPv4 are also taken into consideration and improved.

Such improvements include, among others, the redundancy of foreign agent entities in the network as the mobile host itself can handle the foreign agent functionalities in MIPv6, absence of triangular routing due to route optimization, dynamic address auto-configuration also for care-of-addresses [14][15], and improved security.

2.2.2.IEEE 802.21

2.2.2.1.Main Goals

Because of the user and networks necessity of a heterogeneity access and mobility between several technologies, the IEEE 802.21 standard was defined.

This standard [3] facilitates handovers between heterogeneous networks (wired and wireless) and cellular systems (3GGP and 3GPP2) by providing timely information about currently link states and available access networks for handover decision makers, providing mechanisms to minimize the disturbance of network service during handover.

It may assist handovers not only between wireless systems but also in wired systems like Ethernet. More specifically it provides link layer intelligence and other necessary information to upper layers, to optimize the handovers between heterogeneous media.

We are talking about an architecture which facilitates the Vertical Handovers (between different technologies) but are also enhancing the Horizontal handovers (between the same technology).

With IEEE 802.21 standard [3] a lot of benefits are allowed to the user. Some examples include:

- In case of an interrupt of a service when the environment changes and thus changes in the wireless link conditions, it provides the continuity of the service running (mobile case).

- When a network becomes more attractive than another, due at the changing of network environment, the need of the IEEE 802.21 is an important improvement.

- Heterogeneous handovers may occur when the user need a more faster connection or better quality of service, for example when we want to do a download of a data file.

- For example when we are doing a phone call, and we make a network transaction, the handover procedure and the interruption of the conversation should be non-perceptible to the user.

2.2.2.2.IEEE 802.21 Architecture

The IEEE 802.21 standard supports cooperative use of information available at the mobile node within the network infrastructure. In the one hand, the mobile node is capable of supporting multiple link-layer technologies, which may be wireless or wired, and detect available networks. In the other hand network store network information, relatively at, e.g, Lower Layers, Upper Layers, location of mobile nodes.

The MIHF is the central structure of the standard. It is a logical entity, whose definition has no implications on the way the MIHF is implemented either on the mobile node or in the network.

The IEEE 802.21 reference model (see Figure 6) [3] defines three different services all of which centres around the MIHF.

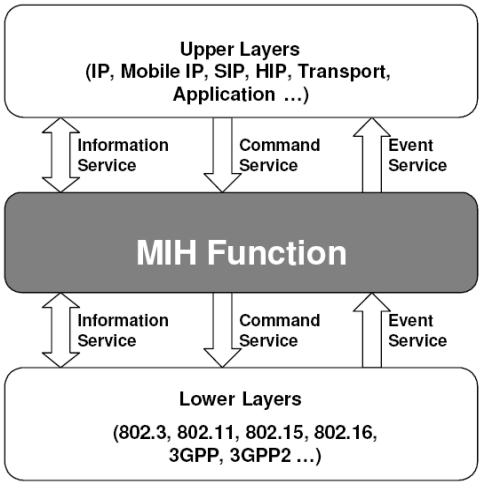


Figure 6 - MIHF reference model

The MIHF implements the three MIH services, namely the Event Service (MIES), the Command Service (MICS), and the Information Service (MIIS).

MIES delivers events which may indicate changes in state and transmission behavior of the physical, data link and logical link layers, or predict state changes of these layers. MIES may also be used to indicate management actions or command status on part of network or some such management entity. The exchanged events can be local or remote (see Figure 7).

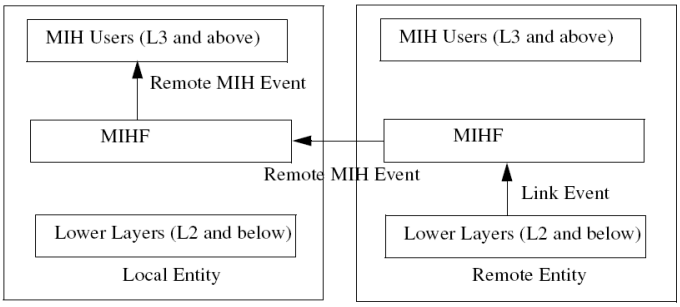


Figure 7 - Remote MIH Event

The following set of link layer events was defined at the standard [3]:

Link event name	Link event type	Description
Link_Up	State Change	L2 connection is established and link is available for use
Link_Down	State Change	L2 connection is broken and link is not available for use
Link_Going_Down	Predictive	Link conditions are degrading and connection loss is imminent
Link_Detected	State Change	New link has been detected
Link_Parameters_Report	Link Parameters	Link parameters have crossed specified threshold
Link_Event_Rollback	State Change	Previous link event needs to be rolled back
Link_PDU_Transmit_Status	Link Transmission	Indicate transmission status of a PDU
Link_Handover_Imminent	Link Synchronous	L2 handover is imminent based on changes in link
Link_Handover_Complete	Link Synchronous	L2 link handover to a new PoA has been completed

Table 1 - Link Events

The following set of MIH events was defined at the standard [3]:

MIH event name	MIH event type	(L) ocal (R) emote	Description
MIH_Link_Up	State Change	L, R	L2 connection is established and link is available for use
MIH_Link_Down	State Change	L, R	L2 connection is broken and link is not available for use
MIH_Link_Going_Down	Predictive	L, R	Link conditions are degrading and connection loss is imminent
MIH_Link_Detected	State Change	L, R	New link has been detected
MIH_Link_Parameters_Report	Link Parameters	L, R	Link parameters have crossed a specified threshold and need to be reported
MIH_Link_Event_Rollback	State Change	L, R	Previous link event needs to be rolled back
MIH_Link_PDU_Transmit_Status	Link Transmission	L	Indicate transmission status of a PDU
MIH_Link_Handover_Imminent	Link Synchronous	L, R	L2 handover is imminent based on either the changes in the link conditions or additional information available in the network
MIH_Link_Handover_Complete	Link Synchronous	L, R	L2 link handover to a new PoA has been completed

Table 2 - MIH Events

MICS enables higher layers to control the physical, data link and logical link layers (also known as "lower layers"). The higher layers may control the reconfiguration or selection of an appropriate link through a set of handover commands. The exchanged command can be local or remote (see Figure 8).

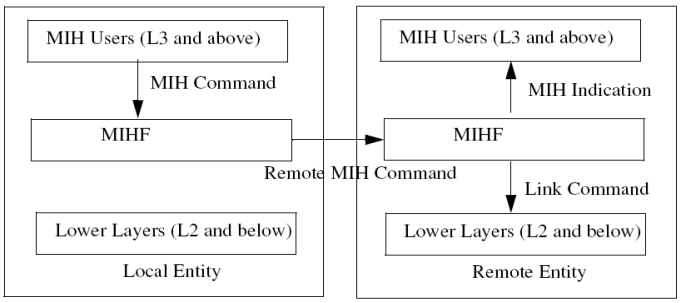


Figure 8 - Remote MIH Command

The following set of link layer commands was defined at the standard [3]:

Link command	Comments
Link_Capability_Discover	Query and discover the list of supported link layer events and link layer commands
Link_Event_Subscribe	Subscribe to one or more events from a link
Link_Event_Unsubscribe	Unsubscribe from a set of link layer events
Link_Configure_Thresholds	Configure thresholds for Link Parameters Report event
Link_Get_Parameters	Get parameters measured by the active link
Link_Action	Request actions on a link layer connection

Table 3 - Link Commands

The following set of MIH commands was defined at the standard [3]:

MIH command	(L)ocal , (R)emote	Comments
MIH_Get_Link_Parameters	L, R	Get the status of a link
MIH_Configure_Link	L, R	Configure a link
MIH_Scan	L, R	Scan a list of links
MIH_Link_Action	L, R	Control the behavior of a set of local or remote lower layer links
MIH_Net_HO_Candidate_Query	R	Network may initiate handover and send a list of suggested networks and associated Points of Attachment
MIH_MN_HO_Candidate_Query	R	Command used by MN to query and obtain handover related information about possible candidate networks
MIH_N2N_HO_Query_Resources	R	This command is sent by the serving MIHF entity to the target MIHF entity to allow for resource query, context transfer (if applicable), and handover preparation
MIH_Net_HO_Commit	R	In this case the network commits to do the handover and sends the choice of selected network and associated PoA
MIH_MN_HO_Commit	R	Command used by MN to notify the network that a candidate has been committed for handover
MIH_N2N_HO_Commit	R	Command used by a serving network to inform a target network that a mobile node is about to move toward that network
MIH_MN_HO_Complete	R	Notification from MIHF of the MN to the target or source MIHF indicating the status of handover completion
MIH_N2N_HO_Complete	R	Notification from MIHF of the MN to the target or source MIHF indicating the status of handover completion

Table 4 - MIH Commands

MIIS provides a framework and corresponding mechanisms by which the MIHF entity may discover and obtain network information existing within a geographical area to facilitate the handovers, such as, general information and access network specific information, point of attachment specific information and vendor/network specific information. The primitive used by an MIHU to request information from a MIH information server is MIH_Get_Information.

Besides these three type of services (MIES, MICS and MIIS) there are several service management primitives used to the properly configuration of the MIH entities. Next table describes these service management primitives.

Service Management Primitive	(L) ocal, (R) emote	Comments
MIH_Capability_Discover	L, R	Discover the capabilities of a local or peer MIHF
MIH_Register	R	Register with a peer MIHF
MIH_DeRegister	R	Deregister from a peer MIHF
MIH_Event_Subscribe	L, R	Subscribe for one or more MIH events with a local or remote MIHF
MIH_Event_Unsubscribe	L, R	Unsubscribe for one or more MIH events from a local or remote MIHF

Table 5 - Service Management primitives

The MIHF interfaces with other layers and functional planes using Service Access Points (SAPs). Each SAP consists of a set of service primitives that specify the information to be exchanged and the format of the information exchanges (Figure 9) [3].

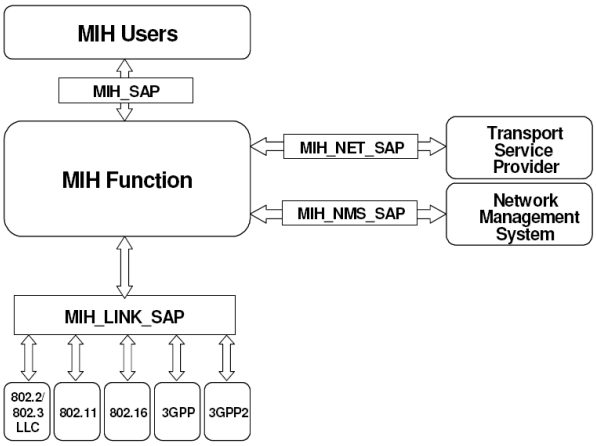


Figure 9 - MIHF interfaces

The MIHF can exchange local services or remote services. For this it has to communicate with the remote MIHFs (see Figure 10) using MIH protocol [3]. The MIHF (located in Mobile Node) communication with remote MIHFs (present in Access Network or Core Network) is provided by the MIH_NET_SAP interface, which supports the exchange of MIH information and messages with remote MIHFs. MIH protocol defines message formats for exchanging these messages between peer MIHFs.

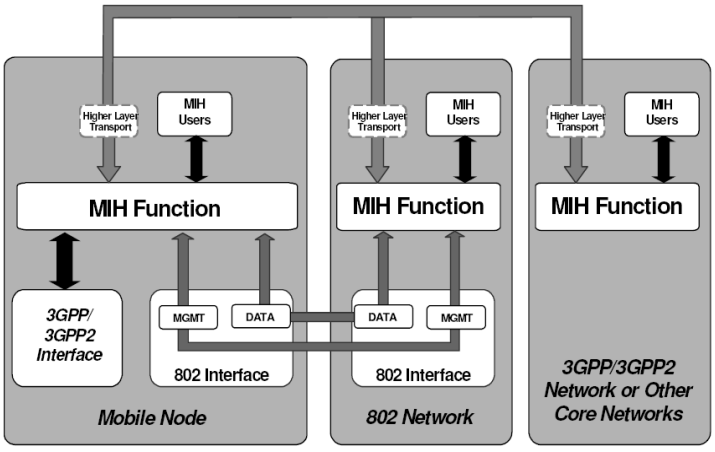


Figure 10 - Communication between different MIHFs

2.3.Summary

In this chapter was presented an overview of the Broadband Wireless technologies giving special emphasis at IEEE 802.16 and their main characteristics. As explained, the 802.16 MAC layer is divided in three sublayers: the Service Specific Convergence Sublayer (CS), the Common Part Sublayer (CPS) and the Privacy Sublayer. In the PHY layer, two main groups are defined: the single carrier and the multi carrier physical layers. The multi carrier physical layer can use OFDM with 256 subcarriers or OFDMA technique provides 2048 subcarriers. In this case, NLOS environments are envisaged and the multipath effect should

be taken into account. The 802.16 equipment features were also described. We also introduce the mobility mechanisms.

As explained, there are several types of handovers, classified by its performance, management, purpose, technologies involved and connectivity. It was depicted the Link Layer mobility in IEEE 802.16e-2005 standard. Because of the necessity of a seamless handover between heterogeneous network, it was explained the IEEE 802.21 standard and its main goals and functionalities.

3.IEEE 802.16 for Real-time Services: IPTV and VoIP

It is widely anticipated that the next generation wireless networks will handle an exponentially larger amount of audio/visual (A/V) content than today's Internet [17]. As these services operate on an IP network, there are some advantages inherent in the protocol regarding the provision of various services in the same infrastructure. This advantage means a reduction of cost to both the operators and users, also giving opportunity to offer new services valued by customers (interactive). Due to their particular requirements, we perform some tests with Voice over IP (VoIP) and Internet Protocol Television (IPTV).

Our main objective is the investigation of WiMAX (Worldwide Interoperability for Microwave Access) performance in practice and the evaluation of WiMAX as VoIP and video streaming backhaul in point-to-multipoint (PMP) scenarios [28]. We also evaluate Quality of Service (QoS) [9] in our testbed, giving more priority to VoIP because it is a real-time service which has to have low delay and a dedicated bandwidth.

We opted for a point-to-multipoint (PMP) scenario because most of the related work done so far has been done using point-to-point (PTP) scenarios, which is not very real for future use of WiMAX networks in which the source and destination of traffic will be in opposite WiMAX links.

In this chapter we also evaluate VoIP performance over a fixed WiMAX testbed and quantify the benefits from employing application-level aggregation. VoIP aggregation appears to be a powerful method to improve performance and increase capacity utilization.

Section 3.1 provides a brief overview of our testbed. Section 3.2 depicts the work done with VoIP and IPTV without using QoS, whereas section 3.3 relates the same tests but now using QoS. The analysis of VoIP aggregation is provided in section 3.4 and finally, section 3.5 provides a final summary of the chapter.

3.1.Testbeds and Methodologies

At this section will be explained the testbed and the methodology used to evaluate VoIP and IPTV over WiMAX.

3.1.1.Testbed

We employ multiple competing traffic sources over a point-to-multipoint WiMAX topology with two subscriber stations (SSs) and one base station (BS) and measure the capacity of our WiMAX equipment to handle a multitude of VoIP flows between SSs while delivering a variable number of IPTV streams. We measure jitter, throughput, packet loss, and one way delay for LOS (Line of Sight) conditions in our testbed. For the one way

delay measurements we synchronize the clocks of all testbed hosts with a software-only, open source implementation of the IEEE 1588 Precision Time Protocol (PTP) [39].

The implemented testbed is depicted at Figure 11. It illustrates our experimental facility comprising a RedMAX [41] fixed WiMAX BS, operating at the 3.5 GHz frequency band, two subscriber stations (SS1 and SS2), and three PCs. Both SSs are RedMAX equipment. On the BS and SSs sides, we connect seeral terminals to act as traffic sources/sinks.

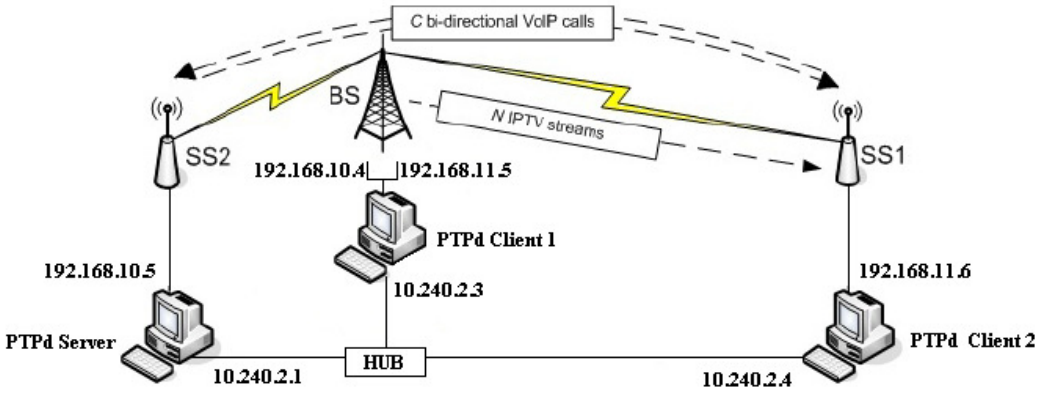


Figure 11 - Schematic of our WiMAX testbed

3.1.2.Methodology

In order to obtain the accurate results from our experiments we have to be rigorous. For this our work was done by phases, passing by the configuration, generation of traffic, synchronization of our testbed. This section provides the details of each one of these phases.

- **Testbed Configuration**

The distances between BS and SSs were 10 m. The measured RSSI values were -48 dBm at both SSs. All tests were performed in our laboratory, where conditions are static, even though there can always be a degree of variance on a wireless link. The modulation scheme employed by SSs was 64 QAM with 3/4 FEC. Table 6 relates the testbed configuration.

Base station and Subscribers Stations	RedMAX
Frequency band	3.5 GHz
Channel bandwidth	3.5 MHz
PHY WiMAX	16d, 256 OFDM FDD
BS and SS Transmission power	1.0 dBm
MAC scheduling	Best Effort
Downlink Ratio	56/44
Uplink & downlink modulation for SSs	64 QAM (FEC: 3/4)
SSs RSSI values	-48 dBm
BS-SSs distances	10 m

Table 6 - Testbed Configuration

We measure performance under LOS conditions. In our testbed there are three main networks: one for the synchronization between all PCs - 10.240.2.0/8; and the others to perform our tests and measurements - 192.168.11.0/8 (between SS1 and BS) and 192.168.10.0/8 (between SS2 and BS).

- **Traffic Generation**

    - **Capturing and emulating IPTV streaming traffic using Jugi's Traffic Generator (JTG)**

In order to emulate a set of IPTV streams, we got access to 20 minutes of live IPTV unicast transmission and created a packet trace with Wireshark [39]. The captured video stream was in H.264/AVC format (also known as MPEG-4 Part 10) [11] and the accompanying audio stream was encoded in MPEG-1 Audio Layer II (also known as MP2) [50]. The content of the transmission was a music video TV channel and thus configured with video stream at 512 kb/s (360×288, 25 f/s) and the audio at 192 kb/s, emphasizing audio over video quality [27]. The video and audio were collected at the receiver side using Wireshark, recording very low delay and delay variance, no RTP [26] packet loss, and no RTSP [25] message exchanges.

The captured video stream, often with dramatic changes in scenery, visual effects and so on, has a variable bit rate (VBR). The total packet sizes of the video varied greatly, with the major mode at 1492 bytes. It was also emulated the corresponding IPTV audio stream using constant bit rate (CBR) traffic with the total packet size fixed at 634 bytes (including codec payload and RTP/UDP/IP/MAC headers). The video and audio parts of the IPTV traffic are separated and streamed to different ports. This separation allows to study in a straightforward manner the relative performance of VoIP and IPTV A/V over a congested fixed WiMAX link.

Based on the Wireshark trace, it was created new trace files with all packet sizes and interarrival times both for video and audio. Based on these trace files, we "play back" N IPTV A/V streams starting from a random point in the 20-minute long IPTV packet trace, and wrap around if needed. Each run lasts 60 s. We use JTG [48] to generate the trace-driven IPTV streaming traffic. JTG is a simple, flexible, and configurable open source traffic generator, which can be used in a command-line fashion in GNU/Linux. The source of the N A/V streams is located at the PC under the BS, while the sinks are in the domain of SS1.

    - **Emulating VoIP traffic using JTG**

In addition to the N A/V streams, we injected C synthetic duplex, bidirectional VoIP flows with source/sink pairs in the domains of SS1 and SS2 in all of tests, again using JTG. We chose to experiment with Speex [49], an open source audio codec specially designed for VoIP applications over packet switching networks. Speex is designed to be robust against packet loss and has been incorporated in several applications. We emulated C Speex VoIP flows each with a wideband codec bitrate of 12.8 kb/s using JTG. For each VoIP flow, JTG generates 50 packets/s with 32 bytes of codec payload, thus leading to an effective

application bitrate of 17.6 kb/s (including RTP headers). After adding a total of 28 bytes of UDP and IP headers, each JTG instance injects 28.8 kb/s of total emulated Speex CBR traffic into the network.

A single VoIP flow is managed by a single JTG [48] instance running at its own port, so that traces for each stream can be post-processed in detail. Although it is possible to use one JTG instance for receiving more than one stream, it is not possible to separate the logs in a straightforward manner and be able to accurately apportion loss and delay to each flow.

- **Use of PTP for host clock synchronization**

For high-precision one way delay measurements, accurate clock synchronization is necessary, taking care of both absolute time and clock drift at different hosts in the network. When only round-trip delay measurements are performed, the critical aspect is clock drift only. Lack of accuracy in the absolute time is not harmful. However for the one way delay measurements we are interested, both absolute time and clock drift are important. We opted to use an IEEE 1588 Precision Time Protocol [47] open source server (Precision Time Protocol daemon - PTPd) to synchronize the clocks at all hosts. Similarly with Network Time Protocol (NTP) [24], PTP synchronization messages are sent over the network.

Although PTP injects a very small amount of traffic when compared with the rest of the sources in our tests, it is preferable that PTP signalling does not interfere with the measured traffic. In short, the testbed synchronization was made using a different network, 10.240.2.0/8, where the PC connected to SS2 was the PTPd Server and the other two PCs were the clients. After initializing the PTPd in each machine and waiting the necessary time to the synchronization, the offset between the different host clocks was even lower than 100 μs, which is feasible for our testbed.

With all hosts synchronized within hundreds of μs, this allows for measurement granularity of one to two orders of magnitude larger than the one way delay. At this stage, and wishing to avoid having to deploy (expensive) GPS-clocks on all hosts in the testbed, we are satisfied with the synchronization accuracy provided by the software-only implementation of PTP [35].

3.1.3.Conduct and Experiment

To perform the tests we have to follow the steps described in this section.

- **Measuring the maximum WiMAX link capacity**

Before proceeding with the measurements, we conducted baseline experiments to determine the maximum throughput that can be attained in our lab testbed. We saturated the fixed WiMAX link and measured the maximum application-level throughput, also called goodput, on the downlink and uplink (from the BS to SS and vice-versa,

respectively). We experimented with various maximum transmission units (MTU), and obtained the best results for application payloads of 1472 bytes (MTU = 1500 bytes, the recommended MTU size for IEEE 802.16 standard-compliant equipment). For the uplink, the average maximum measured goodput was 4.75 Mb/s and for the downlink 5.75 Mb/s, with negligible (<0.1%) packet loss under direct LOS conditions and using Iperf tool to evaluate the capacity of WiMAX link.

- **Starting PTPd**

We generate shell scripts both for server and clients and before ran the JTG we started PTPd in all machines using those scripts.

- **Emulating traffic with JTG**

In order to test VoIP backhauling inside the same WiMAX cell we introduced C = 50 simultaneous, bidirectional flows, yielding an application goodput (Speex payload plus RTP header) of 880 kb/s. This is only 18,5% of the maximum uplink goodput of 4.75 Mb/s, measured with MTU sized UDP packets. But even inserting more VoIP flows, trying to achieve the maximum capacity of the uplink (4.75 Mb/s) this never would be achieved, which indicates that the tested WiMAX equipment does not handle (a large amount of) small IP packets as competently as MTU-sized packets. The measured maximum downlink capacity with MTU sized UDP packets was 5.75 Mb/s, which exceeds the uplink capacity and leaves plenty of bandwidth for downloading for the subscribers inside the WiMAX cell. As we are interested to measure the performance of the tested equipment at its capacity limit in a scenario where VoIP and A/V streaming take centre stage, we emulated a video on demand service to be used by some of the subscribers in parallel with the VoIP conversations. By gradually increasing N, the number of synthetic IPTV A/V streams served via the BS to SS1, we determined the "breakpoint" of the downlink. For each N, we repeated the run ten times.

We generate 5 JTG's shell scripts where we started the senders and the receivers of all traffic (VoIP, video and audio) using JTG. Firstly I started the receivers at SS1 and SS2. Then we ran the senders in all of three machines.

3.2.VoIP and IPTV over WiMAX without QoS

At this section we will perform some tests without QoS. For this we have defined at the Redline Equipment a set of service flows in which the traffic will pass. We inserted at BS-SS1 WiMAX link two services flows based on MAC of the PC on the SS1 domain: one uplink and other downlink. We did the same at BS-SS2 WiMAX link but now based on MAC of the PC located in SS2 domain. With these four service flows all the traffic generated by the different sources will pass through WiMAX links and hit the defined sinks. Taking into account that these tests were performed with Best Effort, both IPTV and VoIP traffic for SS1 can pass through the same service flow. The all procedure to perform the experience was explained in section 3.1, so this section provides the results and conclusions about what have been done.

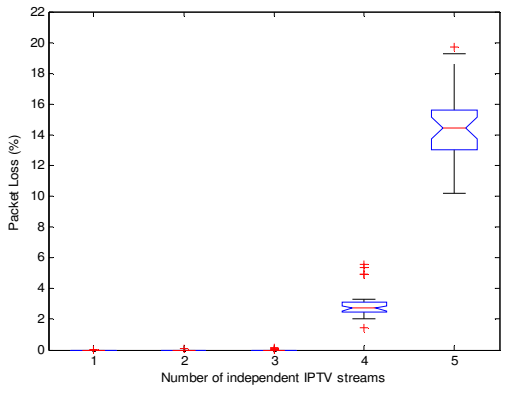
3.2.1.Results

This section presents our measurements in "box-whisker-plots", or simply boxplots. The box in each figure contains the middle 50% of the measured values. The line in the middle represents the median, the top and bottom of the box correspond to Q3 and Q1, respectively. Values outside the whisker lines, shown as crosses, are considered outliers.

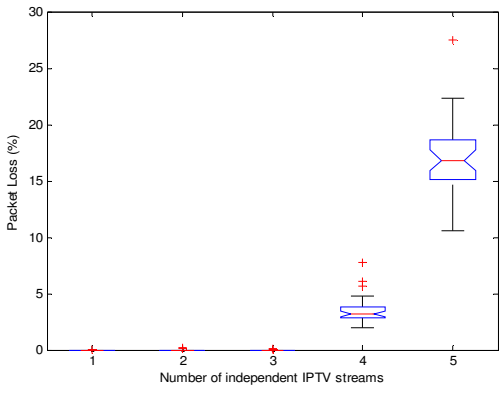
3.2.1.1.Measurements

- **Packet Loss**

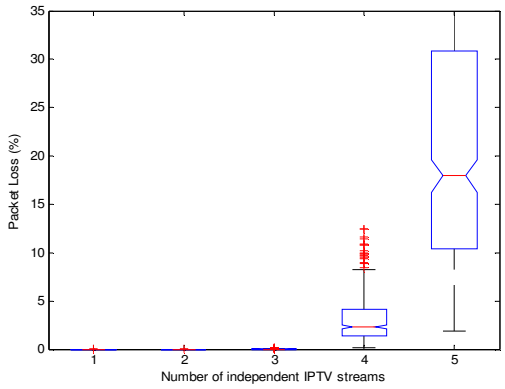
The measured packet loss rates for audio, video and VoIP at SS1 are depicted in Figure 12 a), b) and c) respectively. The box plots show the ten averages of packet loss for the VoIP and A/V streams, as recorded by JTG. The BS-SS1 WiMAX downlink can handle N <= 3 simultaneous A/V streams in parallel with the VoIP traffic with negligible packet loss. When N = 4, packet loss increases rapidly, and even the packet loss average does not exceed 5%, there are occasional situations in which it exceeds, for VoIP, which is unacceptable. Even for the Speex codec, which is the most robust and tolerant to packet loss of the three codecs emulated [49], these situations with this level of losses would be degrading performance considerably. The IPTV video streams suffer packet losses that don't exceed 5%, for both video and audio, with N<=4, which could be handled satisfactorily by a real-world IPTV client. When N > 4 packet losses exceed 15%, which is also unacceptable. If we turn our attention to the performance of the 50 bidirectional VoIP flows at SS2 (Figure 12 d)), the highest packet loss rate observed at the SS2-BS downlink was 0.04%, which is negligible for Speex [49].



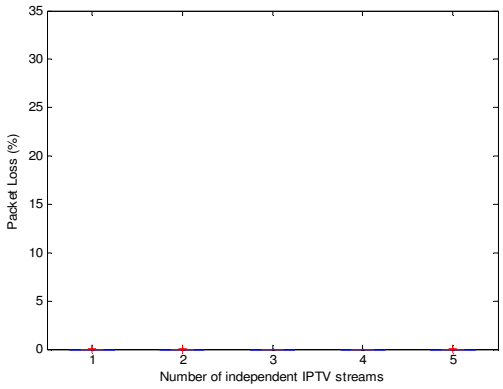
a) Audio at SS1



b) Video at SS1



c) VoIP at SS1

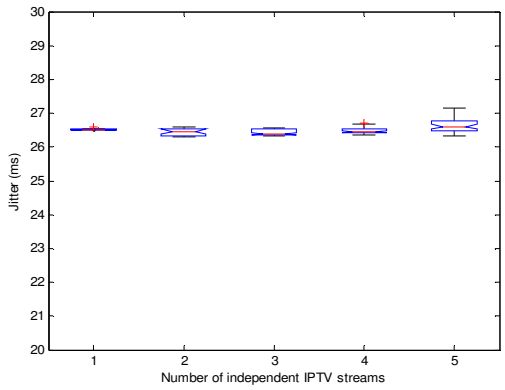


d) VoIP at SS2

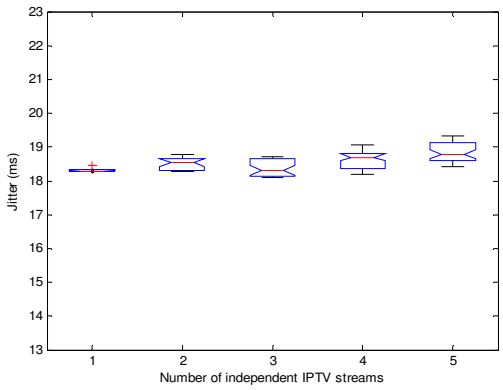
Figure 12 - Measured Packet Loss

- **Jitter**

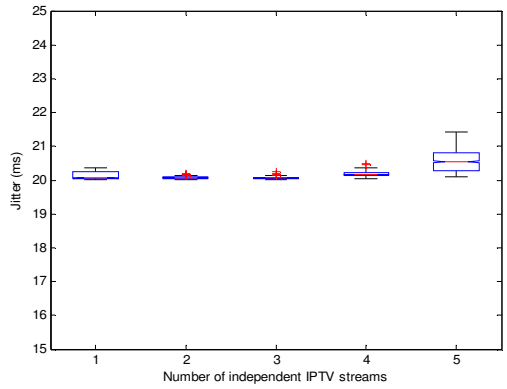
Comparing the results at SS1 for audio, video and VoIP (see Figure 13 a), b) and c), respectively) we conclude that audio is the real time traffic that can achieve transmission rates closer to the theoretical rate because of its higher value of jitter. It means that audio is the traffic that is more strongly adjusted at physical level, in order to achieve a transmission rate more close to real. It is followed by VoIP and finally by video which is the traffic that has the lower value for jitter.



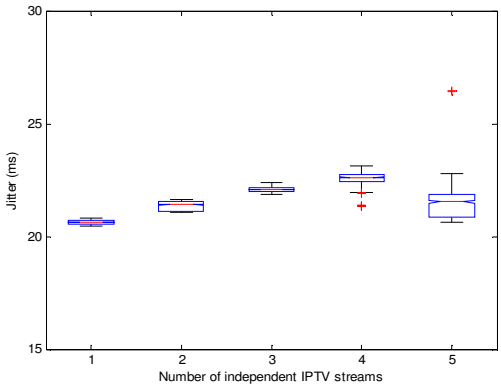
a) Audio at SS1



b) Video at SS1



c) VoIP at SS1

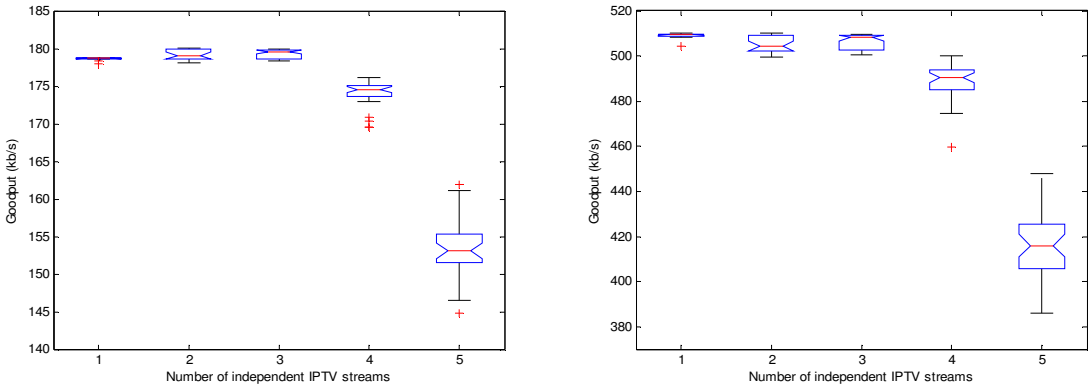


d) VoIP at SS2

Figure 13 - Measured Jitter

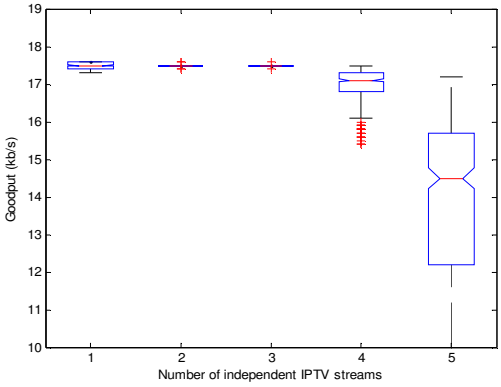
- **Application Throughput**

Figure 14 a), b) and c) illustrate the application throughput or goodput, for the three types of traffic (audio, video and VoIP) over the fixed WiMAX link at SS1. The difference between the VBR H.264/AVC encoded video streams and CBR audio and VoIP is visible. The fluctuation of the video stream throughput is more extensive. This is in part due to the variability of the wireless transmission, but also due to the random starting points in the replayed video packet trace. Note that due to the random starting points in the video trace, goodput of video ranges between 500 kb/s and 512 kb/s, when N <= 3, as one would expect. Meanwhile, the throughput of the audio and VoIP streams remains very close to 178 kb/s and 17.6 kb/s, respectively. Note that although the streamer of audio was configured to transmit the audio at 192 kb/s, the captured audio packet trace recorded a somehow smaller bitrate.When N > 3, the capacity of the WiMAX downlink becomes a restrictive factor and the median goodput of all traffic types starts to fall. The spread of the average goodput in different runs starts to increase, as packets are dropped due to backlogs at the WiMAX interface. When the normalized values of goodput are examined, we note that the behaviour of the three different traffic types is practically the same when N > 3, which is the "breakpoint" of the WiMAX downlink for this scenario. At SS2 the goodput (Figure 14 d)) maintains more constant than at SS1, because there is only this type of traffic at SS2. However when we are working with 4 or 5 IPTV streams it has a greater variation. The congestion in the downlink channel at SS1 should have an effect on its uplink channel, in which also passes the VoIP traffic that comes to SS2 and this should be the main reason for this.

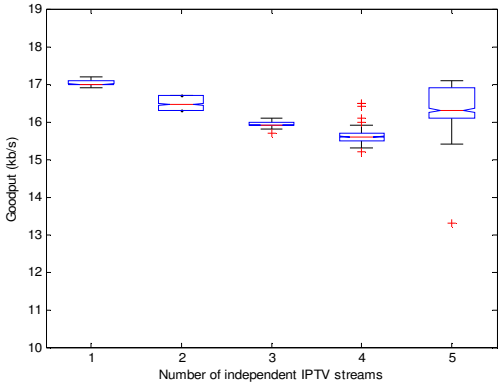


a) Audio at SS1

b) Video at SS1



c) VoIP at SS1

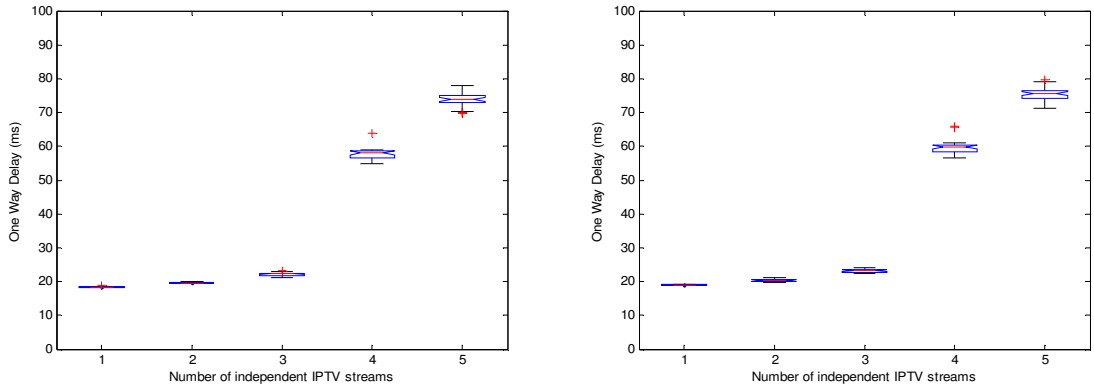


d) VoIP at SS2

Figure 14 - Measured Goodput

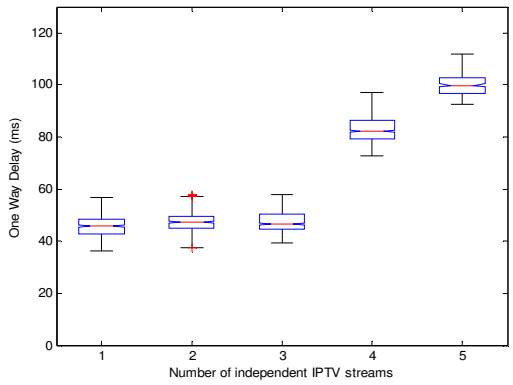
- **One Way Delay**

The one way packet delays, in the BS-SS1 downlink, as measured by the packet inter-arrival times at SS1, are quite similar across all traffic types, as shown in Figure 15 a), b) and c). For audio and video the one way packet delays walks in the house of 20/25 ms which is typical of the equipment used because it is usually the delay involved in a WiMAX link. For VoIP it is roughly twice 45/50 ms, because this traffic passes two WiMAX links. Overall, mean delay < 60 ms when N <= 3. This range of one way delays can be tolerated by all applications involved in the examined scenario. When N = 4, the median value of the inter-arrival times jumps to over 60/80 ms for audio and video traffics and 80/100 ms for VoIP traffic, as the majority of the received packets have queued through full buffers in the network interfaces of the test system. This range of one way delays can be handled with adequate buffering for the IPTV streams, but not for the VoIP calls. At SS2 (Figure 15 d)), when N <= 3, one way delay is basically the same as in the case of SS1. When N> 3 the delay increases slightly to 50/55 ms which may mean that the WiMAX uplink channel is slightly affected when the downlink channel reaches the breakpoint (N>3), as happened with the goodput.

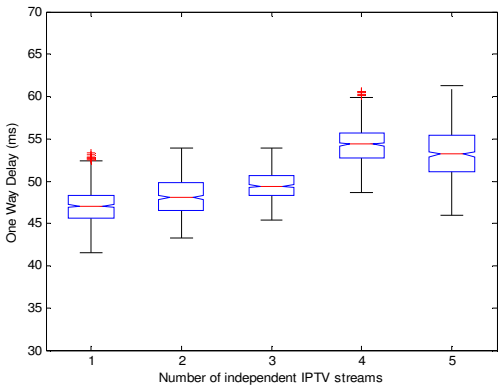


a) Audio at SS1

b) Video at SS1



c) VoIP at SS1



d)VoIP at SS2

Figure 15 - Measured One Way Delay

3.2.2.Conclusions

To sum up, under LOS conditions our testbed can sustain C = 50 emulated bidirectional Speex-encoded VoIP calls within the same WiMAX cell and N = 3 simultaneous emulated IPTV streams with negligible packet loss, adequate application-level throughput, and one way delays within proper bounds. Recall that our BS does not employ any QoS mechanisms and these results are based on the Best Effort fixed WiMAX profile.

3.3.VoIP and IPTV over WiMAX with QoS

At this point we were interested to study the comportment of the WiMAX equipment using classes of traffic. For this we used the testbed of the previous section but we have allocated to VoIP traffic higher priority than to IPTV traffic. We opted first to have no background traffic beyond the VoIP and IPTV traffic. At a second phase we inserted Best Effort (BE) traffic at our testbed.

3.3.1.No Background traffic

Because of the handicaps of the equipment used, the higher class of service we can give to a kind of traffic will be rtPS. VoIP is a real time type of traffic and has to be associated a low delay. Because of this we associated it with rtPS service class but with a minimum of bandwidth allocated of 1440 Kb / s (50 flows of VoIP x 28.8 Kb / s). For the IPTV we decided to assign the rtPS service class but without associated minimum bandwidth, because IPTV may have associated some delay.

To perform the QoS tests we had the same services flows as before where the MAC traffic pass (those services flows were associated at the lower class of service). To differentiate the VoIP and IPTV traffic, we create four services flows at SS1 and SS2 domains (twice uplink and twice downlink) based on IPv4 address of the PCs on these domains, in which VoIP traffic will pass. On the other hand we also create a downlink service flow on SS1 domain but in this case associated with a lower class of traffic, in which IPTV traffic will pass. The all procedure to perform the experience was explained in section 3.1, so this section provides the results and conclusions about what have been done.

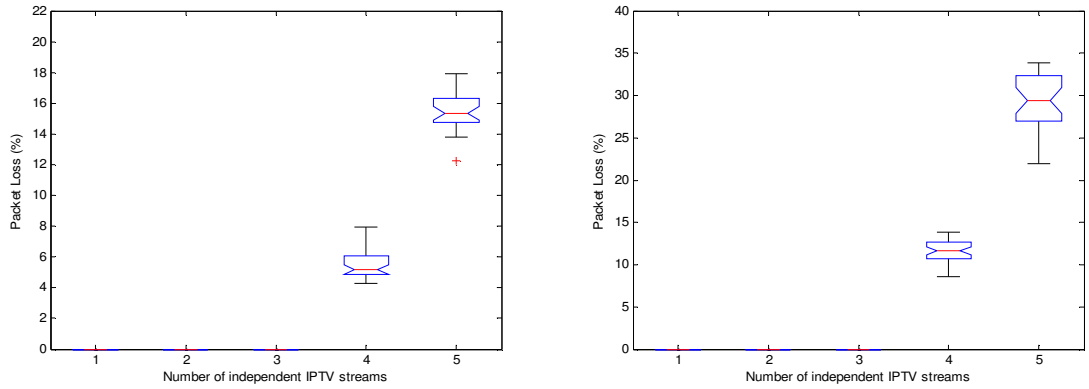
3.3.1.1.Results

At this section our measurements are presented in the following subsections in “box-whisker-plots”, or simply boxplots.

3.3.1.1.1.Measurements

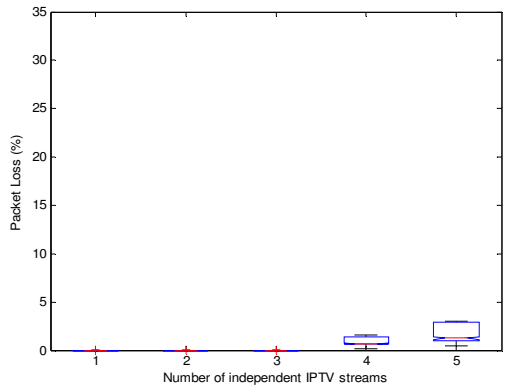
- Packet Loss

Accordingly with the results at SS1 for audio and video (Figure 16 a) and b)) the BS-SS1 WiMAX downlink can handle N <= 3 simultaneous A/V streams in parallel with the VoIP traffic with negligible packet loss as depicted in section 3.2.1.1. When N >= 4, packet loss for IPTV increases rapidly, which is unacceptable. The packet loss values for video and audio are higher than in the tests performed only with Best Effort because in this case the priority for IPTV traffic is lower than for VoIP traffic what makes the traffic IPTV sometimes have to wait, for the WiMAX channel is free, to be sent immediately. It causes the increase of packet loss because the queue in the WiMAX segment for IPTV traffic will saturate earlier than previously. For VoIP the results are depicted in Figure 16 c) and d). These results were expected because VoIP is the most priority traffic and so it had small packet loss.

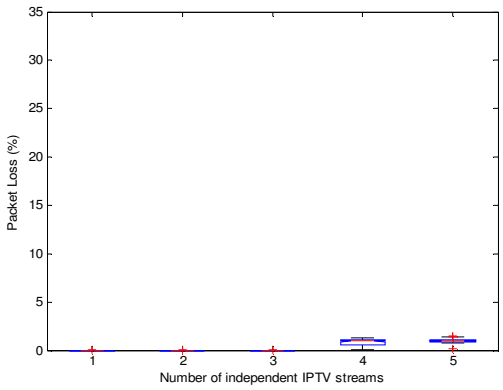


a) Audio at SS1

b) Video at SS1



c) VoIP at SS1

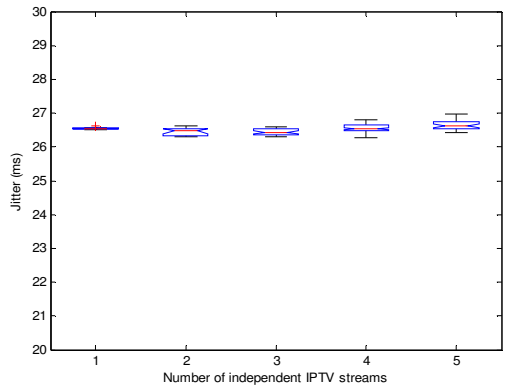


d) VoIP at SS2

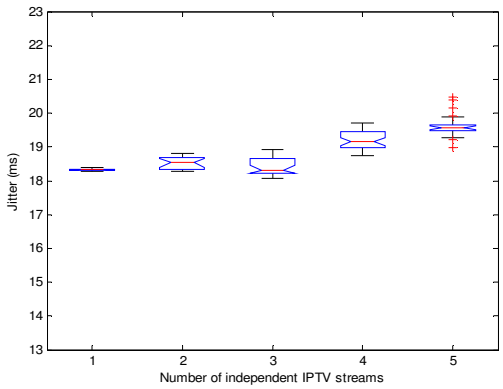
Figure 16 - Measured Packet Loss

- **Jitter**

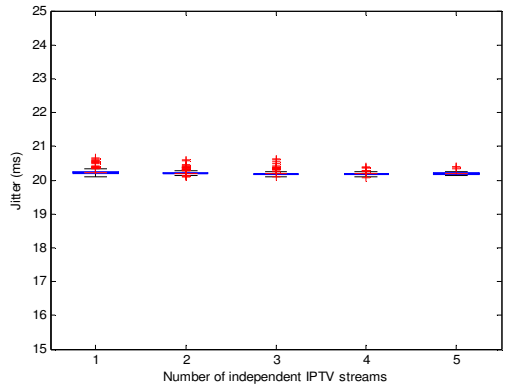
The jitter results described in Figure 17 a), b) c) and d) are similar to the ones described in section 3.2.1.1, except the variation of the jitter for VoIP on both sides. In this case the VoIP jitter is more constant because it was attributed to VoIP the higher service class.



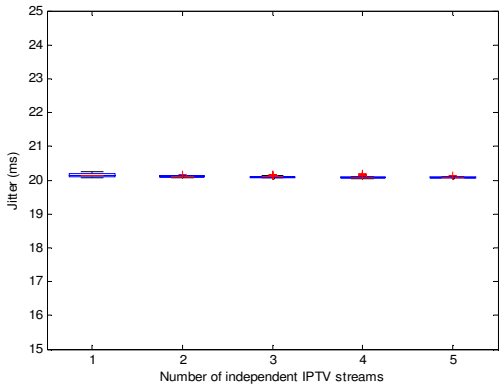
a) Audio at SS1



b) Video at SS1



c) VoIP at SS1

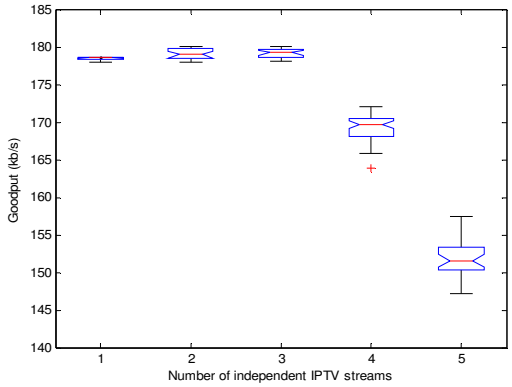


d) VoIP at SS2

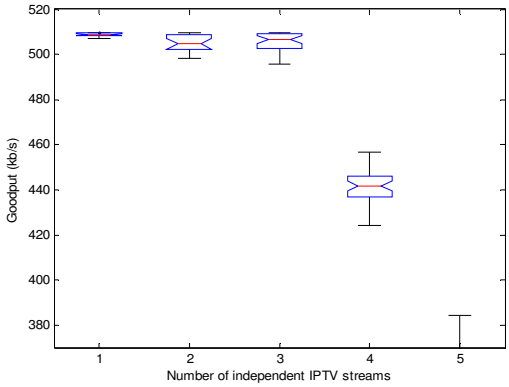
Figure 17 - Measured Jitter

- **Application Throughput**

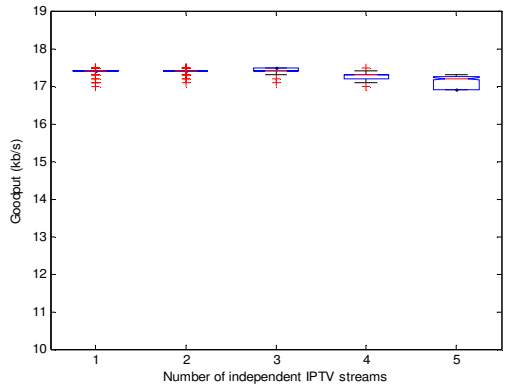
The application goodput results provide the same conclusions than the packet loss results. In result of the higher service class for VoIP this kind of traffic has the bandwidth of WiMAX segment that it needs, whatever the number of IPTV streams, as we can see at Figure 18 c) and d). When N >= 4, goodput for IPTV (Figure 18 a) and b)) decreases rapidly, which is unacceptable. The IPTV lower priority when compared with VoIP traffic means that it is assigned a lower bandwidth at WiMAX link when it is being requested simultaneously by both traffics (VoIP and IPTV).



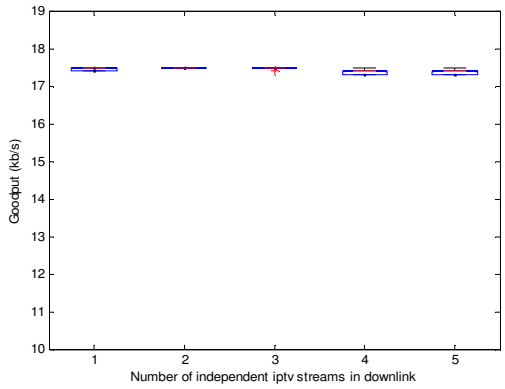
a) Audio at SS1



b) Video at SS1



c) VoIP at SS1

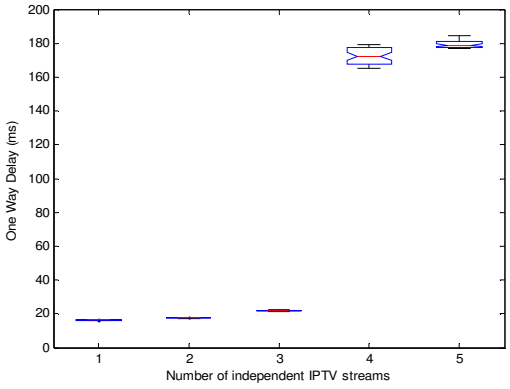


d) VoIP at SS2

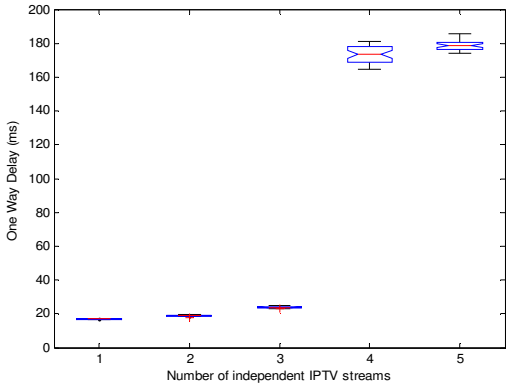
Figure 18 - Measured Goodput

- **One Way Delay**

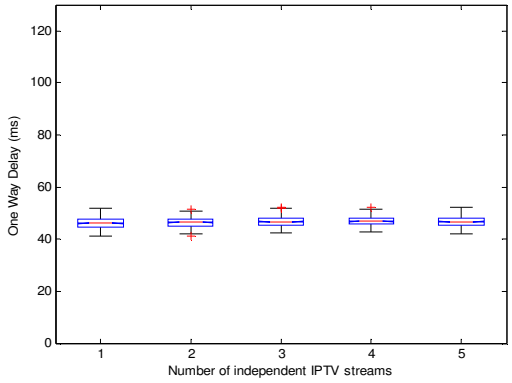
When N >= 4, one way delay for IPTV (Figure 19 a) and b)) increases faster compared with the results of section 3.2.1.1 in which we performed tests with Best Effort. In this case the priority for IPTV traffic is lower than for VoIP traffic what makes the IPTV sometimes have to wait a long time, for the WiMAX channel is free, to be sent. For VoIP the results are depicted in Figure 19 c) and d). These results were expected because VoIP is the most priority traffic. The delay is typical of the equipment used because it is usually the delay involved in a WiMAX link.



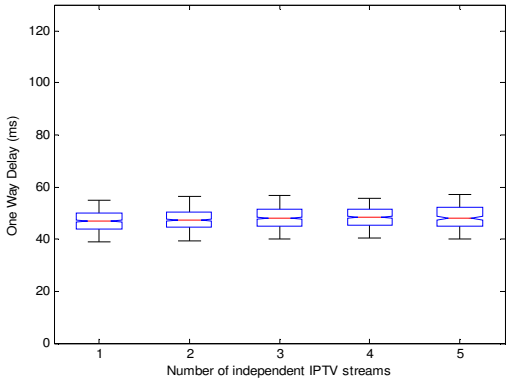
a) Audio at SS1



b) Video at SS1



c) VoIP at SS1



d) VoIP at SS2

Figure 19 - Measured One Way Delay

3.3.1.2.Conclusions

To sum up, our testbed can also sustain C = 50 emulated bidirectional Speex encoded VoIP calls within the same WiMAX cell and N = 3 simultaneous emulated IPTV streams with negligible packet loss, adequate application-level throughput, and one way delays within proper bounds. Nevertheless, at this section, our BS employed QoS mechanisms, attributing higher priority to VoIP traffic which provides it good quality not depending in number of IPTV streams. IPTV deteriorates its quality when we try to insert in the WiMAX link 4 or 5 streams, behaving them as traffic Best Effort when the VoIP is not present.

3.3.2.Background Traffic in Best Effort

At this point we were interested to study the comportment of the WiMAX equipment using classes of traffic mixed with Best Effort. For these tests we added best effort traffic from SS2 to SS1 in order to verify the behaviour of this traffic when there is traffic with higher priority simultaneously. For this we have to change a little our testbed as we can see in Figure 20.

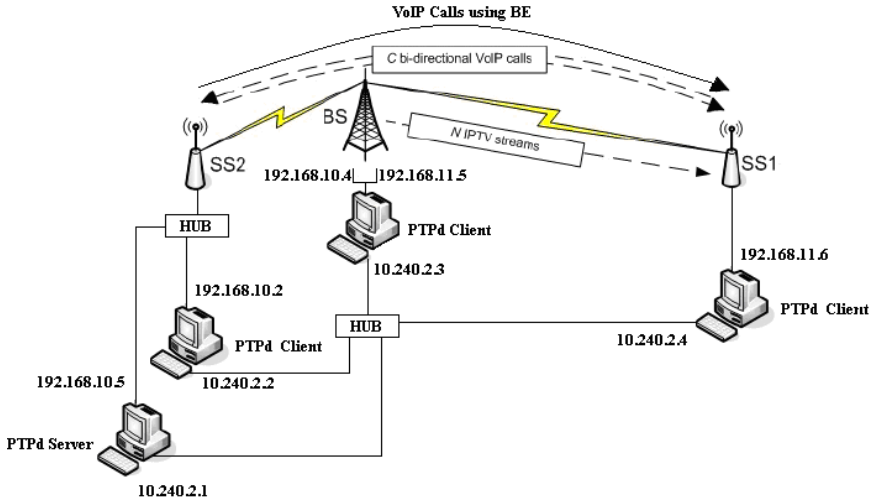


Figure 20 - New schematic of our WiMAX testbed

Note that the background traffic in Best Effort is from SS2 to SS1 and it is emulated at the same manner than for VoIP traffic with QoS, this is, we introduced C = 50 simultaneous VoIP flows from SS2 to SS1, but passing through the lower class of traffic, in order to differentiate it with the VoIP traffic with higher priority. The VoIP and IPTV traffic with different priorities remained as the last section, maintaining the higher priority for VoIP. The service flows established at the equipment remained the same. As we want to add Best Effort traffic, we can use the services flows based on MAC address defined before. Those services flows were associated at the lower class of service which is what we want. The all procedure to perform the experience was explained in section 3.1, so this section provides the results and conclusions about what have been done.

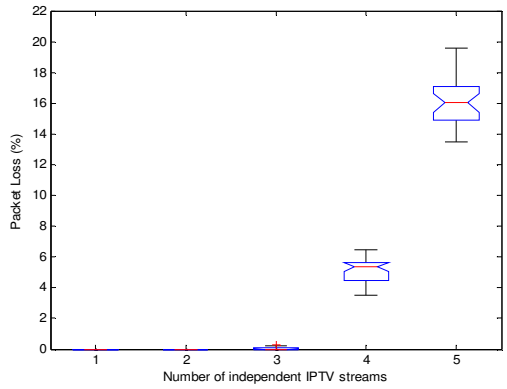
3.3.2.1.Results

At this section our measurements are presented in the following subsections in "box-whisker-plots", or simply boxplots.

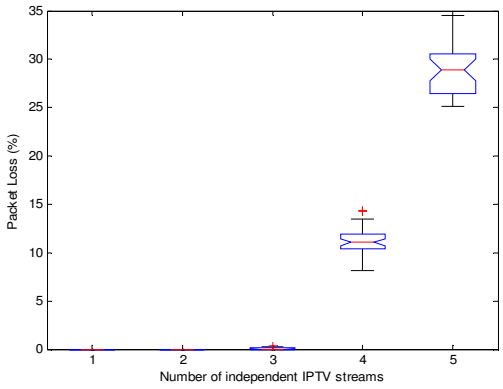
3.3.2.1.1.Measurements

- **Packet Loss**

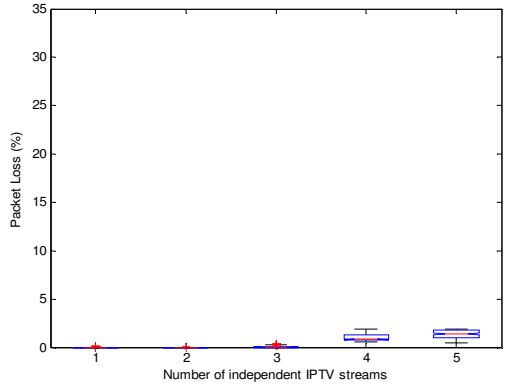
The packet loss results at SS1 and SS2 (Figure 21) are similar to the results obtained in the section 3.3.1.1.1. This was expectable because the only difference introduced was background traffic as Best Effort which doesn't interfere with the more priority traffic. However this Best Effort traffic presents a high level of packet loss, as we expected, since we introduce 3 IPTV streams in WiMAX link. Note that with 5 IPTV streams it keeps almost 100% of packet loss. It demonstrates that good quality in Best Effort is only possible when the link isn't saturated. Since it saturate the priority is given at classes of traffic with higher priority.



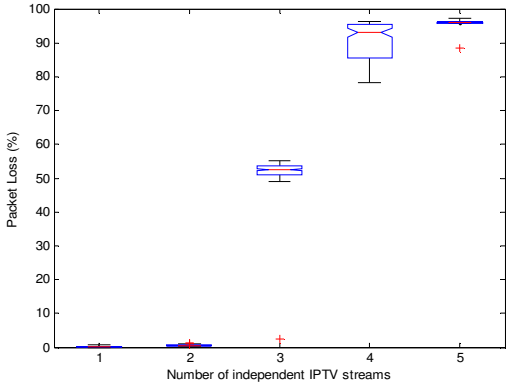
a) Audio at SS1



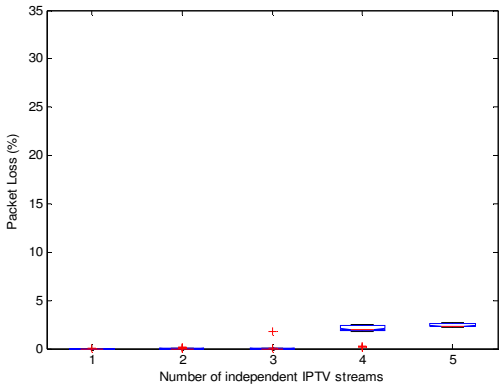
b) Video at SS1



c) VoIP with QoS at SS1



d) VoIP with BE at SS1



e) VoIP at SS2

Figure 21 - Measured Packet Loss

- **Jitter**

The jitter results are similar with the section 3.3.1.1.1 results, as we explained before, except for the Best Effort traffic that presents a high level of jitter which is unacceptable

(see Figure 22). This presents the same problem as before, which is the lower priority of Best Effort traffic compared with other classes of traffic.

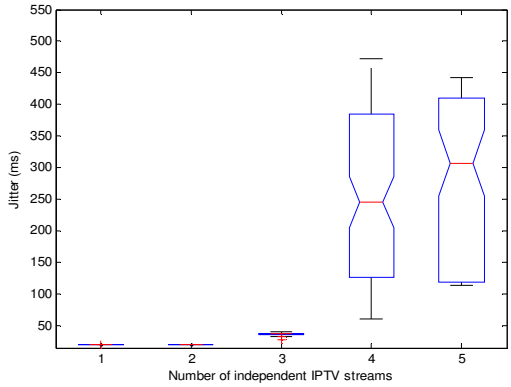


Figure 22 - Measured Jitter at SS1 for VoIP with BE

- **Application Throughput**

The goodput results are similar when compared to the results of the section 3.3.1.1.1, as we explained before, except for the Best Effort traffic (see Figure 23) which has no bandwidth available when the WiMAX link starts to saturate because of its lower priority.

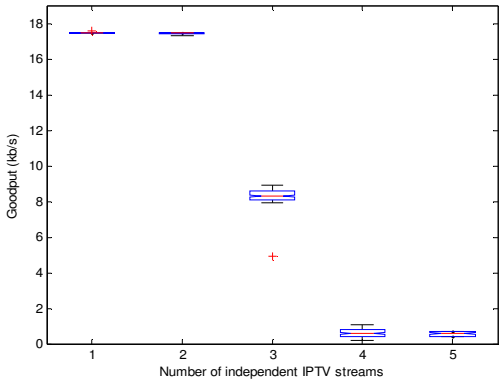


Figure 23 - Measured Goodput at SS1 for VoIP with BE

- **One Way Delay**

The one way delay results are similar with the section 3.3.1.1.1 results, as we explained before, except for the Best Effort traffic (see Figure 24) which has to wait a lot of time to be attended when the WiMAX link starts to saturate because of its lower priority.

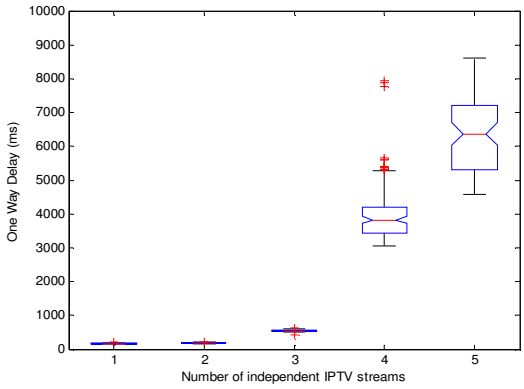


Figure 24 - Measured One Way Delay at SS1 for VoIP with BE

3.3.2.2.Conclusions

At this section, our BS keep maintaining to employ QoS mechanisms, attributing higher priority to VoIP traffic which provides that it keeps good quality for VoIP not depending in number of IPTV streams. IPTV deteriorates its quality when we try to insert in the WiMAX link 4 or 5 streams because of its lower priority. But the main difference between this section and the section 3.3.1 was the background traffic as Best Effort which becomes to have bad quality since we introduce 3 IPTV streams in the WiMAX link.

3.4.VoIP Aggregation over WiMAX

In this section we will evaluate VoIP performance over fixed WiMAX using synthetic traffic generation. We quantify both uplink and downlink performance for G.723.1 emulated VoIP traffic in terms of cumulative goodput, packet loss, and mean opinion scores, based on the ITU-T E Model [46]. Moreover, we empirically investigate the benefits from employing application-level VoIP aggregation when using fixed WiMAX as a backhaul. Aggregation appears as a promising approach for increasing the overall network efficiency and resource utilization. If we use objective mean opinion scores (MOS) as the main gauge of overall performance, application-layer aggregation appears to be the best scheme, allowing our fixed WiMAX testbed to sustain nearly three times more flows in the downlink and over two times more flows in the uplink than when no aggregation is used, at comparable MOS values [34].

3.4.1.Testbed and Methodology

At this section will be explained the testbed and the methodology used to evaluate VoIP Aggregation over WiMAX.

3.4.1.1.Testbed

Figure 25 retracts our new testbed. The main difference between this and the one used to perform the previous tests is that it is a point-to-point testbed. This is not an important fact in order to study VoIP Aggregation and give us the possibility to evaluate the performance of uplink and downlink WiMAX channels, separately.

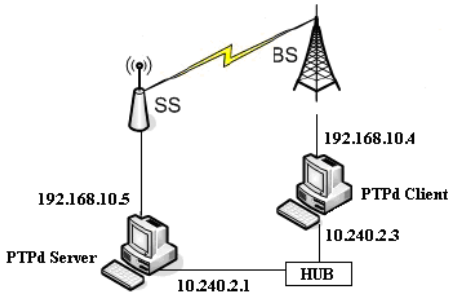


Figure 25 - Schematic of our WiMAX testbed

3.4.1.2.Methodology

In order to obtain the accurate results from our experiments we have to be rigorous. For this our work was done by phases, passing by the configuration, generation of traffic, synchronization of our testbed. This section provides the details of each one of these phases.

- **Testbed Configuration**

The testbed configuration follows the same steps described in section 3.1.2.

- **Traffic Generation**
    - **Emulating VoIP traffic using JTG**

For this empirical study, we generate synthetic traffic load based on the ITU-T G.723.1 codec [51]. This is a low-rate codec, for real time encoding and decoding, and with good voice quality. A single G.723.1 frame can be 24 octets, which translates into an application-only transmission rate of 6.3 kb/s, or 20 octets (5.3 kb/s), or, finally, 4 octets only. The latter type of payloads corresponds to Silence Insertion Descriptor (SID) frames, used to specify comfort noise parameters, whereas the former two are used to transmit actual voice data. We do not consider SID frames in this study. The higher bitrate variant offers better voice quality compared to the lower bitrate one, and is our chosen variant for these tests.

Typically, a single G.723.1 sample is encapsulated in an RTP [26] packet and sent over UDP/IP. When the RTP, UDP, and IPv4 standard headers, consisting of 12, 8, and 20 bytes, respectively, are appended to the 24 octets codec payload, the total actual packet size is 64 bytes. This raises the overall VoIP transmission rate to 17 kb/s. In our setup, a single VoIP flow generated by JTG injects a 64-byte packet (carrying a single audio

sample) every 30 ms. The G.723.1 small frame size and low bandwidth requirement provides a very good benchmark for investigating the gains of VoIP aggregation.

We inject multiple parallel traffic streams using scripts we developed so that testbed hosts can act as VoIP senders and receivers.

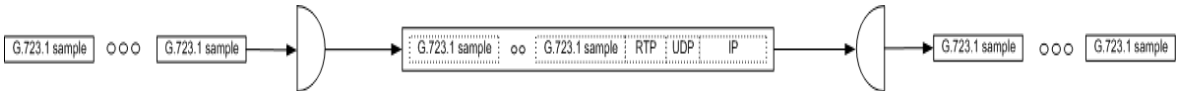


Figure 26 - G.723.1 sample application-layer aggregation

Figure 26 illustrates application-layer VoIP aggregation. Here, a single RTP packet carries more than one G.723.1 samples, which is explicitly allowed by the RTP specification. In our tests, we experimented with two levels of application-level aggregation carrying two or three samples in a single RTP packet. For "L1 aggregation", an 88-byte packet is generated every 60 ms. In the case where three G.723.1 samples are aggregated ("L2 aggregation"), a 112-byte packet is generated every 90 ms.

- **Performance Metrics**

For the purposes of this study we consider three main metrics: (a) cumulative goodput, (b) packet and audio sample loss, and (c) the objective mean opinion score (MOS). MOS expresses the quality of the VoIP transmission in a single number in the 1-5 range (1: worst quality; 5: best quality).

We calculate MOS values based on the well-known transmission rating factor R, or "R-Score" [52], which is derived from packet loss and delay measurements as follows [53]:

$$R = R_0 - I_s - I_d - I_e + A \quad (1)$$

where R_0 represents the basic signal-to-noise ratio, including noise sources such as circuit noise and room noise. I_s captures the effect of impairments to the voice signal, and I_d factors in impairments due to delays. I_e takes into account the effects caused by using low-bitrate codecs. The expectation factor A compensates the impairment in the case that the user has access to alternatives. In conventional (wired) environments A is equal to 0. Besides A, the rest of the factors can be subdivided if needed. In our case there is no need to so, as we assume default values for speech transmission. Therefore, we simplify Equation (1) as follows:

$$R = 94.2 - I_d(d) - I_e(c, l) \quad (2)$$

I_e is a function of the used codec (c) and the loss rate (l):

$$I_e(c, l) = \gamma_1 + \gamma_2 \cdot \log(1 + \gamma_3 \cdot l)$$

where γ_1, γ_2, γ_3 are specified from the codec. For G.723.1, we have $\gamma_1 = 15$, $\gamma_2 = 90$, and $\gamma_3 = 0.05$ [54]. I_d depends on the delays (d) [53]:

$$I_d(d) = 0.024\, d + 0.11\,(d - 177.3)H(d - 177.3)$$

H(x) is the step function (H(x) = 1 if, $x \geq 0$ and 0 if $x < 0$) [55].

The ITU E-Model also specifies the non-linear mapping to the (listening) MOS:

$$MOS = 1 + 0.035R + 7 \cdot 10^{-6}\, R(R - 60)\,(100 - R) \quad (3)$$

- **Use of PTP for host clock synchronization**

The host clock synchronization follows the same steps described in section 3.1.2.

3.4.2.Results

As mentioned earlier, the main goal of this study is to separately quantify the maximum downlink and uplink performance of the tested RedMAX WiMAX equipment for G.723.1 encoded VoIP data traffic in a laboratory environment. We started with a small traffic load yielding no losses and excellent MOS, and increased gradually the offered load measuring the gradual degradation. We continued well beyond the maximum capacity of the tested link in order to see how the system behaves when its maximum capacity is exceeded. As a result from the measurements, the amount of G.723.1 encoded VoIP flows the link can support without seriously decreasing the received voice quality, was identified. Each of the test runs lasted 100 seconds.

We generate 4 shell scripts where we started the senders and the receivers of VoIP traffic using JTG. Firstly I started the receiver at SS and the sender at BS to study the downlink capacity of the channel. Afterwards I started the receiver at BS and the sender at SS to study the uplink capacity of the channel.

At WiMAX equipment we have to generate two service flows (uplink and downlink) based on MAC address of the PC located on the SS domain.

This section provides the results obtained.

3.4.2.1.Measurements

- **Cumulative Goodput**

The small size of single-sample G.723.1 VoIP packets has a substantial effect on the cumulative goodput and the number of flows that can be supported on the downlink and uplink of our WiMAX testbed. Figure 27 shows that, the maximum downlink goodput for

non-aggregated VoIP traffic is no more than 2.7 Mbits/s. In uplink, the goodput saturation point is reached already at 1.75 Mbits/s, as can be seen in Figure 28. This very poor performance is mainly attributed to the overhead introduced by the RTP, UDP and IP headers, when compared to the size of the actual VoIP codec payload. Indeed, every 64 byte VoIP packet carries only 24 bytes of application payload (total overhead of 167%).

When application-layer aggregation is used, the negative effects of, on the one hand, excessive header overhead, and on the other, the more frequent packet generation, can be mitigated. Figure 27 and Figure 28 show that application-layer VoIP aggregation outperforms the simple audio sample encapsulation in both downlink and uplink. When employing L1 aggregation (two codec samples in an IP packet) the header overhead drops to 83%. As a result, 450 flows can be injected into the downlink, instead of 275 in the non-aggregated runs.

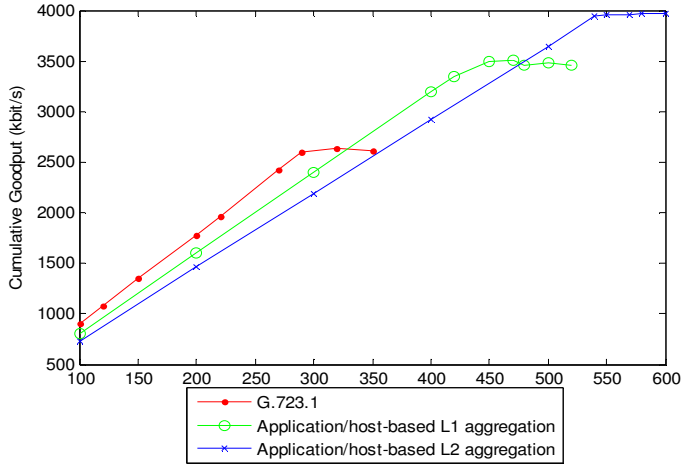


Figure 27 - Cumulative downlink Goodput

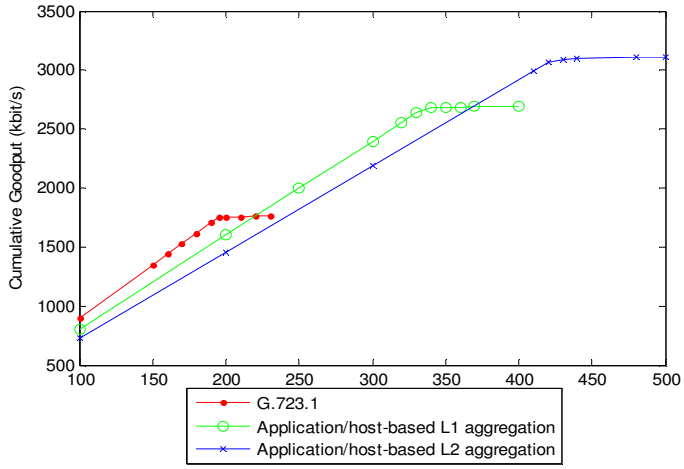


Figure 28 - Cumulative uplink Goodput

When L2 application-layer aggregation is used (3 codec samples/IP packet), we need 550 flows to saturate the fixed WiMAX downlink. This means that L2 aggregation effectively doubles the number of VoIP flows that can be served in the downlink. This is a direct result of limiting the header overhead to 55%. The L2 cumulative goodput is nearly 4 Mbits/s.In the uplink, the gains in terms of VoIP flows that can be served at the cumulative goodput saturation point are even greater. With L1, more than 340 flows can be sustained instead of only 190 in the non-aggregated VoIP scenario. With L2, the number of VoIP flows effectively is more than the double of non-aggregated VoIP scenario. In terms of cumulative goodput, L2 can deliver almost 3.1 Mbits/s.

Although the goodput performance gains attained with application-layer aggregation are remarkable, the total goodput over the fixed WiMAX link with several hundred of VoIP flows is substantially lower than our baseline measurements with MTU-sized packets (see section 3.1.3). Even with L2 application-layer aggregation, the cumulative downlink goodput is roughly only 2/3 of the single-flow baseline downlink goodput of nearly 5.75 Mbits/s, measured with 1500-byte packets. This is a significant reduction. The case in the uplink is similar (4.75 Mbits/s vs. 3.1 Mbits/s).

- **Packet and Sample Loss**

Figure 29 and Figure 30 illustrate the measured packet loss rates as we increase the number of concurrent flows in the fixed WiMAX downlink and uplink, respectively. When no aggregation is employed, our testbed downlink can sustain only approximately 270 concurrent VoIP flows with negligible loss. In the uplink about 195 flows can be sustained with negligible loss. If we introduce more flows, the uplink emerges as a clear bottleneck. With 300 flows, the downlink loss rate rises to 4% and with 315 flows we exceed the threshold of 5% drops. In general, drop rates less than 5% are tolerable for G.723.1 VoIP clients. Drops in excess of 10% are unacceptable. In the uplink, injecting 210 flows is enough for crossing the 5% threshold.

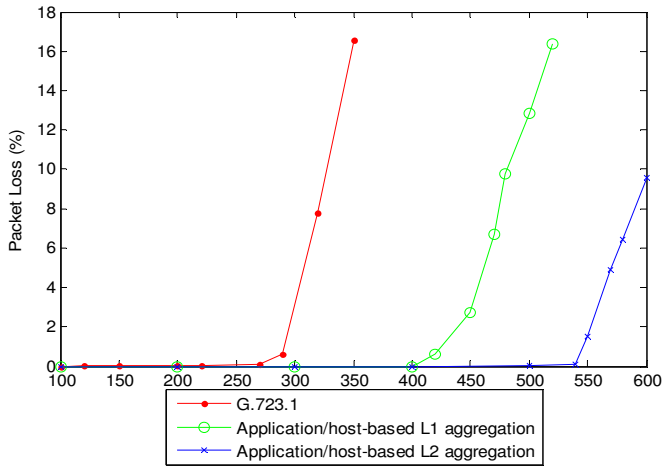


Figure 29 - Average downlink Packet Loss

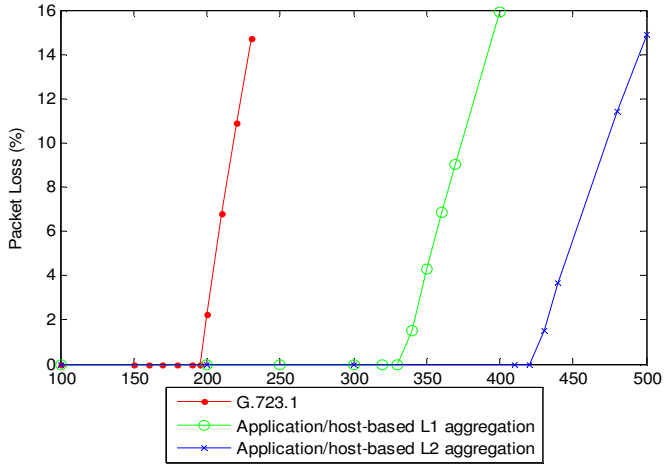


Figure 30 - Average uplink Packet Loss

The drops in the uplink are distributed very unevenly between the concurrent flows. When some flows experience near-zero packet loss, others may end up losing up to 90% of their packets. This very interesting behaviour appears, especially, with small packets, such as non-aggregated VoIP packets.

When we consider application-layer aggregation, both L1 and L2 outperform the straightforward single-sample transmission. With L1, no packets are dropped until we start introducing 400 concurrent flows in the downlink and nearly 330 flows in the uplink. With L2, drops start to occur only after we inject 540 flows into the downlink and more than 420 flows into the uplink. The 5% packet loss threshold is exceeded with L1 aggregation with 460 flows in the downlink and nearly 350 flows in the uplink. With L2 aggregation we need to inject more than 570 and 450 flows in the downlink and uplink, respectively, in order to start observing an average of 5% packet loss.

However, since we are aggregating samples, it is fairer to compare the actual sample loss rates of the different schemes. That is, when considering L1 aggregation, for example, a packet loss rate of x% corresponds to an effective sample loss rate of 2x%. For L2, the effective sample loss rate is 3x%. The effective loss rate for downlink is shown in Figure 31 whereas corresponding uplink values can be seen in Figure 32.

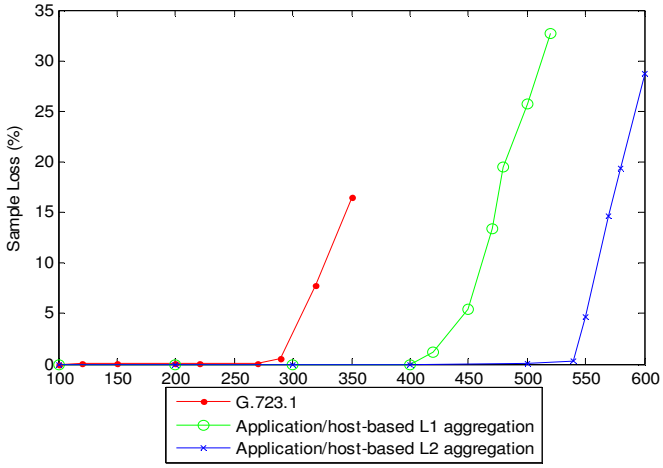


Figure 31 - Average downlink Sample Loss

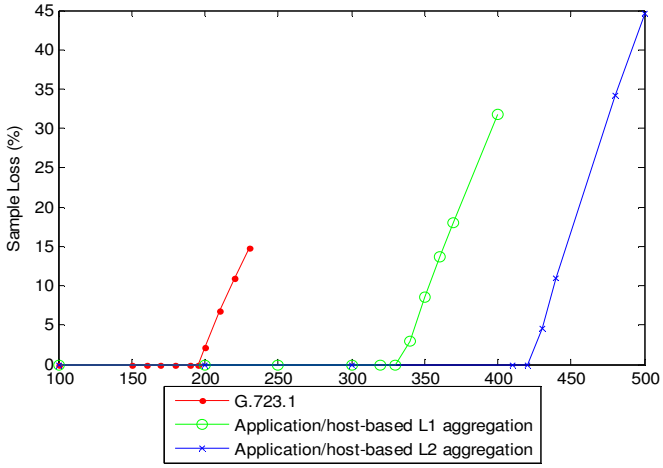


Figure 32 - Average uplink Sample Loss

The clear winner with respect to sustaining more flows without any loss is application-layer aggregation in both the uplink and the downlink. In the downlink with L1 application-layer aggregation more than 400 flows can be sustained without any drops; with L2, more than 540 flows can be sustained. These are the improvements over the non-aggregated results. More importantly, perhaps, this is achieved while saturating the testbed WiMAX link, and using more wireless resources for actual user data (recall Figure 27 and Figure 28). If the WiMAX link operator is willing to accommodate more flows at a slightly degraded service level, L1 aggregation can sustain nearly 470 flows with less than 10% sample loss rate, while L2 aggregation raises the same bar to higher than 570 flows. In the uplink, L2 application-layer aggregation increases the tolerable flow amount by nearly 25% when compared with the corresponding L1 results: L2 can allow for up to 440 flows to be sustained. If the one way end-to-end delay, over and above the buffering delay introduced by the aggregation scheme is in the order of 60 to 90 ms, application-layer

aggregation is the best solution for increasing VoIP capacity according to our measurements.

Note that the tested WiMAX equipment does not have any built-in intelligent algorithms to assure QoS to individual data flows. When the link is operating above its maximum capacity, dropped packets and additional delays caused by congestion in the test network, affected all active VoIP flows sharing the link, as would be the case in any Best Effort network.

- **Mean Opinion Score**

Based on our packet loss and one way delay measurements, we calculate the objective mean opinion scores for the received speech quality using Equation (3). The packet loss rate experienced by a VoIP flow is a more critical factor when calculating the R-score that delay deterioration and, thus, has significant impact on the MOS values calculated at the receiving end. Even slight increases in loss, decrease the R-score more rapidly than would similar (in proportion) increases in delay. Packet loss in our tests occurs when the bottleneck link, this is, the fixed WiMAX link, is overwhelmed with traffic. Congestion on the best-effort WiMAX downlink will translate in rapid declines in MOS, especially when aggregation is employed in the downlink.

Improvements in the measured packet loss rates, when aggregation is used, lead directly to better MOS values. In Figure 33, MOS values for different number of concurrent VoIP flows in the downlink are shown. MOS for VoIP packet flows without aggregation declines to unacceptable levels after injecting 300 concurrent flows. For application-layer aggregation, MOS remains at a very high level with more than 400 flows. With L1 application-layer aggregation, our testbed WiMAX link can sustain more than 410 flows with high MOS values. For L2 application-layer aggregation, MOS remains above 3.5 even when more than 550 flows are injected.

As can be seen from Figure 34, without aggregation, we can only inject 200 concurrent flows in order to keep MOS at tolerable levels; after that threshold, MOS declines sharply. L1 application-layer aggregation sustains MOS values above unacceptable level until 330 flows are injected. The far and away best results can be achieved by using L2 application-layer aggregation which lets our testbed sustain up to 430 high quality VoIP flows in the uplink.

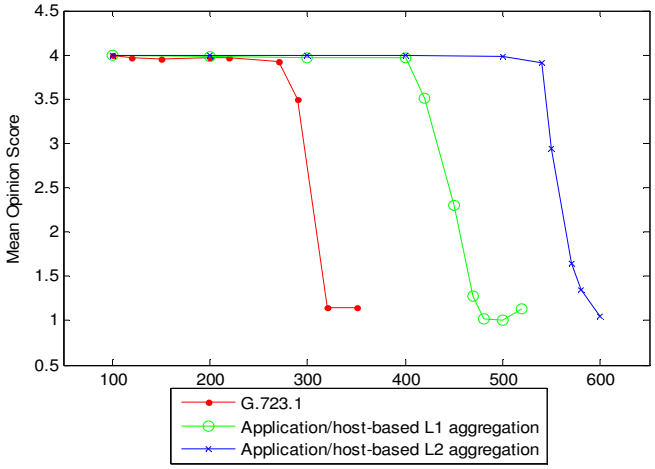


Figure 33 - Downlink Mean Opinion Score

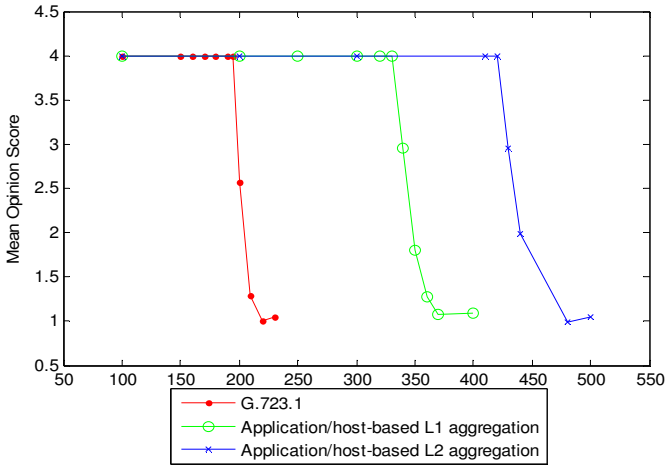


Figure 34 - Uplink Mean Opinion Score

If we use MOS as the only gauge of overall performance, application-layer aggregation seems to be the best scheme, allowing our fixed WiMAX testbed to sustain nearly two times more flows in the uplink and in the downlink than when no aggregation is used, at comparable level of MOS values.

3.4.3.Conclusions

We considered the performance of aggregated and non-aggregated VoIP over a fixed WiMAX testbed. We measured the performance of different transmissions schemes in terms of cumulative goodput, packet and sample loss rates, and calculated the objective mean opinion scores using the R-Score specified by ITU. We found that VoIP flows carrying single sample payloads generated by the G.723.1 codec are clearly

underperforming in both uplink and downlink. Indeed, the header overhead introduced by RTP, UDP and IP lead to significant waste in wireless bandwidth resources. The strategy of sending a single sample encapsulated in an RTP/UDP/IP packet is, to say the least, suboptimal.

We found that, application layer VoIP aggregation can do more than double the number of VoIP flows in the downlink, without any network or hardware support. The results are of the same order for the uplink as well.

3.5.Summary

With these measurements we tried to understand what is realistically possible using off-the-shelf fixed WiMAX equipment today. We conclude that it allows us to provisioned QoS for different type of traffics.

We evaluate, not only, WiMAX as VoIP and IPTV streaming backhaul in a point-to-multipoint scenario, but also, conclude that VoIP aggregation appears to be a powerful method to improve performance and increase capacity utilization in a point-to-point scenario.

4.WEIRD Architecture – Overview and Results

The WEIRD (WiMAX Extension to Isolated Research Data networks) project [4] aims to exploit and enhance the WiMAX (Worldwide Interoperability for Microwave Access) technology in convergent heterogeneous network architecture, in order to cope with future needs of research user communities. In this section we will evaluate the WEIRD's phase 1 architecture in the resource allocation at the WiMAX equipment and Quality of Service (QoS) performance.

Section 4.1 provides a brief overview of WEIRD's architecture, whereas section 4.2 explains the scenarios implemented. Section 4.3 depicts the performed tests and the results obtained, whereas section 4.4 provides a final summary of the chapter.

4.1.High Level View of WEIRD architecture

The architecture considered in WEIRD (see Figure 35) [4][29][31] is vertically structured into two "macro-layers": 'Application and Service Macro-Layer' and 'Transport Macro-Layer'. Horizontally the architecture may be traditionally divided into Management Plane (MPl), Control Plane (CPl) and Transport/Data Plane (DPl). This approach follows the recent architectural trends, which aim at decoupling the applications and services from transport technologies, in order to allow heterogeneity in the core and access.

Vertical decomposition:

- Applications and Service stratum includes the architectural layers and functions performing management, control and also operations of data (e.g. adaptation, transcoding, etc.) at higher layers, independently of network transport.

- Transport Macro-Layer/Stratum includes the architectural layers and functions performing management, control for resources and traffic and also operations on data in order to transport the data traffic through various networking infrastructures.

Horizontal decomposition:

- Management Plane (MPl): - performs management functions generally-medium and long term related to service management at the Application and Service Layer macro-layer and resource and traffic management at Transport layer. It provides coordination between all the planes. The following management functional areas identified in ITU-T Rec. M.3010 are performed in the management plane: FCAPS - Fault, Configuration, Accounting, Performance, Security management. Each architectural layer may have its own layer-manager associated with it; also a general management macro-layer may exist, to coordinate all layer managers

- Control Plane (CPl) includes all layers which perform short term control actions related to higher layers (high level services and applications): through signalling, the control plane sets up and releases high level connections, and may restore a connection in case of a failure; transport layers: CPl performs the short term actions for resource and traffic engineering and control, including routing.

- Data Plane (DPl) (also called Transport Plane) is mainly responsible for transferring the user/application data. In case of IP architectures the data plane also transports (via unique IP) the control and management related data between the respective entities. The DPl may include functions and mechanisms to act upon the packets transported. In multi-domain environment the transport stratum may be split in inter and intra-domain parts.

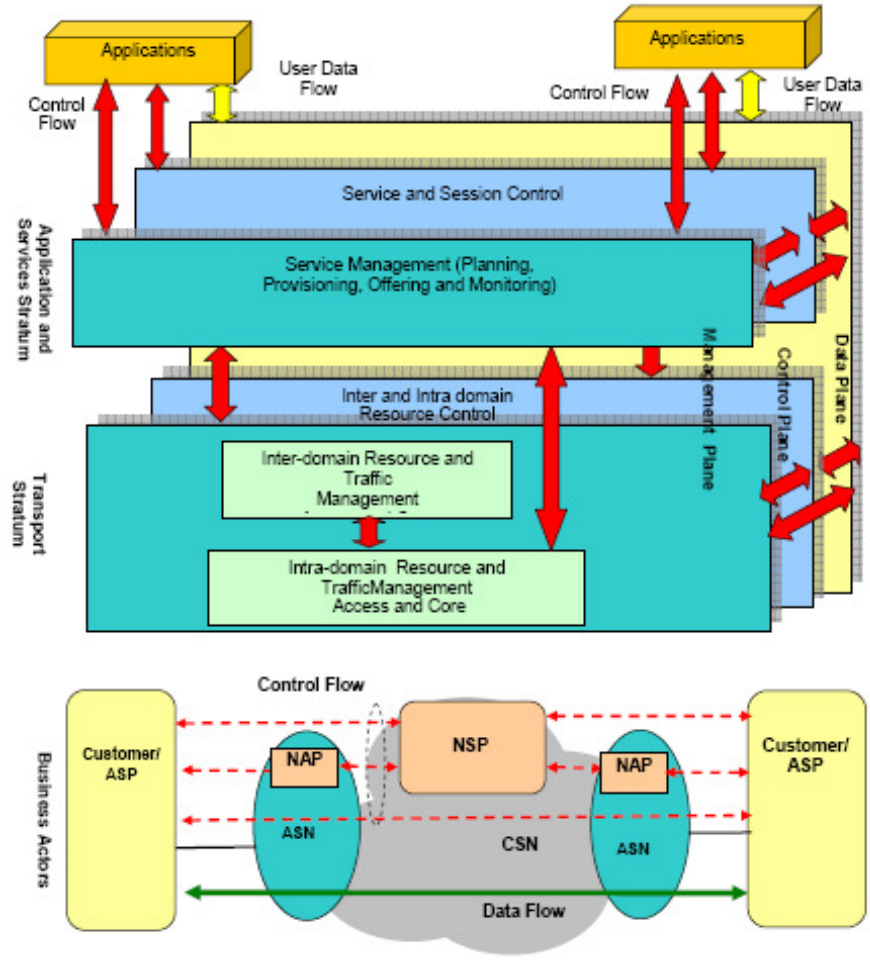


Figure 35 - General architectural planes in a multi-domain environment [4]

The WEIRD system is layered according to the architecture model described above. The applications are running on the client endpoints and are located in the highest layer of the model. The WEIRD application and service stratum contains a signalling control channel to let applications to ask for services. This control channel lets applications to request QoS in the local AS (including WiMAX channel).

The application service control plane is located in – Application and Service Stratum – providing session and service control to the applications. It communicates upward with applications, either by APIs or application signalling protocol(s), like SIP (Session Initiation Protocol), RTSP (Real Time Streaming Protocol), etc.... It communicates downwards with the WEIRD control plane, which provides Resource and Control functions, by control signalling.

The WEIRD resource control plane is located in the lower vertical macro-layer – Transport Stratum and performs typically transport of data and resource control.

4.1.1.Control Plane

WEIRD's architecture considers the functional entities as Mobile Station (MS), Access Service Network (ASN) and Connectivity Service Network (CSN), based on WiMAX Forum [40] [42].

Attempting at the resource allocation in WiMAX link promoted by WEIRD architecture, there are many modules that have different responsibilities at the all process, which endorse a lot of signalling between them as depicted in Figure 36 [36][37].

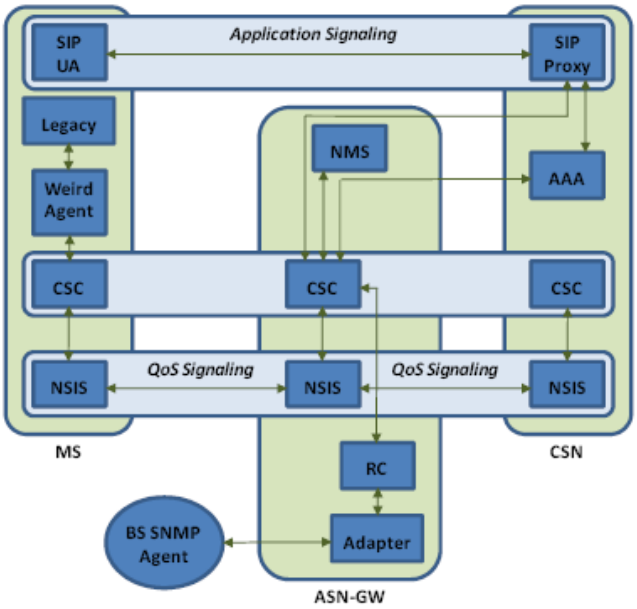


Figure 36 - WEIRD's Phase 1 Architecture – Control Plane

- **CSC_MS** (Connectivity Service Controller located at Mobile Station) can be both initiator (for legacy applications triggered by WEIRD Agent or by a WEIRD aware application) and responder (for SIP applications [22] where the destination is the Mobile Node) of resource reservations in the WiMAX link and the management of QoS signalling.

- **CSC_ASN** is the main coordination point for the resource reservation in the WiMAX link and the management of the related QoS signalling; the role of the

CSC_ASN and its communication with other modules depends on the type of the managed application: Legacy and WEIRD aware applications or SIP applications. CSC_ASN is the coordination point of the ASN-GW and it receives requests from the NSIS (Next Step in Signaling) module, interacts with AAA (Authentication, Authorization and Accounting) server for user authorization, performs Admission Control, and sends requests to the Resource Control for Servive Flow (SF) creation/deletion.

- **CSC_CSN** is the controller of Connectivity Service Network, communicating with the rest of the architecture through NSIS.

- **NSIS** is a signalling protocol for QoS reservations and allows the communication between all CSCs [13].

- **Resource Controller** (RC) is responsible for managing the WIMAX network(s), as well the interface with the upper layers. It has the capability to differentiate among 802.16d and 802.16e requests and trigger the correspondent interface with the appropriate Adapter module.

- **Generic Adapter** (GA) is the module that provides an abstracted interface for the interactions between the upper modules and the vendor Base Station (BS).

- **Redline Specific Adapter** (RSA) is responsible to enforce the RC decisions on the WiMAX BS.

- **AAA** [21] is the module that is in charge to perform user authentication, QoS authorization and session accounting communicating with CSC_ASN through Diameter [23] signalling.

- **WEIRD Agent** allows a user to trigger the resource request reservation by specifying the QoS requirements of an application.

- **SIP Proxy** is the software module supporting SIP application signalling. It performs authentication and resource reservation on behalf of SIP users.

- **NMS** (Network Management System) is the centralized management system in the ASN that provides a single interface to manage and monitor the network elements in the WiMAX and ASN access network.

4.2.Legacy Scenarios Implemented

At this section will be explained the scenarios implemented to obtain values for WEIRD's phase 1 signalling in resource allocation and to study the QoS attribution by WEIRD's architecture.

Figure 37 and Figure 38 demonstrates the scenarios implemented. As we can see, both of scenarios have three different parts: MS where exists the Mobile Terminal and the Subscriber Station, which communicate via WIMAX with Base Station located in ASN.

There is the ASN-GW responsible to communicate with CSN. In point-to-point (PTP) scenario (Figure 37) the server is (MS1) and the client is CSN. In point-to-multipoint (PMP) scenario (Figure 38), the server is MS1 and the client MS2. Note that the IPs [16] of the different interfaces was defined firstly, like the figures presents.

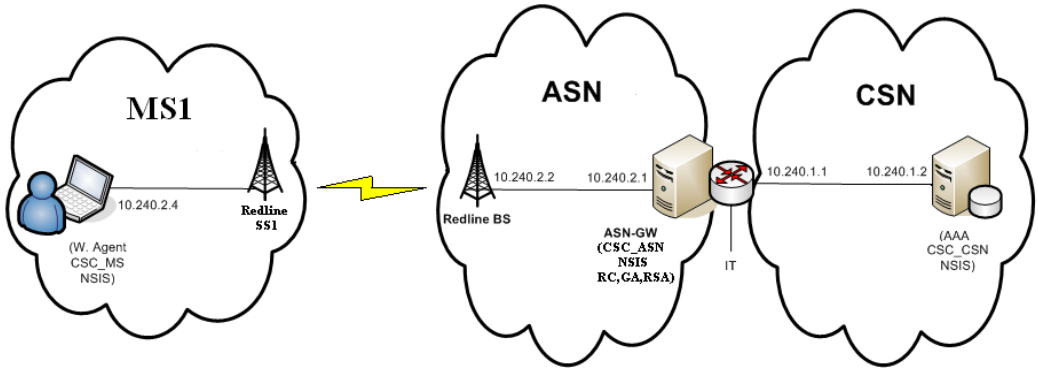


Figure 37 - Point-to-Point Scenario

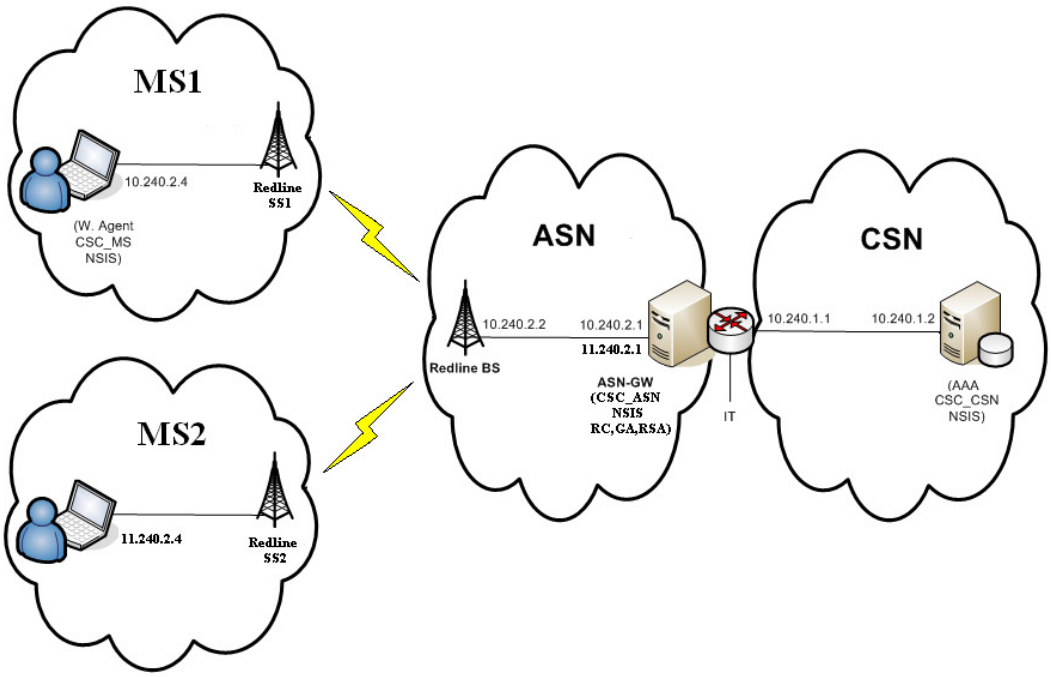


Figure 38 - Point-to-Multipoint Scenario

4.2.1.Inter Module Signalling

Figure 39 shows the whole signalling between the various modules in order to start a session with QoS from a server (MS1) and a client (CSN).

- The QoS request is performed by the WEIRD Agent present in the MS1, and then is sent to the CSC_MS (1).

- Then through NSIS signalling the request reaches the ASN (more properly the module CSC_ASN) (2-4).

- Afterwards the request is sent by Diameter signalling to the AAA present in the CSN to be logged (5-6).

- Returned to the ASN, the request will be made on the WiMAX equipment (uplink service flow associated with SS1). For this the CSC_ASN communicates with the RC which subsequently sends the request to the Generic Adapter and the Redline Specific Adapter [38] (7-9).

- Done the request at the equipment, the response returns to the CSC_ASN (10-12).

- As the client is on the CSN side, it will have to be made a reserve of QoS on CSN side, and so the request goes there through NSIS signalling (13-15).

- Arrived the response at ASN (16-17), the answer returns to MS1 (CSC_MS) through NSIS signalling (18-19).

- Finally the reply is forwarded to the WEIRD Agent (20).

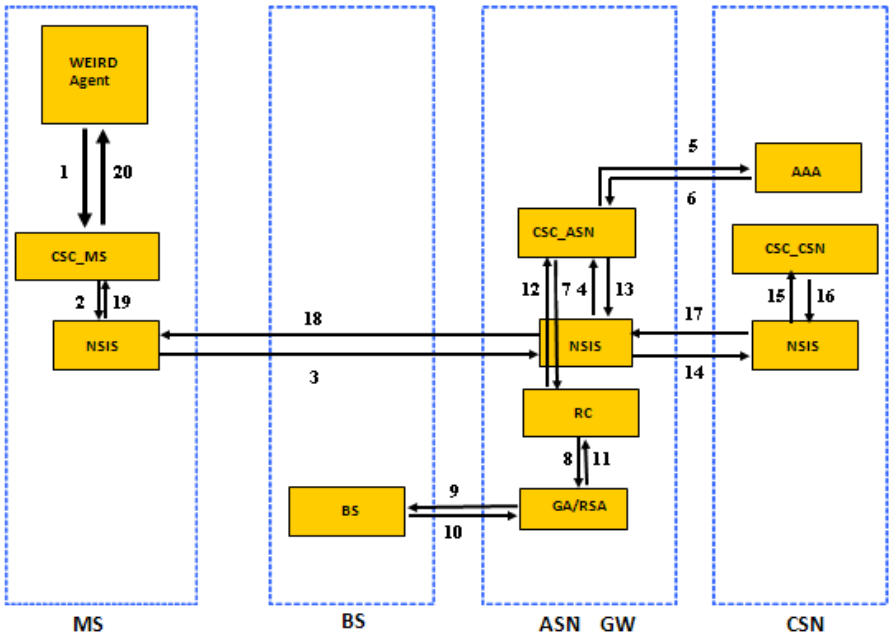


Figure 39 - PTP Inter-module Signalling

Figure 40 shows the whole signalling between the various modules in order to start a session with QoS from a server (MS1) and a client (MS2).

- The QoS request is performed by the Agent WEIRD present in the MS1, and then is sent to the CSC_MS (1).

- Then through NSIS signalling the request reaches the ASN (more properly the module CSC_ASN) (2-4).

- Afterwards the request is sent by Diameter signalling to the AAA present in the CSN to be logged (5-6).

- Returned to the ASN, the request will be made on the WiMAX equipment (uplink service flow associated with SS1). For this the CSC_ASN communicates with the RC which subsequently sends the request to the Generic Adapter and the Redline Specific Adapter [38] (7-9).

- Done the request at the equipment, the response returns to the CSC_ASN (10-12).

- As the client is on the SS2 side, it will have to be made a new reserve at the equipment (downlink service flow associated with SS2) (13-18).

- Done the second request and arrived the response at CSC_ASN, the answer returns to MS1 (CSC_MS) through NSIS signalling (19-21).

- Finally the reply is forwarded to the WEIRD Agent (22).

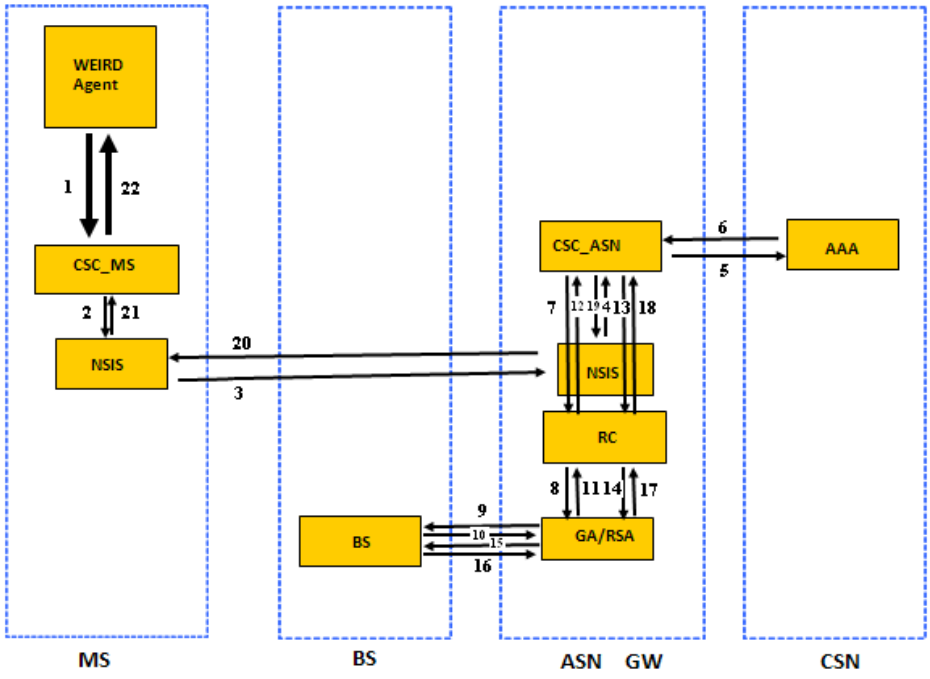


Figure 40 - PMP Inter-module Signalling

4.3.Performed tests

4.3.1.Processing times for signalling

After establishing the scenarios, it was time to measure the processing times of the various modules needed to make a reservation of QoS using WEIRD's phase 1 architecture.

For that we sent all the logs produced by the different modules to different files (to optimize the processing times). Another of the changes we made in the various modules was slightly change the code in order to know when messages were sent or arrived them, using the time functions provided by the languages that were used to develop the software. We made 10 followed reservations in the equipment (for each scenario).

Before we start the request in WA we have defined at the RedMAX Equipment a set of service flows in which the traffic will pass. We inserted at BS-SS1 WiMAX link two services flows based on MAC of the PC on the SS1 domain: one uplink and other downlink. We did the same at BS-SS2 WiMAX link but now based on MAC of the PC located in SS2 domain. With these four service flows all the signalling of the architecture will pass through WiMAX links.

We are also interested to obtain the processing times for signalling when there is some application traffic filling the WiMAX links. For this we add some VoIP traffic between the MS (located in SS side) and ASN (located in BS side) and perform some requests while that traffic is passing the WiMAX link. The VoIP traffic was generated like depicted in section 3.4.1.2 for VoIP (without aggregation) case. We started measuring the signalling time without traffic from application, then with 100 VoIP flows flowing through WiMAX (both uplink and downlink), then we increased it for 200, 300 and finally to 400.

4.3.1.1.Point-to-Point Scenario

This section provides all the measures withdrawn from the WEIRD's phase 1 signalling for point-to-point scenario.

Figure 41 shows us that when the WiMAX channel begins to be occupied by traffic of a particular application (in this case VoIP), the percentage of successful requests made by Weird Agent begins to decline.

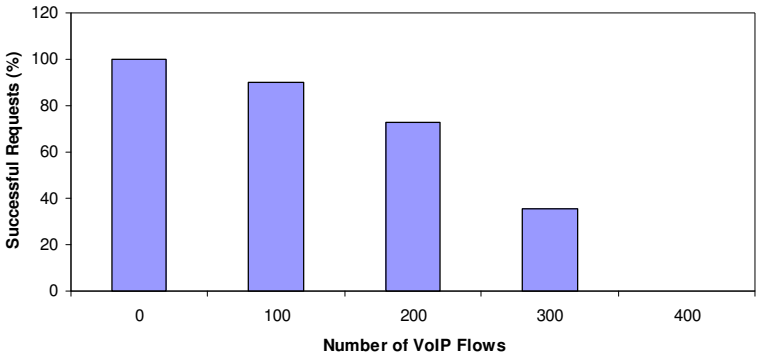


Figure 41 - Percentage of Successful Requests

Figure 42 shows us that when the VoIP traffic begins to increase and saturate the capacity of the WiMAX channel, NSIS signalling, which is performed through WiMAX, greatly increases its processing time, due particularly of the congestion of the WiMAX channel. In this situation if time is too high the NSIS generates a time-out and the requests are not routed to the ASN. Because of this behaviour some requests were not successful at the equipment.

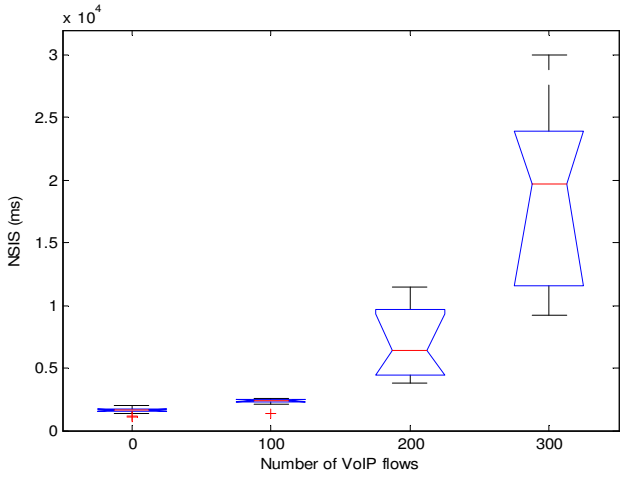


Figure 42 - Processing time by NSIS (MS<->ASN)

Figure 43 and Figure 44 shows us the processing times for Diameter signalling (between CSC_ASN and AAA) and for the communication with the equipment to perform the request of the service flow, respectively. It demonstrates that these two times are approximately constant, even increasing the VoIP flows through WiMAX.

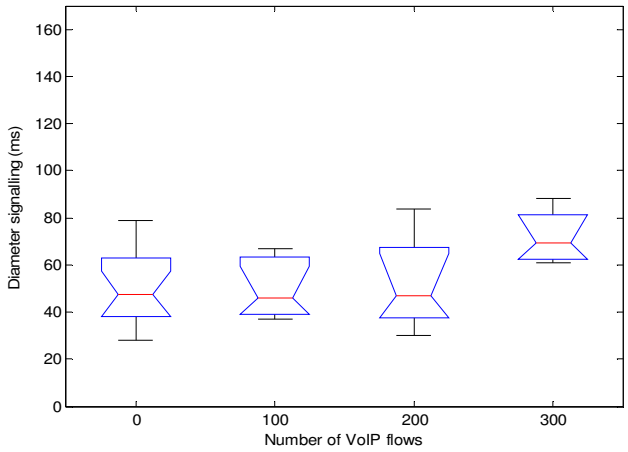


Figure 43 - Diameter Signalling

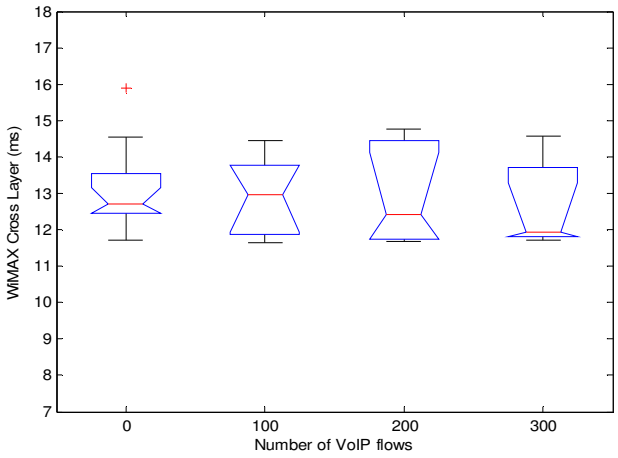


Figure 44 - Processing time between CSC_ASN and the Equipment

As we can see in Figure 45 the CSCs processing time increases slowly between the different experiments. This demonstrates that its processing is affected by the delay of the signalling between the MS and ASN due of the increasing congestion of the WiMAX channel.

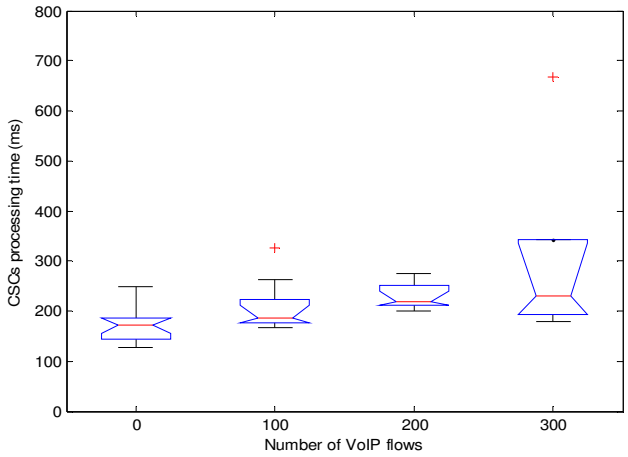


Figure 45 - Processing time by CSCs

Finally the Figure 46 provides the end-to-end time for a QoS request made by Weird Agent. As we can see the time increases mainly because of the increasing of the processing time depicted in Figure 42.

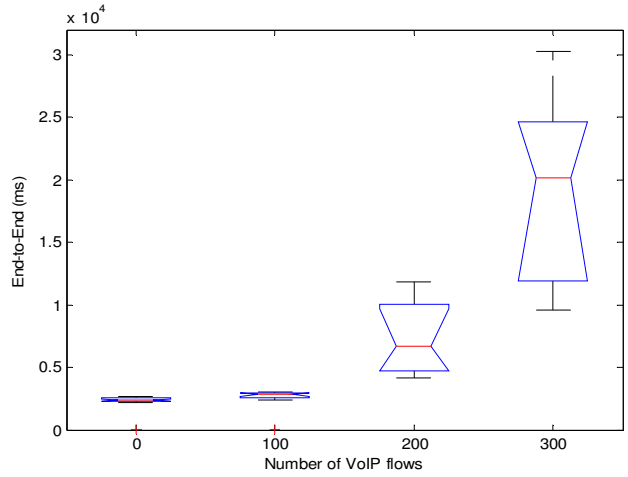


Figure 46 - End- to-End time

4.3.1.2.Point-to-Multipoint Scenario

This section provides all the measures withdrawn from the WEIRD's phase 1 signalling for point-to-multipoint scenario.

As we can see in Figure 47 the WEIRD's phase 1 architecture is not available for point-to-multipoint scenarios. The end-to-end time to perform a reservation for QoS is always about 30 seconds, even with no traffic from applications in WiMAX channels, which is a totally unacceptable when we are talking about a QoS architecture.

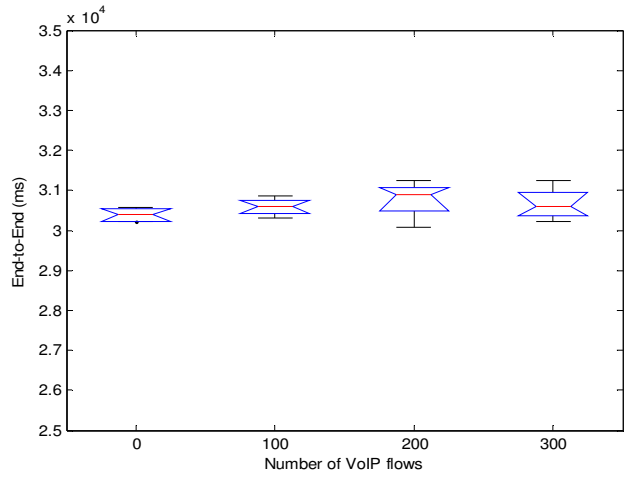


Figure 47 - End- to-End time

Note that in this situation the processing time for AAA is basically the same as before and the processing time of CSCs is lower than before because the request doesn't have to go through NSIS signalling to CSC_CSN, as the client is on the SS2 side. Because of this, it will be made two reservations at the equipment: the first at SS1 and the second at SS2.

4.3.2.QoS Tests

After analysing the signalling process we will be now study the QoS provided by WEIRD architecture. With the scenario depicted in Figure 37 we will firstly analyse the uplink channel, doing a reservation in Weird Agent from the source (MS) to the sink (CSN) and compare the results with the ones described in section 3.4.2.1 (VoIP without aggregation) without the WEIRD software. After this, we will do the same but now to study the downlink channel (source of traffic is CSN and the sink the MS). Note that, after the service flow is made on the equipment we want to see if the traffic generated with the JTG (see section 3.4.1.2) passes through the service flow made in equipment by WEIRD software, and its influence on QoS.

In Figure 48, Figure 49 and Figure 50 are described the results for uplink channel.

We saw that VoIP generated traffic by JTG passes through the "WEIRD's service flow" and not by default service flows generated before starting WEIRD's software (it is true not only for uplink channel but also for downlink channel).

The results give us the perception that one of the main objectives of the WEIRD's architecture was completed, we mean, WEIRD tries to be an architecture that controls the traffic that passes by the WiMAX equipment, giving more priority or not to a particular type of traffic as it is required or not, thus allowing the proper allocation of resources at equipment.

Analysing the measures taken from the experience we conclude that they are similar with the results presented in section 3.4.2.1 for the uplink channel. So, it is demonstrated that WEIRD´s architecture is able to control all the resources for the uplink channel and the QoS results are the same having obtained with a static configuration of service flows (section 3.4.2.1).

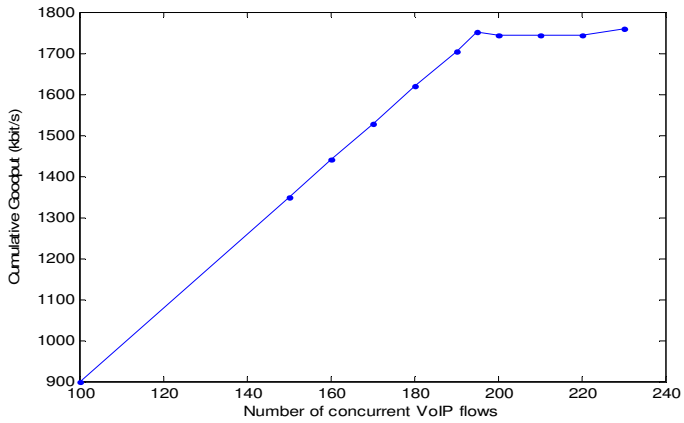


Figure 48 - Cumulative uplink Goodput

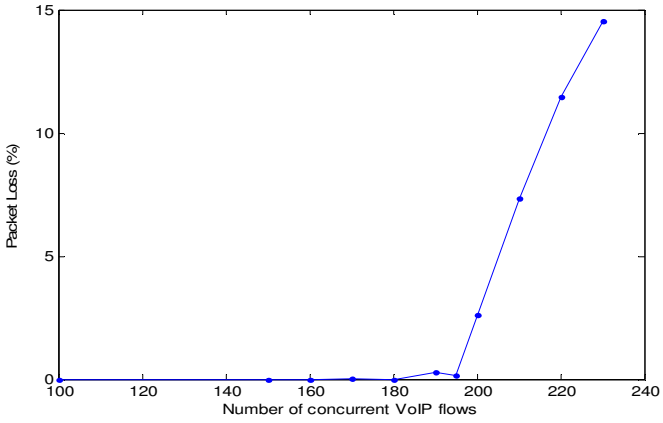


Figure 49 - Average uplink Packet Loss

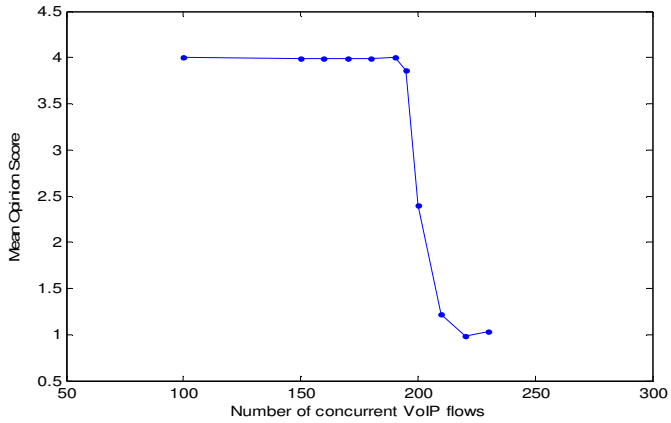


Figure 50 - Uplink Mean Opinion Score

Attempting now to the downlink channel results (see Figure 51, Figure 52 and Figure 53) we conclude that for the downlink channel the results are worst compared with the ones obtained at section 3.4.2.1.

In this case the WiMAX downlink channel only can sustain about 220 VoIP flows with negligible loss and with an acceptable MOS unlike the results obtained before, where 270 flows could flowing the channel with lower values for packet loss.

This can be explained with the use of signalling messages that ASN machine sends to MS in order to refresh its states, which fills the downlink WiMAX channel capacity and promotes a worst quality of service for VoIP traffic. Notice that these tests were not performed simultaneously to the tests of the section 3.4.2.1 and so, the WiMAX radio communication could have different interference conditions.

Nevertheless, the resource allocation at the equipment is done correctly, and the data traffic flows through the "WEIRD's service flow".

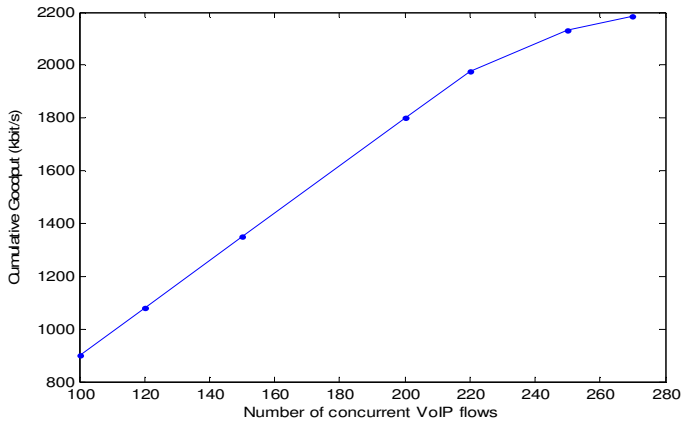


Figure 51 - Cumulative downlink Goodput

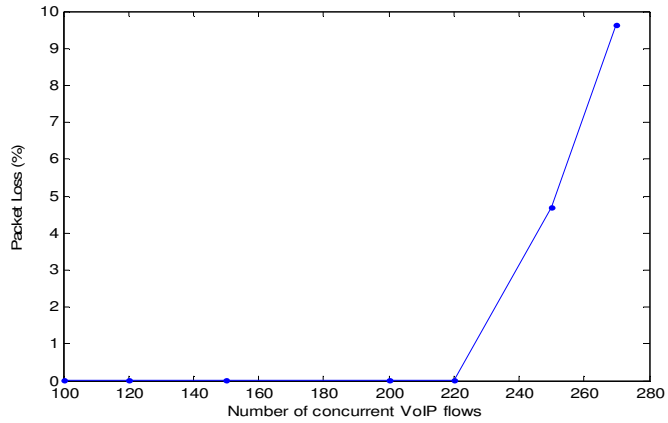


Figure 52 - Average downlink Packet Loss

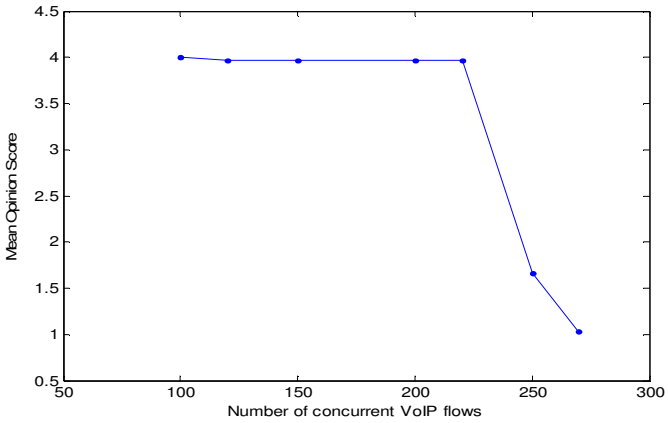


Figure 53 - Downlink Mean Opinion Score

4.4.Summary

At this chapter, unlike the point-to-point scenario, which give us acceptable values for the signalling in the resource allocation at the WiMAX equipment, the point-to-multipoint scenario doesn't work in the correct manner in the WEIRD project.

Finally, with the results of the section 4.3.2 we conclude that the QoS specification done by the WEIRD's software, for a specific application, is established correctly at the equipment.

5.Mobility Architecture and Development

The ability to connect and trasmit voice, video and data connections anywhere and anytime is a compelling vision for consumers and a main goal for near future. In order to obtain this, IEEE 802.21 Media Independent Handover (MIH) standard [3] provides link layer intelligence and other related network information to upper layers to optimize handovers (HOs) between heterogeneous media providing the seamless handover between networks of the same (HO Horizontal) or different technologies (HO Vertical), being independent of the physical networks.

This chapter presents the WEIRD's (WiMAX Extension to Isolated Research Data networks) mobility architecture in which the developed work is inserted, which aims to demonstrate the correct integration between IEEE 802.21 architecture through WiMAX (Worldwide Interoperability for Microwave Access) segments. MIHF is a module of this architecture and its implementation will be described at this chapter.

In section 5.1 we present the overview of the architecture in its all, presenting the main objectives and differences between the phase 2 and phase 1 of WEIRD's architecture. Section 5.2 presents the mobility architecture and its modules. Section 5.3 presents the MIHF (Media Independent Handover Function) implementation including the specification, implementation and its configuration, whereas section 5.4 provides the specification of the messages exchanged between MIHF and the rest of the architecture. Finally section 5.5 provides a final summary of the chapter.

5.1.WEIRD architecture with mobility

5.1.1.Objectives

The WEIRD project was implemented in two phases: phase 1 where most modules were developed with basic functionality, in order to perform more tests with applications such as Video, VoIP (Voice over IP), Telemedicine, Fire Prevention [30][32][33], and phase 2 where new modules and advanced features, like the implementation of a mobility scenario including MIP and MIH over WiMAX, were added to the software developed for phase1.

5.1.2.Overwiew

WEIRD's phase 2 [5] software components are illustrated in Figure 54. Besides the modules developed for phase 1 [4], it also shows the new modules developed for phase 2. The new modules developed for phase 2 were: MIHU - Media Independent Handover User, MIHF - Media Independent Handover Function, NSIS Mobility NSLP (NSIS Signaling Layer Protocol), LLC - Lower Layer Controller, Mobility GUI and Mobility Manager (MM). The other ones were enhanced in order to perform Quality of Service (QoS) session setup and reservations both with legacy and SIP (Session Initiation Protocol) scenarios.

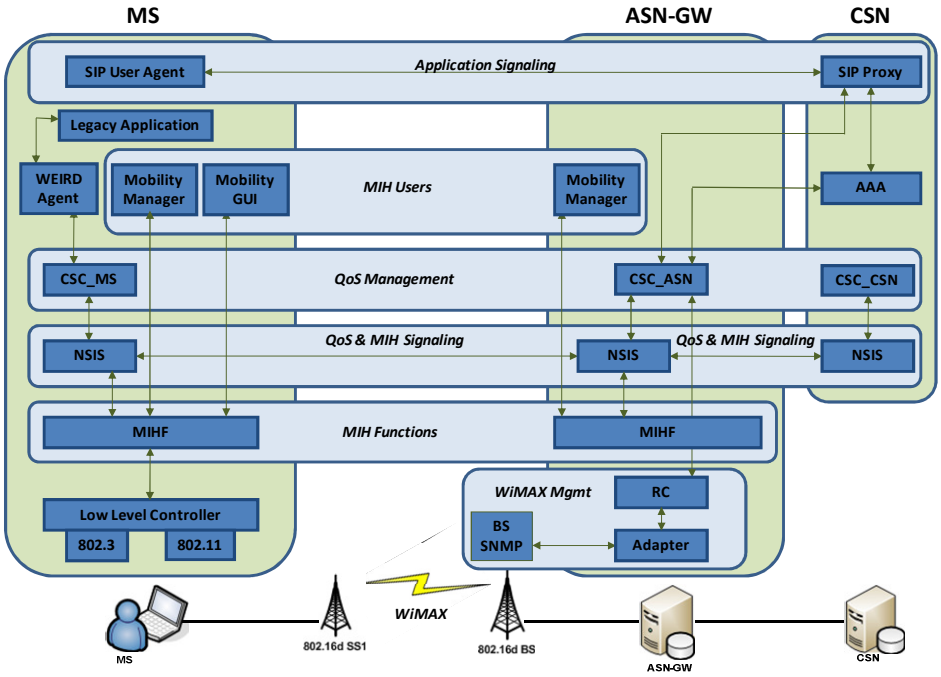


Figure 54 - WEIRD's Phase 2 Architecture – Control Plane

The WEIRD's phase 2 applications can be split into two categories:

- WEIRD-aware applications: that use services offered by WEIRD, including SIP-based modules and other applications that can be modified to directly use WEIRD-defined services.

- Legacy applications: that cannot be updated but can use WEIRD services through the use of a WEIRD Agent, where mobility scenario is included.

5.2.Mobility Modules

This section provides the understanding of the interaction between mobility modules. We will introduce the high level overview of the mobility modules, not only MIHF, which is the purpose of the developed work, but also the modules that communicate with it. Note that is very important the understanding of those modules in order to know how to implement MIHF, accordingly with the requirements of the architecture.

5.2.1.Lower Layer Controller

The Low Level Controller (LLC) [5] is the software module located on the Mobile Station (MS) that is in charge of monitoring the state of the local network interfaces (Ethernet and WiFi) and interacts with the MIHF in order to trigger the resource reservation on the new WiMAX segment when an handover procedure is necessary.

The communication between LLC and MIHF is compliant with the MIH_LINK_SAP [3] that specifies an abstract media independent interface between the MIHF and the lower

layers media-specific protocol stacks such as IEEE 802.3 (Ethernet) and IEEE 802.11 (WiFi).

The primitives exchanged between LLC and MIHF are:

- Link_Up – This event is sent by the LLC to notify that a layer 2 interface (Ethernet or WiFi) is configured and ready to be used.

- Link_Going_Down – This event is sent by the LLC to notify that a layer 2 connection (Ethernet) is expected to go down. It is used to trigger the resource reservation procedure on the new WiMAX channel.

- Link_Down – This event is sent by the LLC to notify that a layer 2 connection (Ethernet or WiFi) is broken. It is used to trigger the handover process and delete the QoS reservation on the old WiMAX segment.

- Link_Action – This request is sent by the MIHF to perform an action on a pre-defined link layer connection. It used by the LLC to notify the user that the resource reservation on the new WiMAX channel has been completed successfully.

The detailed description of the messages sent by this module is described on chapter 11.

The LLC is endowed with a GUI that allows the user of the MS to know the networks connectivity state (Figure 55). When the state of a network interface changes, the colour in the circle depicted in the GUI varies and a new message appears in the text area to notify the user of the event. Therefore he can evaluate the situation and take a decision. For example if both the Ethernet and WiFi interfaces are ready to be used, he can trigger the Link_Going_Down event by pushing the button on the GUI.

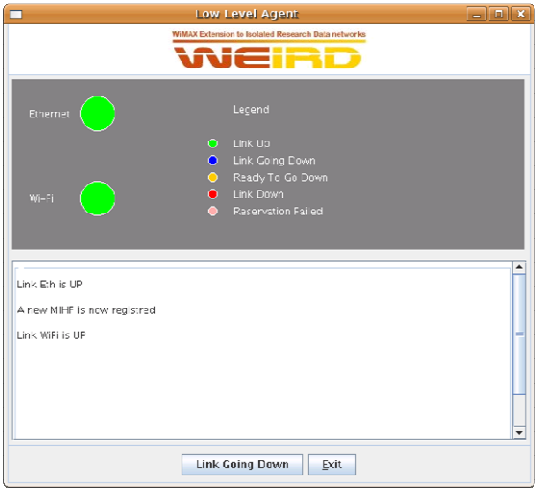


Figure 55 - LLC Graphical User Interface

Moreover the GUI is also employed to allow the user to know the result of the resource reservation procedure on the new WiMAX channel. An internal timer is started when the LLC sends the Link_Going_Down event to the MIHF. If the Link Action is received before the timeout, the QoS reservation is considered successfully completed and a message is shown on the GUI. Otherwise the QoS reservation is failed.

5.2.2.NSIS Mobility NSLP

In order to use the NSIS framework to transport MIH messages [12], a specific NSLP [13], the Media Independent Handover NSLP, was developed [5]. The MIH NSLP allows the distribution of MIH messages across different networks (between different MIHFs). Next is described the procedure to transport MIH messages within the MIH NSLP, followed by the specification of the MIH NSLP architecture.

The MIH NSLP is responsible for the transport of MIH Messages using the GIST (General Internet Signaling Protocol). Figure 56 details the architecture of NSIS usage as the MIHF transport protocol putting in evidence the interaction between the MIH NSLP, the MIHF and the GIST protocol [56].

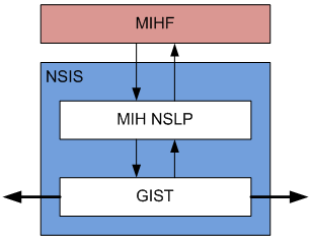


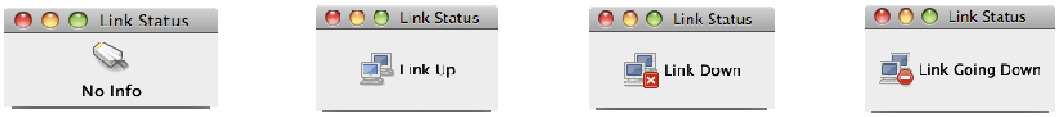
Figure 56 - MIH NSLP architecture

The MIH NSLP interface with MIHF handles the MIHF MIH Message exchange. This interface is compliant with the MIH_NET_SAP defined in the IEEE 802.21 Standard [3] for Media Independent Handover Services. The MIH NSLP interface with GIST handles message transport. This interface is specified in the GIST protocol [56].

The detailed description of the functionalities of this module is provided on chapter 11.

5.2.3.Mobility GUI

The Mobility GUI [5] application is a simple graphical interface that interacts with the mobile node user to inform him of handover events. This application acts as a MIHU (Media Independent Handover User) by registering to the local MIHF and subscribing specific MIH events. These events (specified in the IEEE 802.21 Draft Standard for Media Independent Handover Services) are: link up, link down, link going down and link action. Each event that is received from the MIHF is showed to the user in a graphical way.



a) No Information b) Link Up c) Link Down d) Link Going Down

Figure 57 - Mobility GUI

In Figure 57 a) the Mobility GUI shows its default state, that no information could be read and presented to the user. In Figure 57 b) the Mobility GUI displays the information that the Link is up. In Figure 57 c) the Mobility GUI displays the information that the Link is down. In Figure 57 d) the Mobility GUI displays the information that the Link is going down.

5.2.4.CSC_MS

The management of all the control plane functionalities related to the resource update for mobility is performed at the CSC (Connectivity Service Controller), through a new specific module called Mobility Manager (MM) [5]. This module acts as a MIHU interacting with the MIHF module in order to exchange IEEE 802.21 MIH Services.

The main functionalities of the CSC_MS MM are the following: management of the MIH messages received from the MIHF and update of its internal status; management of the new resource reservation between the target Subscriber Station (SS) and the Base Station (BS) when the MN moves between different SSs; management of the release of the old resources between the serving SS and the BS.

The CSC Mobility Manager manages all the information about the network interfaces of the host and inspects the retrieved MIH messages in order to update their status. If an incumbent change of the active network interface is detected, the CSC Mobility Manager interacts with the CSC Engine [5] in order to prepare the handover following a Make-Before-Break approach.

When the MM receives a MIHF Link_Going_Down message that indicates an imminent handover, it initiates the NSIS signaling in order to create new SFs (between the target SS and the target BS) for the data traffic of the existing application sessions. If the reservation result is successful, the MM sends a MIHF Link_Action message to the MIHF so that the handover procedure can proceed. The end of the handover process and the availability of the new L3 connection is signaled by the MIHF Link_Down message: when this type of message is received, the NSIS signaling is triggered again in order to delete the old SFs between the BS and the serving SS.

Figure 58 shows the architecture of the CSC_MS, underlining the strict interaction between the CSC Mobility Manager and the CSC engine that manages the NSIS QoS signaling sessions for the active applications. The interaction between the CSC_MS MM and the MIHF module uses the MIHF Attendant. This entity handles the connection between the MIHF and the CSC_MS, is in charge of the MIHU initialization and performs a first parsing of the IEEE 802.21 messages. Messages received from the MIHF are first processed by the MIHF Attendant and then forwarded to the CSC Mobility Manager through the MM Queue. Messages from the CSC Mobility Manager are sent to the external MIHF module using the API of the MIHF Attendant.

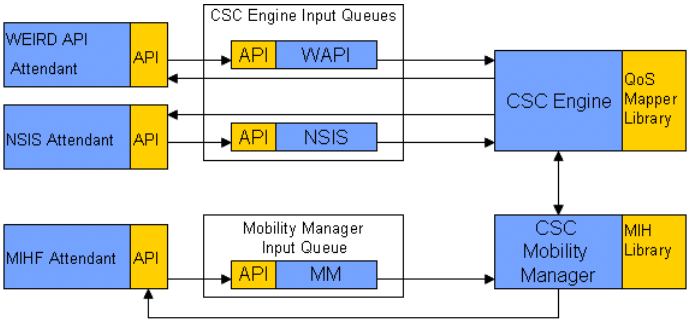


Figure 58 - CSC_MS architecture

The architecture of the CSC_MS Mobility Manager and its interaction with the external modules is shown in Figure 59.

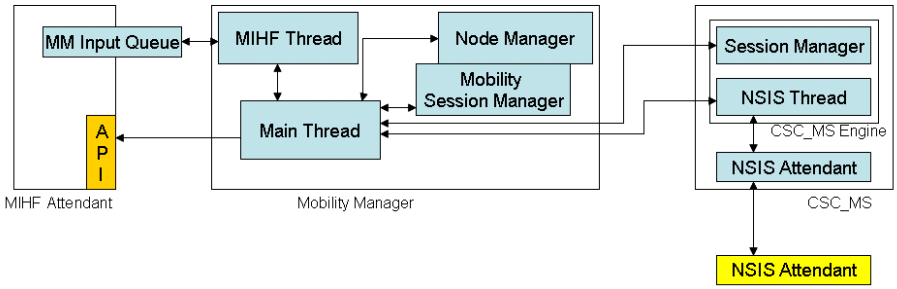


Figure 59 - CSC_MS Mobility Manager architecture

Messages from the MIHF module are retrieved from the MM Input Queue of the MIHF Attendant by the MIHF Thread. For each received MIHF message, the Node Manager updates its internal status. In particular, the Node Manager handles all the information related to the network interfaces of the host (Table 7).

Network Interfaces Information	
Network Interface ID	
Network Interface Type	Eth/WiFi
MAC Address	
IP Address	
Priority	
Status	Up/Going-Down/Down
Active	True / False
With traffic	True / False

Table 7 - Network Interfaces Information handled by the node manager

The priority value is used to decide which interface is active when more network interfaces are in the status Up. In this case, the active interface is the one with the lower value of priority. The interface "with traffic" is the one that is currently used for the data traffic.

The Main Thread handles all the procedures related to the handover. When new handover actions must be performed, according to the received MIHF message and the current Node Manager status, the MIHF Thread triggers the Main Thread that controls all the handover phases. In particular, the handover procedure consists of two different phases: the HO MAKE, when new SFs are allocated between the target SS and BS, and the HO BREAK, when old SFs between serving SS and BS are deleted.

The HO MAKE Phase Involves all the existing active sessions for legacy applications. In order to retrieve all the required information about them, the Main Thread interacts with the CSC_MS engine, in particular with its Session Manager. Information about existing sessions are stored in the Mobility Session Manager, used to handle the status of all the application sessions and the associated NSIS sessions for mobility during the handover process, checking the resource reservation result for each of them.

The Main Thread also interacts with the CSC_MS engine in order to initiate the NSIS signalling for the reservation and the activation of the WiMAX SF to be used after the HO. The QSPEC carried with the NSIS messages includes the following values: Application Type (MOBILITY), QoS parameters (as defined in the WiMAX QoS model), Classifier (IP addresses and ports, ToS, protocol), Mobility Command (Make, Break), Application NSIS Session ID.

The mobility command specifies the type of operation to be performed, while the application NSIS session ID specifies which previous reservation must be updated at the CSC_ASN level.

The signalling result is retrieved by the NSIS Thread of the CSC_MS engine and is notified to the Main Thread. It updates the Mobility Session Manager, the Node Manager and the engine Session Manager. If needed, it also sends MIHF messages to the MIHF Module using the API exported by the MIHF Attendant.

- **MIHF Attendant**

The MIHF Attendant [5] is a stateless module that allows the Mobility Manager (MIHU) to communicate with the MIHF module. It is in charge of the mapping between the MIHF messages received by the MIHF (following the format defined in the IEEE 802.21 specification) and the messages handled by the Mobility Manager.

The interaction with MIHF module is based on the TCP protocol, so that the message reliability is assured at the transport layer, avoiding the IEEE 802.21 ACK mechanism. The specific format for each message and TLV is defined in the IEEE 802.21 specification.

The architecture of the MIHF Attendant is shown in Figure 60. Messages received from the external MIHF module are handled by the Receiving Thread that performs the first parsing of the MIHF messages. The parsed structure includes the message header with the transaction ID, the Service ID, the Operation Code and the Action ID, as well as a vector with the parsed TLVs. This structure is further elaborated by the MIHF/MM Mapper that extracts only the information required by the Mobility Manager. Each message is inserted in a specific Queue Element and is added to the MM Input Queue. Here it is retrieved by the Mobility Manager itself, following a FIFO mechanism.

The Mobility Manager uses the MIHF Attendant API for the communications to the MIHF module. Messages coming from the Mobility Manager are elaborated by the MIHF/MM Mapper and the resulting message is sent to the MIHF Module by the Sending Thread.

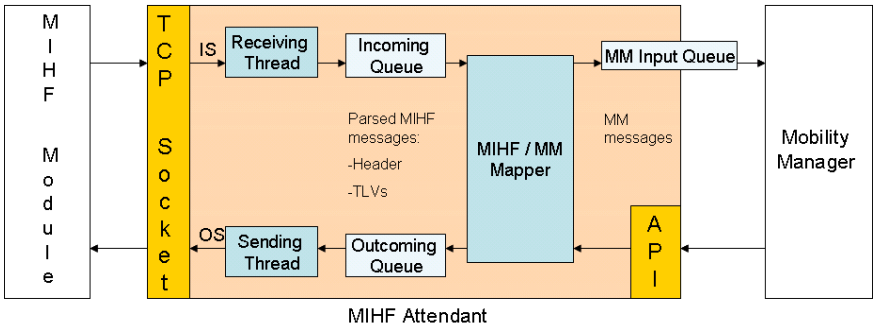


Figure 60 - MIHF Attendant architecture

5.2.5.CSC_ASN

The CSC_ASN Mobility Manager [5] handles the procedures for the resource re-configuration in the WiMAX link in case of mobility scenarios involving SIP applications. The CSC_ASN MM acts as a MIHU, that receives information about imminent handovers from the lower layers of the MNs located in the controlled ASN through the local MIHF module on the ASN-GW. This entity exchanges some remote MIHF messages with the MIHF module located on the MN using the MIH protocol.

The CSC_ASN Mobility Manager handles the information related to the network interfaces of all the nodes located in the ASN. The adopted mechanism is similar to the CSC_MS MM one: when an imminent handover is notified, all the resource reservations related to the involved MN are updated. This procedure is performed only for SIP sessions, while the reservations for legacy applications are managed on the host side. The resource update is restricted to the SS – BS – ASN-GW segment, so it is handled directly with the SF creation and deletion through the RC.

Figure 61 shows the high level architecture of the CSC_ASN, including the Mobility Manager. The interaction between the CSC_ASN MM and the MIHF module located on the ASN-GW is based on the MIHF Attendant (as described in Figure 60), following the same approach used in the CSC_MS.

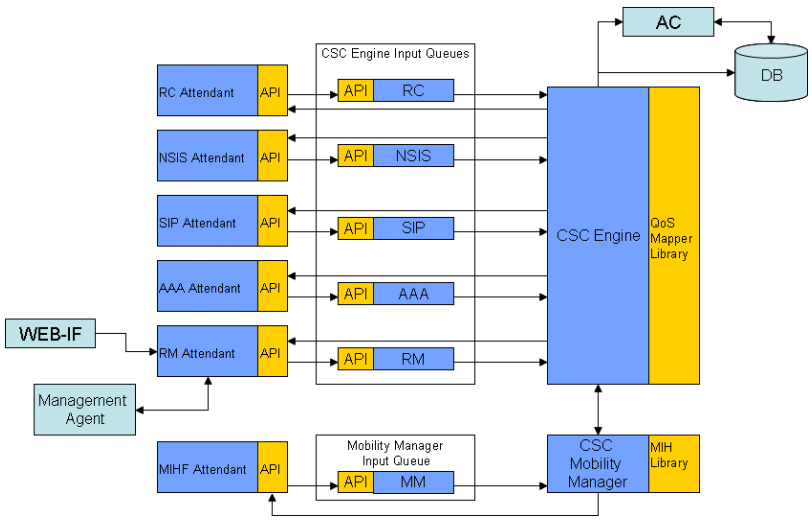


Figure 61 - CSC_ASN architecture

The finite state machine managed by the CSC_ASN MM is based on the same approach of the CSC_MS MM. The main different is the mechanism adopted for the reconfiguration of the WiMAX link: at the CSC_MS level the NSIS signaling is used to request the SF creation and deletion, while at the CSC_ASN level the resource reconfiguration is directly managed through the interaction with the RC.

5.2.6.MIHF

MIHF is the central unit of IEEE 802.21 architecture. It provides communication with LLC (lower layers) and MIHUs (upper layers). Furthermore MIHF will have to communicate with remote MIHFs via NSIS. Figure 62 describes the relationship between MIHF and all mobility modules.

The MIHF interfaces with other layers and functional planes using Service Access Points (SAPs). Each SAP consists of a set of service primitives that specify the interactions between the service user and provider.

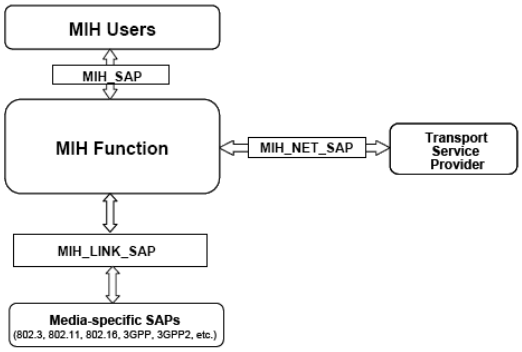


Figure 62 - Relationship between different MIHF SAPs

The MIH_LINK_SAP specifies an abstract media dependent interface between the MIHF and lower layers media-specific protocol stacks of technologies such as IEEE 802.3, IEEE 802.11 and IEEE 802.16.

The MIH_NET_SAP specifies an abstract media dependent interface of the MIHF which provides transport services over the data plane on the local node, supporting the exchange of MIH information and messages with remote MIHFs, using MIH protocol [5].

The MIH_SAP specifies a media independent interface between the MIHF and upper layers of the mobility management protocol stack, designed MIHUs.

5.2.7.Interaction

This section presents the interaction between the mobility modules.

At a first stage a MIHU of a defined domain (MS or ASN-GW) should register it in the properly MIHF sending it a MIH_Register.request starting the register process as described in Figure 63.

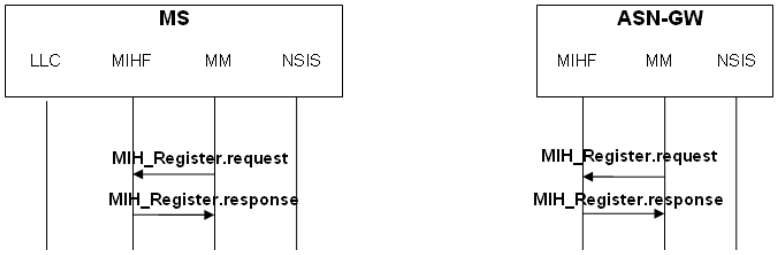


Figure 63 - MIHU Register

At a second stage MIHUs have to subscribe in MIHF the events that want to receive. The subscription may be required by a local MIHU or a remote MIHU. Figure 64 describes the subscription of events of MIHUs at MIHF.

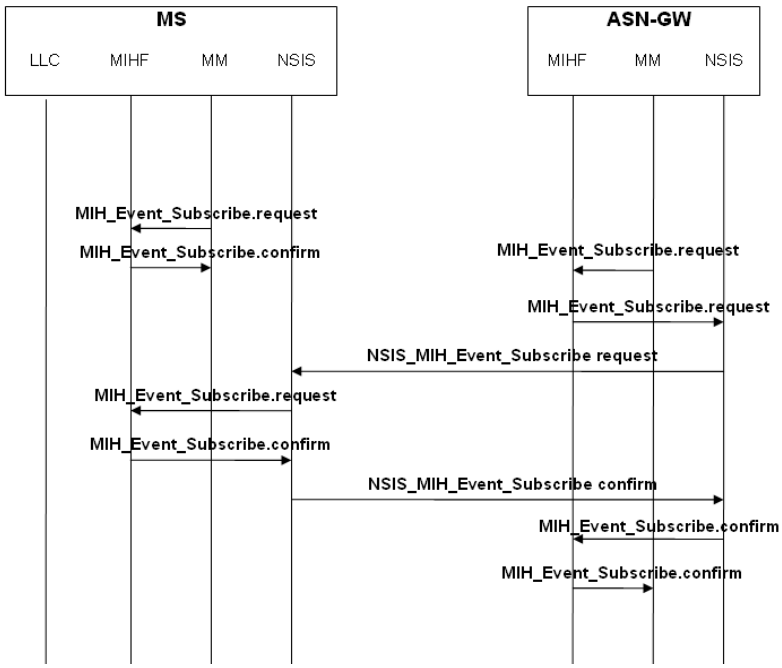


Figure 64 - MIHU Event Subscribe

The next procedure in a mobility scenario using IEEE 802.21 architecture is the forward of the events that Lower Layer Controller (LLC) triggers. MIHF should send them only to MIHUs which have subscribed such type of event.

First of all the LLC should detect the interfaces that are available and send this information to MIHF. At this case Ethernet and Wireless interfaces are both up (see Figure 65).

MIHF should forward the messages to Mobility Managers because they are the main responsible about all the questions related with mobility and it have to trigger the resource reservation on the new WiMAX segment when an handover procedure is necessary.

When we want to move from one interface to another Lower Layer Controller should send a Link_Going_Down event (see Figure 66) to Mobility Manager which triggers the resource reservation on the new WiMAX segment when an handover procedure is

necessary. The Mobility Manager should send a notification to MIHF about the end of this process (in this case a Link_Action.request message).

When a user unplugs the Ethernet cable its communication with the rest of the world should be made by wireless interface and it is from this way that mobility manager receives a Link_Down event (see Figure 67).

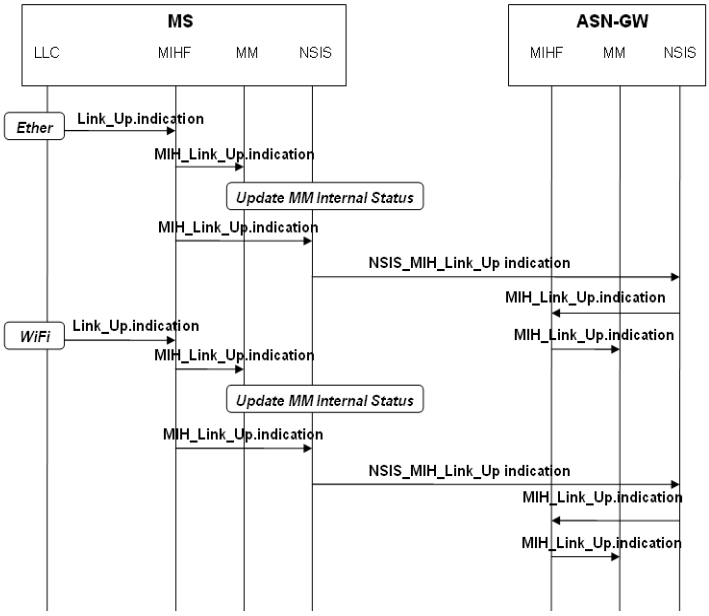


Figure 65 - Link_Up Event processing

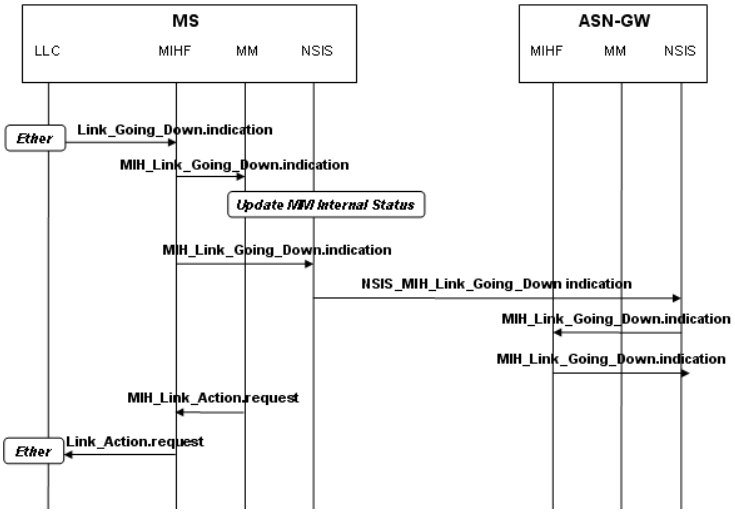


Figure 66 - Link_Going_Down Event processing

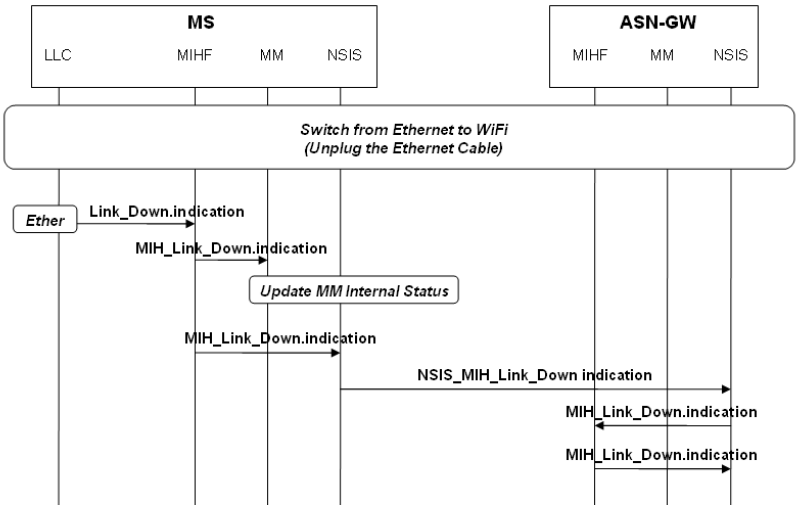


Figure 67 - Link_Down Event processing

5.3.MIHF Implementation

This section provides the specification of the MIHF, explaining its functionalities and its intelligence. MIHF implementation follows a set of steps, which are necessary for the proper integration of the module with the rest of the architecture. This module had to be made the most general possible, because it has to run not only in the MS but also in the ASN-GW and in CSN. Figure 68 shows the principal features of the MIHF architecture. As we can see initially we have to configure all the topology of the network with the important information of MIHFs, MIHUs and LLCs. It follows the creation of means of communication (sockets) with all modules. After this MIHF are able to receive any message from MIHUs, LLCs or NSIS and have the correct behaviour accordingly with the message received. The main MIHF functions, which will be described in the following sections, are:

- Configuration and topology;
- MIHF Engine;
- LLC message process;
- MIHU Message process;
- NSIS message process.

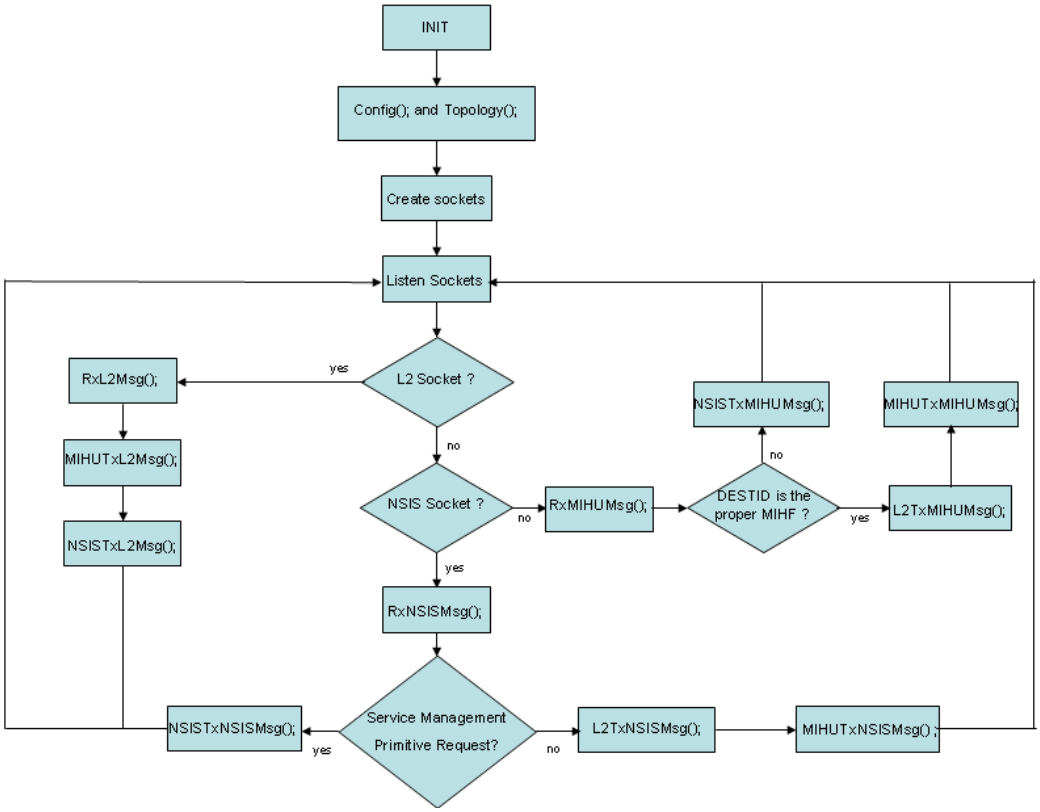


Figure 68 - MIHF intelligence

5.3.1.Configuration and Topology

It was decided to store all existing MIHFs (both the MS as the ASN-GW and in CSN) in a map (a data structure of the stdlib C++), and have a global variable indicating the location of MIHF in we are working. This is important because we have always access to all MIHFs and so, we know immediately if the information that arrives is local or remote. Each element of the map store relevant information about each MIHF. The MIHF struct is described in Table 8.

Parameter Name	Parameter Type
MIHFIndex	unsigned int
MIHFPort	unsigned int
MIHFName	unsigned char*
MIHFMacAddr	unsigned char*
MIHFIPv4Addr	unsigned char*
MIHFID	unsigned int
MIHFEvents	unsigned char
CommandElem	map<unsigned int, Event>
EventElem	map<unsigned int, Command>
ServiceElem	map<unsigned int, Service>
InformationElem	map<unsigned int, Information>
sockMIHU	ServerSocket

Table 8 - MIHF struct

All existing MIHUs were also structured in a map of MIHUs. Each element of the map store relevant information about each MIHU. It was found a way of having a link between each MIHU and its local MIHF. The MIHF struct is described in Table 9.

Parameter Name	Parameter Type
MIHUIndex	unsigned int
MIHFIndex	unsigned int
MIHUPort	unsigned int
MIHUName	unsigned char*
MIHUMacAddr	unsigned char*
MIHUIPv4Addr	unsigned char*
MIHUNSIS	unsigned int
MIHFDestId	unsigned int
MIHFName	unsigned char*
CommandElem	map<unsigned int, Event>
EventElem	map<unsigned int, Command>
ServiceElem	map<unsigned int, Service>
InformationElem	map<unsigned int, Information>
sockMIHU	ServerSocket

Table 9 - MIHU struct

All existing physical layers (LLCs) were also structured in a map. The physical layer struct is described in Table 10.

Parameter Name	Parameter Type
L2Index	unsigned int
MIHFIndex	unsigned int
L2Port	unsigned int
L2Name	unsigned char*
L2MacAddr	unsigned char*
L2IPv4Addr	unsigned char*
MIHFName	unsigned char*
sockL2	ServerSocket

Table 10 - Physical Layer struct

Each MIHF has associated maps of events, commands, information services and elements of control that provides. Each MIHU will also be associated themselves these sets of maps, after having subscribe each one of these services. These services are structured as shown in Table 11.

Struct Name	Parameter Name	Parameter Type
Event	EventIndex	unsigned int
	event	unsigned char
	transactionID	vector<int>
Command	CommandIndex	unsigned int
	command	unsigned char
	transactionID	vector<int>
Information	InformationIndex	unsigned int
	information	unsigned char
	transactionID	vector<int>
Management	ManagementIndex	unsigned int
	management	unsigned char
	transactionID	vector<int>

Table 11 - MIHF and MIHU services struct

To store the important information about the MIHF and its location, about MIHUs and LLCs, it was defined a configuration file (MIHF.conf) which should be update before the start of a new test with MIHF if necessary.

5.3.2.MIHF Engine

The MIHF Engine is the central structure of the entire code.

Each MIHF has a set of listening TCP sockets. Each one is responsible for communicating with each MIHU associated with it. For a local MIHF communication with a remote one will be used NSIS (see section 5.2.2). In the communication with LLC, MIHF will be the client and LLC will be the server.

For the communication between modules we established a C++ class ('Socket' and the derived 'ServerSocket') with some methods that provide all the requirements to the communication between all the modules. They provide the accepting, listening and binding of a new element that communicates with MIHF and the reception and sending of messages between it and MIHF. After the creation of the sockets, MIHF are able to receive messages from the different interfaces and have the correct procedure whether the message reaches from LLC interface or from MIHU or NSIS interface.

After the creation of the sockets MIHF stays in a loop, listening if there is any message from an interface. If there is something, it should instantiate an object which allows the processing of these messages, calling the function L2MsgProcess(), MIHUMsgProcess() or NSISMSgProcess() as it is a LLC, a MIHU or NSIS.

5.3.3.L2 Message Process

The MIHF must have the ability to receive messages from the LLC (Link_Up.indication, Link_Down.indication or Link_Going_Down.indication). After that must process these messages, identify the event in question (Link_Up, Link_Down or Link_Going_Down) and forward it to the MIHUs (local or remote-via NSIS) that subscribe it. Figure 69 describes the receiving of LLC events by MIHF.

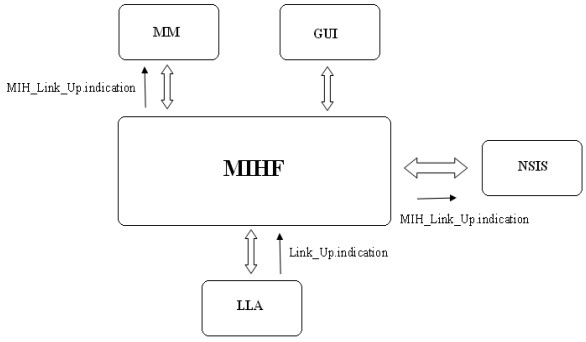


Figure 69 - Receiving LLA Event

If at the moment of the reception of the LLC message by MIHF, no MIHU had registered the MIHF or had subscribed its events, the events have to be stored in a struct. Later, when a new MIHU subscribes any event, we have to verify in this struct if there is an important event and send the correct information from a specific Layer 2 to the MIHU in question.

5.3.4.MIHU and NSIS Message Process

- **MIHU Register**

The MIHF must have the ability to receive messages coming from MIHUs who want to register (MIH_Register.request). The registration may be requested by a local MIHU or a remote MIHU. Moreover must generate and submit their response to these requests (MIH_Register.response). Figure 70 describes the register of MIHUs at MIHF.

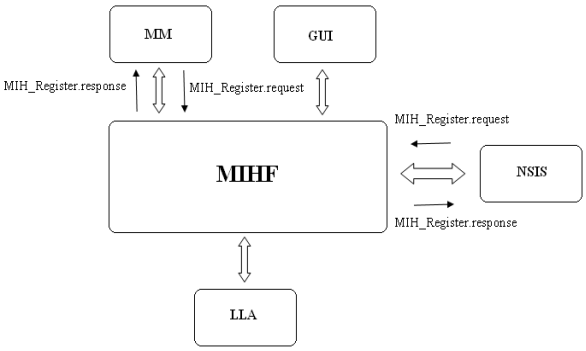


Figure 70 - Receiving MIHU Register

- **MIHU Subscribe**

The MIHF must have the ability to receive messages coming from MIHUs which want to subscribe their events (MIH_Event_Subscribe.request). The subscription may be required by a local MIHU or a remote MIHU. Moreover must generate and submit their response to these requests, indicating if it supports or not the requested events (MIH_Event_Subscribe.response). Figure 71 describes subscription of events by MIHUs at MIHF.

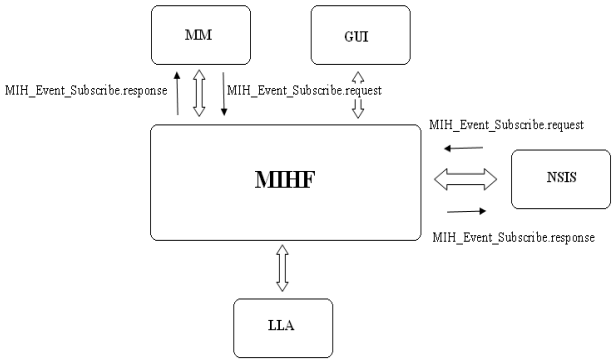


Figure 71 - Receiving MIHU Event Subscribe

- **MIHU Link Action**

The MIHF must have the ability to receive MIH_Link_Action.request and send the respective answer to all MIHUs or LLCs, who signed this type of command as described in Figure 72.

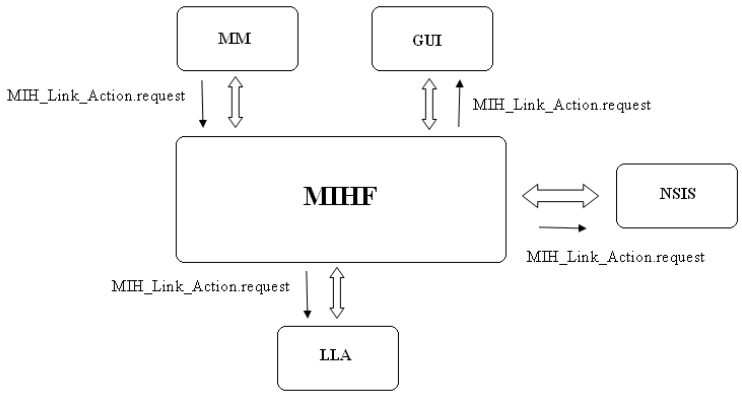


Figure 72 - Receiving MIHU Link Action

- **MIHU Link Up, MIHU Link Down, MIHU Link Going Down**

As mentioned previously, MIHF should be able to forward the events that are coming from LLC for MIHUs that subscribed them, whether they local or remote, as described in Figure 69. For this, it should be defined the following primitives: MIH_Link_Up.indication, MIH_Link_Down.indication and MIH_Link_Going_Down.indication.

- **MIHU Get Information**

The MIHF must have the ability to receive messages coming from MIHUs who want to get information about the network topology (MIH_Get_Information.request). It has to forward these messages to the CSN, where resides the MIIS (Media Independent Information Service) which provides a framework and corresponding mechanisms by which the MIHF entity may discover and obtain network information existing within a geographical area to facilitate the handovers.

5.4.Messages exchanged between Mobility Modules

This section presents with more detail the MIHF interfaces (including the format of the primitives using such interface) through which LLC, MIHUs and remote MIHFs are able to communicate with local MIHF.

The received message from any interface is always processing at the same manner accordingly with the MIH protocol [5]:

- Read the header of the message to know the message in question.
- As the messages are sent accordingly with the IEEE 802.21 Draft Standard for Media Independent Handover Services, we have to read the type of TLV that follows the header.
- Next, we have to read the length of the TLV.

- Finally, we have to read the value of the TLV.

5.4.1.MIH_LINK_SAP Interface

The interface between the LLC and the MIHF (MIH_LINK_SAP) is described in this section (according to the IEEE 802.21 [5]).

This interface will be implemented via a TCP Socket.

At this interface arrive service events, which come from LLC. All of these events have to be processed by MIHF and propagated for MIHUs that subscribed them (can be local or remote). This interface is also be used to propagate commands for LLC.

The structure of primitives, which represents these events, is described in Figure 73.

Figure 73 - MIH_LINK_SAP Frame Format

5.4.1.1.MIH_LINK_SAP Header

The MIH_LINK_SAP Header structure is presented in Figure 74.

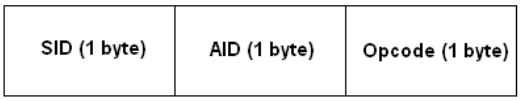


Figure 74 - MIH_LINK_SAP Header Structure

The MIH_LINK_SAP Header fields are presented Table 12.

Field name	Size (bits)	Description
Service Identifier (SID)	8	Identifies the different MIH services, possible values are: 1: Service Management 2: Event Service 3: Command Service 4: Information Service
Operation Code (Opcode)	8	Type of operation to be performed with respect to the SID, possible values are: 1: Request 2: Response 3: Indication
Action Identifier (AID)	8	This indicates the action to be taken with regard to the SID

Table 12 - Description of MIH_LINK_SAP Header fields

5.4.1.2.MIH_LINK_SAP Primitives

When MIHF is connected to LLC via a TCP socket, it can receive three types of events: Link_Up, Link_Down and Link_Going_Down and the MIHF can send Link_Action command to LLC. Table 13 describes the parameters of those primitives.

	Primitive Name	Primitive Parameters
MIH_LINK_SAP Interface	Link_Up.indication	Link Identifier MAC Old Access Router MAC New Access Router IP Renewal Flag Mobility Management Support
	Link_Down.indication	Link Identifier MAC Old Access Router Reason Code
	Link_Going_Down.indication	Link Identifier Time Interval Confidence Level Link Going Down Reason Unique Event Identifier
	Link_Action.request	PoAMACAddress LinkAction ExecutionDelay

Table 13 - MIH_LINK_SAP primitives

- **Link_Up.indication**

This primitive is used by the LLC to notify the MIHF that a layer 2 connection is established on the specified link interface.

- **Link_Down.indication**

This primitive is used by the LLC to notify the MIHF that the layer 2 connection is broken on the specified link.

- **Link_Going_Down.indication**

This primitive is used by the LLC to notify the MIHF that the layer 2 connection is expected to go down within a certain time interval.

- **Link_Action.request**

This primitive is used by the MIHF to request an action on a link layer connection to enable optimal handling of link layer resources for the purpose of handovers. The link layer connection can be ordered, e.g., to shut down, to remain active, to perform a scan, or to come up active and remain in stand-by mode. The command execution delay time can also be specified for cases where the link layer technology under consideration supports the action.

More details about the content of those primitives are available in chapter 11.

5.4.2.MIH_NET_SAP Interface

The interface between the MIHFs (MIH_NET_SAP) using NSIS is described in this section (according to the IEEE 802.21 [5]).

This interface will be implemented via a TCP Socket.

This interface provides the exchange of services (events, commands, management or information) between a pair of MIHFs, which is designed remote information.

MIHF could be used in mobile nodes and also in entities located in the network (ASN-GW or CSN). The MIHFs in MS and network entities communicate with each other using the MIH protocol messages [5]. The MIH protocol allows any peer MIH Function entities to communicate with each other.

The structure of primitives at this interface, based in MIH protocol, is described in Figure 75.

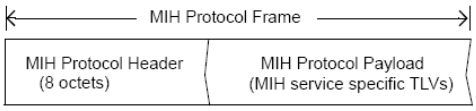


Figure 75 - MIH_NET_SAP Frame Format

5.4.2.1.MIH_NET_SAP Header

The MIH Protocol Header structure is presented in Figure 76.

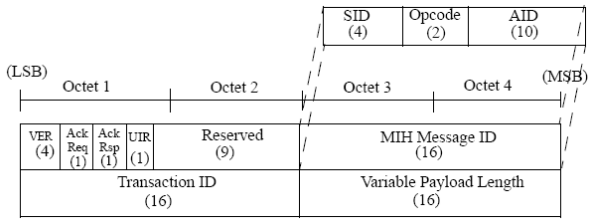


Figure 76 - MIH Protocol Header Structure

The MIH Protocol Header fields are presented in Table 14.

Name	Size (bits)	Description
Version	4	This field is used to specify the version of MIH protocol used. 0: Not to be used 1: First version 2 - 15: (Reserved)
ACK-Req	1	This field is used for requesting an acknowledgement for the message
ACK-Rsp	1	This field is used for responding to the request for an acknowledgement for the message
Unauthenticated Information Request (UIR)	1	This field is used by the MIH Information Service to indicate if the protocol message is sent in pre-authentication/pre-association state so that the length of the response message can be limited
Reserved	9	This field is intentionally kept reserved. When not used, all the bits of this field are to be set to '0'
MIH Message ID (MID)	16	Combination of the following 3 fields
--Service Identifier (SID)	4	Identifies the different MIH services, possible values are: 1: Service Management 2: Event Service 3: Command Service 4: Information Service
--Operation Code (Opcode)	2	Type of operation to be performed with respect to the SID, possible values are: 1: Request 2: Response 3: Indication
-- Action Identifier (AID)	10	This indicates the action to be taken with regard to the SID
Transaction ID	16	This field is used for matching Request and Response, as well as matching Request, Response and Indication to an ACK
Variable Load Length	16	Indicates the total length of the variable load embedded in this MIH protocol frame. The length of the MIH protocol header is NOT included

Table 14 - MIH Protocol Header fields

5.4.2.2.MIH_NET_SAP Primitives

Through this interface will arrive requests for registering and event subscribing by remote MIHFs On other hand this interface has to forward services for remote MIHFs.

Because of this, should be defined the following primitives: MIH_Register (request and response), MIH_Event_Subscribe (request and response), MIH_Get_Information (request and response), MIH_Link_Action, MIH_Link_Up, MIH_Link_Down and, finally, MIH_Link_Going_Down. Table 15 describes the parameters of those primitives.

	Primitive Name	Primitive Parameters
MIH_NET_SAP Interface	MIH_Register.request	Source Identifier Destination Identifier RequestCode
	MIH_Register.response	Source Identifier Destination Identifier ValidTimeInterval Status
	MIH_Event_Subscribe.request	Source Identifier Destination Identifier LinkIdentifier RequestedMihEventList
	MIH_Event_Subscribe.response	Source Identifier Destination Identifier LinkIdentifier ResponseMihEventList Status
	MIH_Link_Up.indication	Source Identifier Destination Identifier LinkIdentifier MacOldAccessRouter MacNewAccessRouter IPRenewalFlag MobilityManagementSupport
	MIH_Link_Down.indication	Source Identifier Destination Identifier LinkIdentifier MacOldAccessRouter Reason Code
	MIH_Link_Going_Down.indication	Source Identifier Destination Identifier LinkIdentifier TimeInterval ConfidenceLevel LinkGoingDownReason UniqueEventIdentifier
	MIH_Get_information.request	Source Identifier Destination Identifier InfoQueryBinaryDataList InfoQueryRDFDataList InfoQueryRDFSchemaURL InfoQueryRDFSchemaList MaxResponseSize
	MIH_Get_information.response	Source Identifier Destination Identifier InfoResponseBinaryDataList InfoResponseRDFDataList InfoResponseRDFSchemaURLList InfoResponseRDFSchemaList Status
	MIH_Link_Action.request	Source Identifier Destination Identifier Link Actions List

Table 15 - MIH_NET_SAP primitives

- **MIH_Register.request**

This message is transmitted to the remote MIHF to perform a registration or pre-registration.

- **MIH_Register.response**

This message is sent in response to a registration or re-registration request.

- **MIH_Event_Subscribe.request**

This message is sent by an MIHF to subscribe to one or more events from a particular MIHF.

- **MIH_Event_Subscribe.response**

This response indicates which of the requested events were successfully subscribed.

- **MIH_Link_Up.indication**

This notification is delivered from an MIHF when a layer 2 connection is up.

- **MIH_Link_Down.indication**

This notification is delivered from an MIHF when a layer 2 connection is down.

- **MIH_Link_Going_Down.indication**

This notification is delivered from an MIHF when a layer 2 connection is expected to go down.

- **MIH_Get_Information.request**

This message is used by an MIHF to retrieve a set of Information Elements provided by the information service.

- **MIH_Get_Information.response**

This is used as a response to the MIH_Get_Information request message. In one response message, one or more results can be returned.

- **MIH_ Link_Action.request**

This message is used to control the behavior of a set of lower link layer.

More details about the content of those primitives are available in chapter 11.

5.4.3.MIH_SAP Interface

The interface between the MIHF and the MIHU (MIH_SAP) is described in this section (according to the IEEE 802.21 [5]).

This interface will be implemented via a TCP Socket.

This SAP defines the media independent interface between the MIHF and MIHUs such as an upper layer mobility protocol or a handover function which might reside at higher layers or a higher layer transport entity as well. It provides the exchange of services (events, commands, information and management) between a MIHUs and its MIHF.

The structure of primitives at this interface is based in MIH protocol, as described for MIH_NET_SAP interface.

5.4.3.1.MIH_SAP Header

The MIH Protocol Header structure was presented in section 5.4.2.1.

5.4.3.2.MIH_SAP Primitives

Through this interface will arrive requests for registering and event subscribing by the MIHUs of a MIHF. On other hand this interface has to forward LLC events for local MIHUs.

Because of this, should be defined the following primitives: MIH_Register (request and confirm), MIH_Event_Subscribe (request and confirm), MIH_Link_Up, MIH_Link_Down and finally, MIH_Link_Going_Down, MIH_Get_Information (request and confirm), MIH_Link_Action. Table 16 describes the parameters of those primitives.

	Primitive Name	Primitive Parameters
IH_SAP Interface	MIH_Register.request	Destination Identifier RequestCode
	MIH_Register.confirm	Source Identifier ValidTimeInterval Status
	MIH_Event_Subscribe.request	Destination Identifier LinkIdentifier RequestedMihEventList
	MIH_Event_Subscribe.confirm	Source Identifier LinkIdentifier ResponseMihEventList Status
	MIH_Link_Up.indication	Source Identifier LinkIdentifier MacOldAccessRouter MacNewAccessRouter IPRenewalFlag MobilityManagementSupport
	MIH_Link_Down.indication	Source Identifier LinkIdentifier MacOldAccessRouter Reason Code
	MIH_Link_Going_Down.indication	Source Identifier LinkIdentifier TimeInterval ConfidenceLevel LinkGoingDownReason UniqueEventIdentifier
	MIH_Get_Information.request	DestinationIdentifier InfoQueryBinaryDataList InfoQueryRDFDataList InfoQueryRDFSchemaURL InfoQueryRDFSchemaList MaxResponseSize
	MIH_Get_Information.confirm	SourceIdentifier InfoResponseBinaryDataList InfoResponseRDFDataList InfoResponseRDFSchemaURL InfoResponseRDFSchemaList Status
	MIH_Link_Action.request	Destination Identifier Link Actions List

Table 16 - MIH_SAP primitives

- **MIH_Register.request**

This primitive is used by an MIHU to register the local MIHF with a remote MIHF.

- **MIH_Register.confirm**

This primitive is used by the local MIHF to convey the result of the registration request to the MIHU.

- **MIH_Event_Subscribe.request**

This primitive is used by an MIHU to subscribe to one or more MIH events from a local or a remote MIHF.

- **MIH_Event_Subscribe.confirm**

This primitive returns the result of an MIH event subscription request.

- **MIH_Link_Up.indication**

This primitive is sent by the MIHF to notify the MIHU that a specific link layer technology is up.

- **MIH_Link_Down.indication**

This primitive is sent by the MIHF to notify the MIHU that a specific link layer technology is down.

- **MIH_Link_Going_Down.indication**

This primitive is sent by the MIHF to notify the MIHU that a specific link layer technology is going to be down.

- **MIH_Get_Information.request**

This primitive is used by an MIH User to request information from an MIH information server. The information query may be related to a specific interface, attributes to the network interface, as well as the entire network capability..

- **MIH_Get_Information.confirm**

This primitive is generated by the MIHF to respond to a MIH_GET_Information.confirm primitive.

- **MIH_Link_Action.request**

This primitive is used by the MIHU to control the behavior of a set of local or remote lower layer links.

More details about the content of those primitives are available in chapter 11.

5.5.Summary

In this chapter the WEIRD's phase 2 architecture was presented. The mobility architecture developed in the WEIRD's framework aims to demonstrate the correct integration between IEEE 802.21 architecture and Mobile IP through WiMAX segments. In the framework of the mobility scenario, a MIHF module was specified and implemented. It provides communication with LLC (lower layers) and MIHUs (upper layers). Furthermore, MIHF will have to communicate with remote MIHFs via NSIS. MIHF provides a set of events,

commands, information and management services that can be subscribed by MIHUs. MIHUs take decisions of handover based on information received from MIHF. All of this provides the seamless handover between networks of the same (HO Horizontal) or different technologies (HO Vertical) being independent of the physical networks.

6.Mobility: Real Experimental Scenarios and Results

In this chapter we will evaluate the WEIRD's (WiMAX Extension to Isolated Research Data networks) phase 2 architecture [5], in which it is included the MIHF (Media Independent Handover Function) described in chapter 5, in a real mobility scenario with the integration of MIPv4 and resource allocation at the WiMAX (Worldwide Interoperability for Microwave Access) equipment. We will also evaluate the signalling of the second phase of the WEIRD project, comparing them with the signalling of the first phase, in the resource allocation at the WiMAX equipment.

Section 6.1 depicts the scenario implemented to evaluate the mobility mechanisms in the second phase of the project and the results obtained with the performed tests, such as, the values for signalling in the resource allocation at this stage of WEIRD project, and the processing times related with MIHF. Section 6.2 presents a scenario to evaluate advanced mobility questions, whereas section 6.3 presents a brief overview of the chapter.

6.1. Mobility Scenario

This section explains the mobility scenario and its three phases. We tested the mobility mechanism, as demonstrated in Figure 77:

- The testbed is composed by the CSN (Connectivity Service Network), the ASN (Access Service Network) and the MS (Mobile Station).
- Under the ASN we have the BS (Base Station) directly connected to the ASN-GW.
- Two SSs (Subscriber Stations) are connected to the BS creating a Point-to-Multipoint (PMP) topology.
- The MS can be connected to SS1 by Ethernet and to SS2 by WiFi.
- The server was located in CSN and the client in the MS.
- Note that the IPs [16] of the different interfaces was defined firstly, like the figure presents.
- Because of the mobility questions related with MIPv4, we can see that was specified the Home Network and the Home Agent, the Foreign Network and the Foreign Agent, and the Mobile Node.

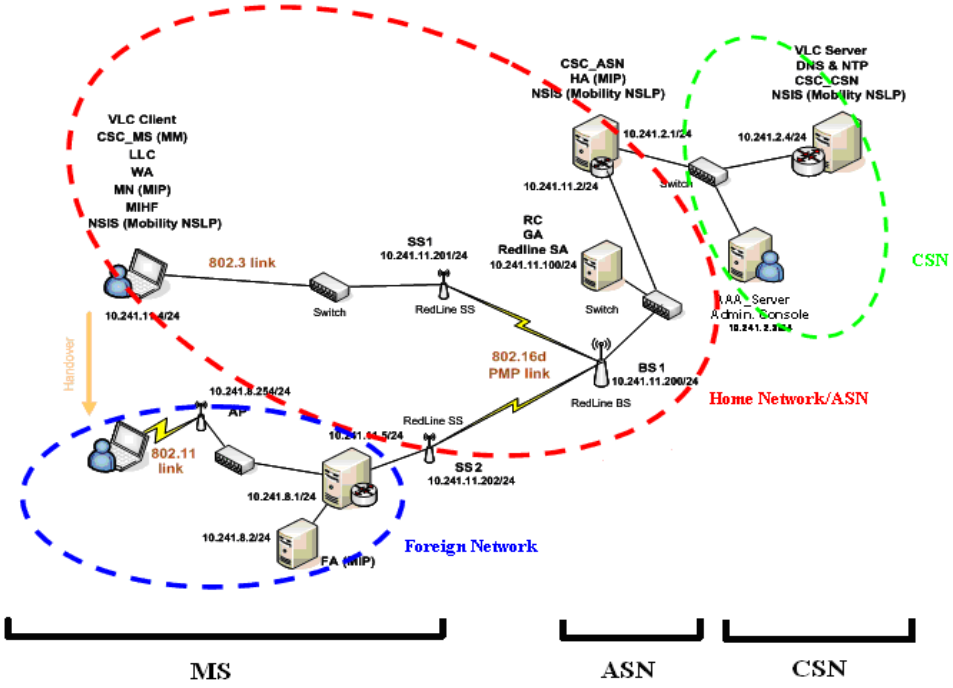


Figure 77 - Mobility Scenario

The goal of this scenario is to demonstrate a handover between Ethernet and WiFi, backhauled by a fixed WiMAX link (802.16d). The main technologies accomplishing this solution are the Mobile IP (MIP) protocol, and the IEEE 802.21 - Media independent Handover standard. While the user is watching a Video received by Ethernet+WiMAX link on the MS, a vertical handover occurs. After this process, the user can continue to watch the Video by the WiFi+WiMAX link, experiencing the same video-quality. The video streaming server has been installed on the same node of the CSC_CSN module to demonstrate that the WEIRD's signalling is still valid in the more general case where the Video Server application is located in the Core Network. WEIRD modules involved in this scenario are described in Table 17.

Module	Description
VLC Client and Server	Application
CSC_MS	Connectivity Server Controller located on the MS
Low Level Controller (LLC)	Monitoring the state of MS Network Interfaces
WEIRD Agent (WA)	Resource Reservation provisioning for Legacy Applications
MIHF	MIH Function (IEEE 802.21)
NSIS (Next Step in Signaling)	NSIS Signalling
Generic and Specific Adapters (for Redline equipment	Service Flow management
Resource Controller (RC)	Control the Resource Reservation on the ASN Gateway
AAA Server	Authentication, Authorization and Accounting
Administration Console	Control Plane Monitoring
CSC_ASN	Connectivity Service Controller located on the ASN Gateway
CSC_CSN	Connectivity Service Controller located on the Core Service Network
MIP Module (Home Agent, Foreign Agent, Mobile Node)	Agent enabling the Mobile IP protocol

Table 17 - WEIRD modules involved

6.1.1.Inter module signalling

With this scenario we want to see an Handover (HO) between Ethernet (SS1 is connected to Ethernet) and WiFi (SS2 is connected to WiFi), running video streaming application, using MIPv4 in a make before break topology. At the first part of the scenario (see Figure 78), the sequence of the events is the following:

- A pre-condition to begin is that both Ethernet and Wifi interfaces of the MS are configured and ready to be used.
- When the Lower Layer Agent (LLA) is started, it detects the status of the network interfaces and sends two Link_Up events to the MIHF.
- MIHF forwards these events to the Mobility Manager (MM) included into CSC_MS, so that the MM can update its internal state machine.
- The user can watch the status of the network interfaces by the LLA GUI.
- The user triggers the Quality of Service (QoS) reservation process between SS1 and BS by using the WA module. The WA GUI shows that the process has been completed successfully, when the WA receives the reply from the CSC_MS.
- The Network Administrator can monitor the control plane status by using the Administration Console: parameters and Service Flow associated to the new NSIS session can be known.
- The user can watch the video from the VLC Client.

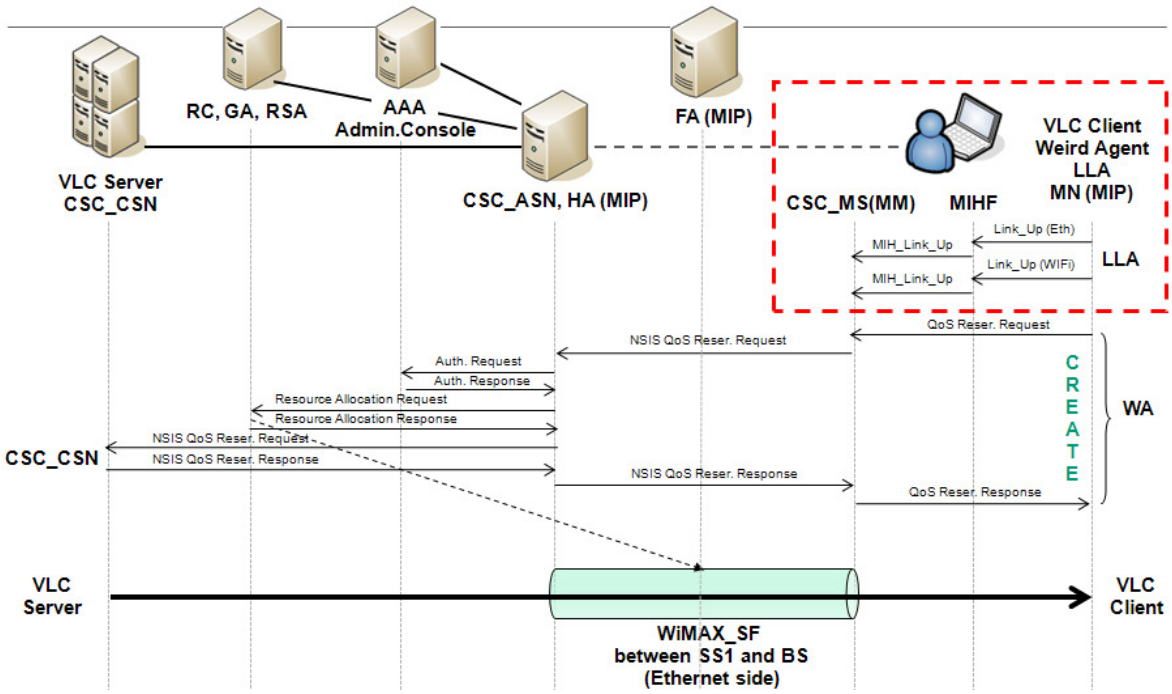


Figure 78 - State 1 – QoS Reservation

At the second part of the scenario (see Figure 79), the sequence of the events is the following:

- The user uses the LLA GUI to notify the network that he/she is going to change the MS position.
- LLA sends the Link_Going_Down event to the MIHF.

- MIHF forwards the received event to the Mobility Manager (MM) included into the CSC_MS.
- MM triggers the handover preparation by sending a HO reservation request through NSIS.
- When the MM receives the HO reservation response, it sends a MIH_Link_Action request the MIHF.
- MIHF forwards this request to the LLA.
- The user can see that the HO preparation process has been completed successfully by the LLA GUI.
- The Network Administrator can monitor the control plane status by using the Administration Console: the Service Flow transporting the data traffic is unchanged.

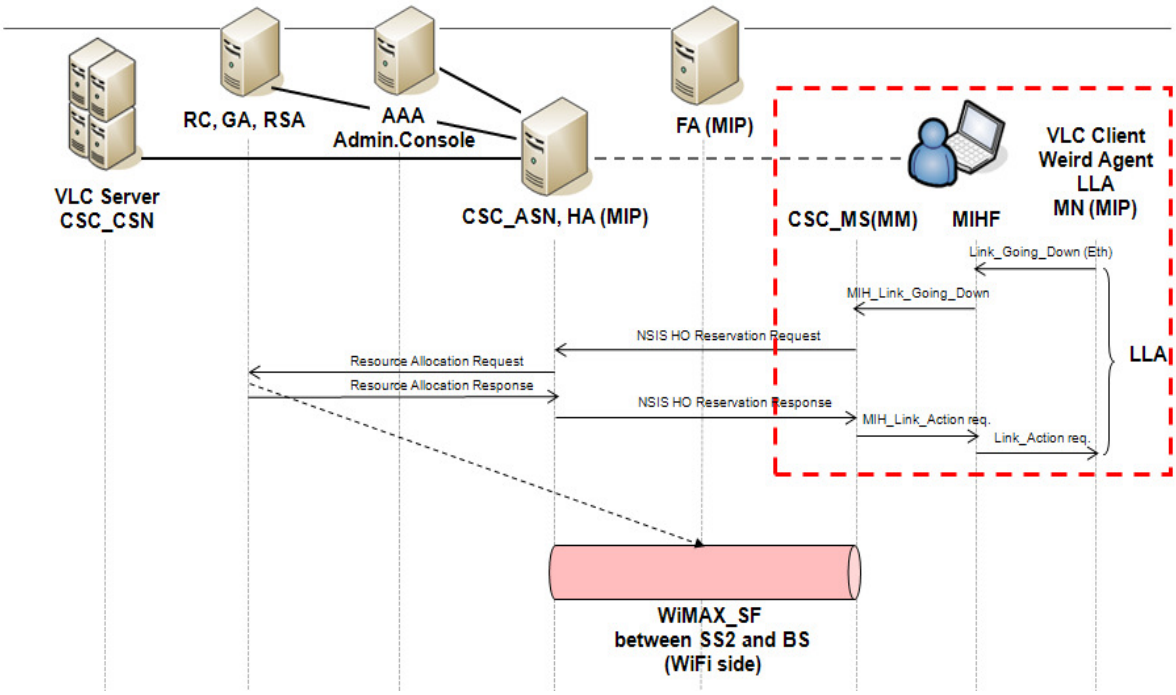


Figure 79 - State 2 – Handover Preparation

At the third part of the scenario (see Figure 80), the sequence of the events is the following:

- The user unplugs the Ethernet cable from the MS.
- MN agent detects that the MS is no more connected to the Home Network and identifies the FA presence in the WiFi network through the received Agent Advertisements.
- MN agent sends the Registration Request (MIP) to the FA which forwards the message to the HA.
- HA updates its internal tables and replies with a registration response (MIP) to the FA which forwards the message to the MN. At the end of these steps an IP over IP tunnel between HA and FA is established.
- LLA detects that the Ethernet cable has been unplugged and sends a Link_Down event to the MIHF.

- MIHF forwards the received event to the Mobility Manager into the CSC_MS.
- MM triggers the deletion of the Service Flows between SS_1 and BS_1 by sending a HO Deletion Request through NSIS.
- The user can watch the new Ethernet interface status by the LLA GUI.
- The Network Administrator can monitor the control plane status by using the Administration Console: parameters and Service Flow associated to the previous NSIS session are now updated.
- The user can watch the video from the VLC Client.

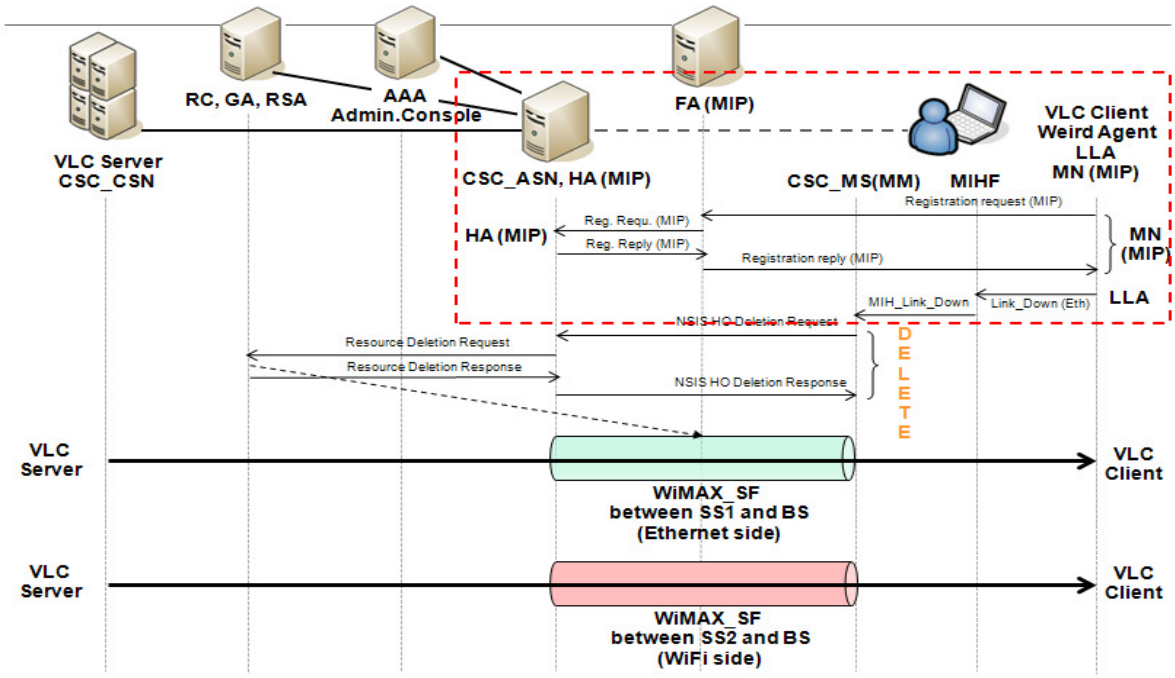


Figure 80 - State 3 – Handover Process

6.1.2.Performed tests

6.1.2.1.Processing times for resource allocation

At this section we will evaluate the processing times for resource allocation at the WiMAX equipment, comparing these values with the results presented in chapter 4. We will use the same scenario and conduct explained at section 4.3.1 for the point-to-point scenario. The main procedure is explained below:

- We sent all the logs produced by the different modules for different files (to optimize the processing times) and we have slightly changed the modules code in order to know when messages were sent or arrived them, using the time functions provided by the languages that were used to develop the software.

- We made 10 followed reservations in the equipment.

- Before we start the request in Weird Agent, we have defined at the RedMAX Equipment a set of service flows in which the traffic will pass. We inserted at BS-SS1 WiMAX link two services flows based on MAC of the PC on the SS1 domain: one uplink and other downlink.

- We are also interested to obtain the processing times for signalling when there is some application traffic filling the WiMAX links. For this we add some VoIP traffic between the MS (located in SS side) and ASN (located in BS side) and perform some requests while this traffic is passing the WiMAX link. The VoIP traffic was generated like depicted in section 3.4.1.2 for the VoIP (without aggregation) case. We started measuring the signalling time without traffic from application, then with 50 VoIP flows flowing through WiMAX channels (both uplink and downlink), then we increased it for 100, 150 and finally to 200.

We didn't use directly the mobility scenario explained at this section because the modules in a mobility scenario are waiting to a correctly order of events, and so, with this scenario we can't perform 10 consecutive requests at the equipment.

So, we opted to use a point-to-point scenario in order to know the time processing in the communication between the different modules. Note that these measures give us also the knowledge of the resource allocation times in the State 1 and State 2 of the mobility scenario, because the modules are the same and the communication between them is also the same.

- In State 1 the resource allocation is done as the same manner that it is in a point-to-point scenario used.

- In State 2 the resource allocation is performed by CSC_MS and not by WA, but the processing time for the NSIS communication between CSC_MS and CSC_ASN and for communication between CSC_ASN and the equipment can be measured with this point-to-point scenario too.

6.1.2.1.1.Results

This section presents the signalling results.

With WEIRD's phase 2 software, the percentage of successful requests made by WEIRD Agent is always 100%. While in phase 1, if the time performed by the request is too high the NSIS generated a time-out and the requests are not routed to the ASN, in phase 2 all the requests were sent to ASN, which give us already a great improvement compared to phase 1.

Figure 81 and Figure 82 show us the processing times for the communication with the equipment to perform the request of the service flow and for Diameter signalling (between CSC_ASN and AAA), respectively. It demonstrates that these two times are approximately constant, even increasing the VoIP flows through WiMAX. Note that while the processing time between the CSC_ASN and the equipment is quite similar to the WEIRD's phase 1

case, the diameter signalling is approximately ten times more slowly compared with the Diameter signalling of the first phase, mainly because of the higher complexity of the AAA in this case.

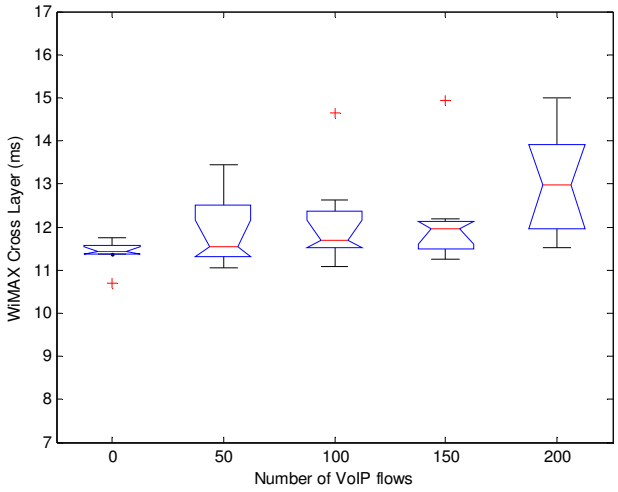


Figure 81 - Processing time between CSC_ASN and the Equipment

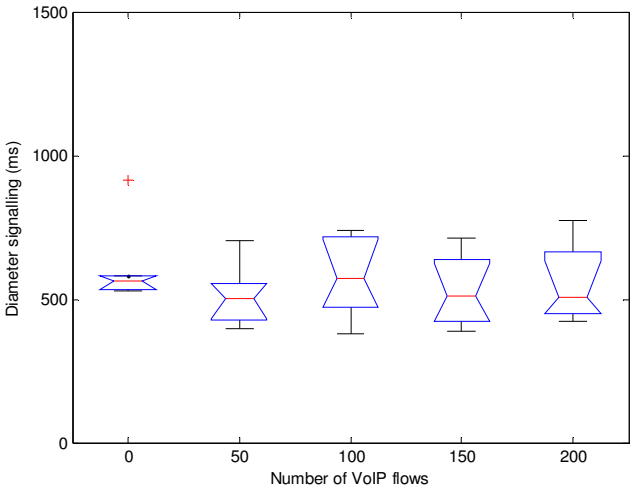


Figure 82 - Diameter Signalling

Figure 83 shows us the time taken by NSIS in the communication between MS->ASN, ASN->CSN and CSN->MS, respectively.

We can conclude that the communication between ASN and CSN is quite constant and presents a small value, mainly because it is done by Ethernet.

Attempting at MS->ASN processing time, we can conclude that it continues to increase when the VoIP traffic begins to increase and saturate the capacity of the WiMAX channel,

but at this time the increasing is slower than for WEIRD's phase 1 case, which give us another great improvement compared to phase 1.

For the NSIS communication between CSN->ASN->MS, the time starts to increase as in the MS->ASN case when the VoIP traffic under WiMAX channel begins to increase. But at this case the values are lower than for MS->ASN communication, because a piece of CSN->ASN->MS communication is done by Ethernet and not by WiMAX link.

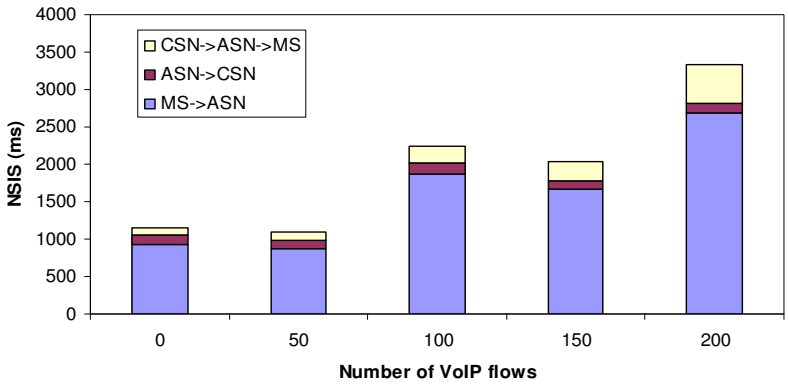


Figure 83 - Processing time by NSIS

As we can see in Figure 84, the processing time by CSCs increase between the different experiments. This demonstrates that its processing is affected by the delay of the signalling between the MS and ASN due of the increasing congestion of the WiMAX channel. Note that the processing time by CSC software is higher than in the first phase due its larger complexity.

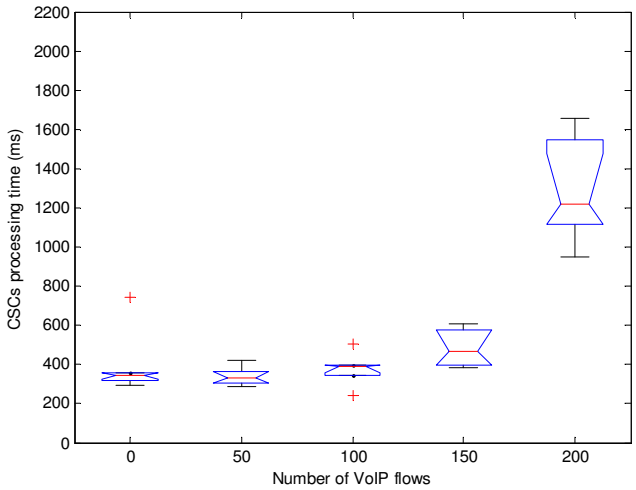


Figure 84 - Processing time by CSC's

Figure 85 demonstrates the end-to-end time processing when we perform a request in WA for resource allocation at the WiMAX link. We can see that he end-to-end time for signalling increases when the VoIP traffic under WiMAX channel begins to increase. Note that the increasing is slower, comparing it with the phase 1 of the project, which give us the idea that the modules were correctly enhanced to obtain more acceptable values in the resource allocation.

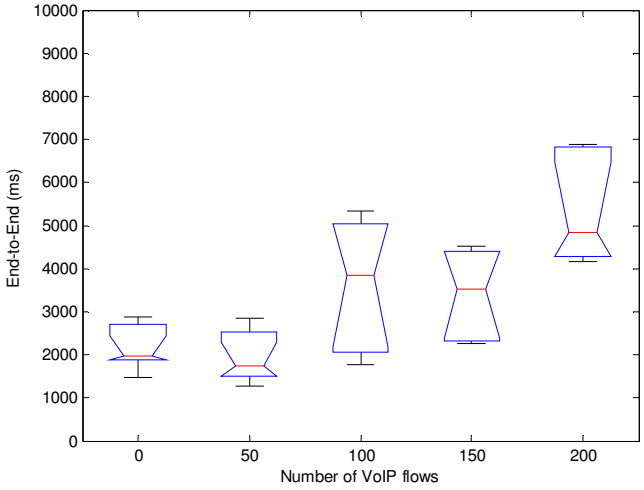


Figure 85 - End- to-End time

6.1.2.2.Processing times for MIHF

At this section we will present the measured times for the MIHF internal processing and communication between all the mobility modules. Figure 86 shows the MIHF processing times at different situations:

- When MIHF_MS does the forward of events sent by LLC, MIHF_MS have a processing time, since it receives the event from its forward, of nearly 210 µs when the forward is done for CSC_MS, or about 310 µs when the forward is done for MIHF_ASN.

- After receiving the Link_Action from CSC_MS, MIHF_MS delays 120 µs to process the message and do the forward of it for LLC.

- When MIHF_ASN receives the MIH messages from MIHF_MS, it has a processing time, since it receives these messages from its forward for CSC_ASN, of nearly 300/400 µs.

This demonstrates the good performance of MIHF, because it is a small processing time.

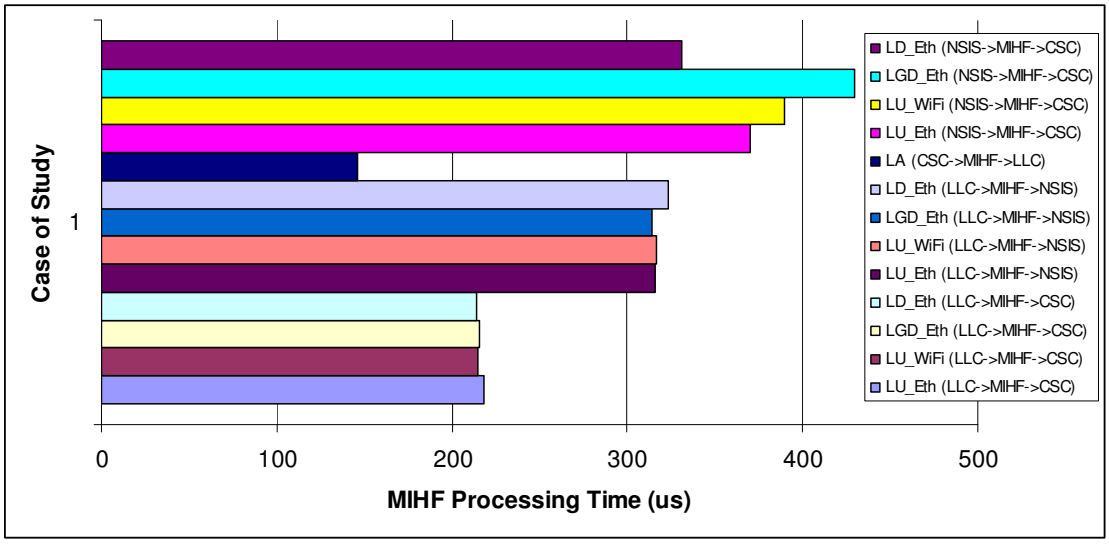


Figure 86 - MIHF processing times at different situations

Figure 87 shows the time left in the MIHF<->CSC communication. We can see that is nearly 750 µs which is good (less than 1 ms).

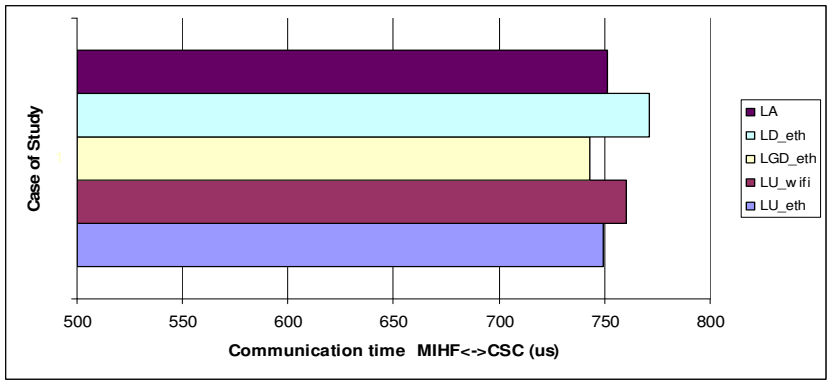


Figure 87 - Time left in the MIHF<->CSC communication

In other hand the time gone in the communication between two MIHFs (see Figure 88) is nearly 110 ms, which is higher than for MIHF<->CSC communication. The main problem is that the communication between MIHF is done by NSIS protocol and it is made through the WiMAX equipment which increases the communication time, unlike the MIHF<->CSC communication which is done through Ethernet cable.

Note that for Link_Down for Ethernet, the time left in MIHF's communication is higher than for others events. The main reason is that the communications between MS and SS2, in the State 3 of the mobility scenario evaluated, is done through WiFi and not by Ethernet, which increases the communication time.

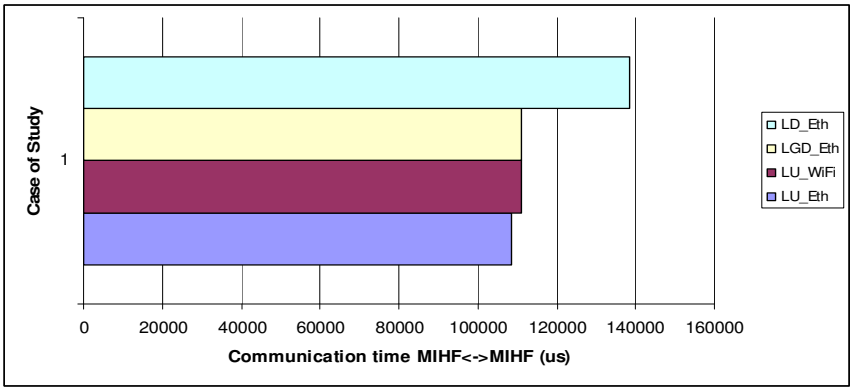


Figure 88 - Time left in the MIHF<->MIHF communication

Note that the handover time provided by MIPv4 software is nearly 5 seconds. This time was measured since we unplugged the Ethernet cable (and the video streaming stopped at Mobile Node) until the video streaming restarted at Mobile Node, using now the wireless interface.

6.2.Mobility Advanced Scenario

With this scenario (see Figure 89) we want to evaluate the inter-base stations mobility, when a Mobile Station (MS) migrates from the air-interface provided by one Base Station (BS-1) to the air interface provided by another Base Station (BS-2).

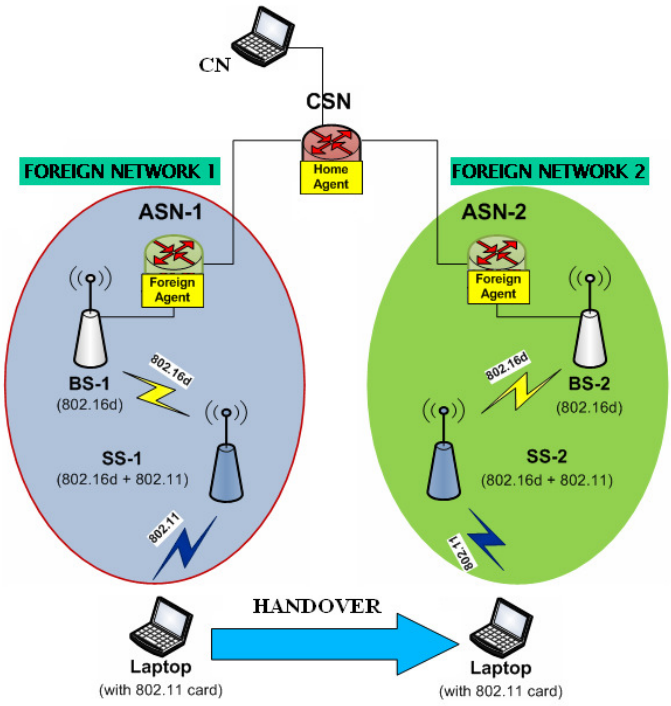


Figure 89 - Mobility Advanced Scenario

For this the MIHF should reside not only in the MS and in the ASN-GW, as before, but also in CSN in order to communicate with the Media Independent Information Service (MIIS) which has the information about the network topology.

Firstly the communication, between the server located on CSN side and the MN client, is done through Foreign Network 1, because the QoS resource allocation is performed through SS-1<->BS-1 domain, even when both WiFi interfaces are up. When the user wants to move, it sends a Link_Going_Down which is forwarded to Mobility Manager located on ASN-1. At this point, ASN-1 wants to know the network topology for the handover preparation. For this, it will send a MIH_Get_Information.request message to MIHF_ASN, which forwards it to MIHF_CSN, through NSIS signalling. MIHF_CSN will forward them to MIIS. Returned to MIHF_CSN, the MIH_Get_Information.response will be sent to the MIHF_ASN. The next step is the communication between CSC_ASN-1 and CSC_ASN-2 in order to allocate the necessary resources in SS-2<->BS-2 domain. After that the user can move to the Foreign Network 2 because all the handover preparation was done correctly.

Attempting at MIPv4 features, this type of handover can be described as the handover from a foreign (visited) network to another foreign (visited) network.

In one hand, the section 6.1 provides a scenario to show an HO transition between 802.3 and 802.11, both connected to a separate 802.16d SS (running a video-streaming application) and both 802.16d SS are connected to the same BS. In the other hand, this mobility advanced scenario shows an HO between two different 802.11 cells, both connected to a separate 802.16d SS, but each 802.16d SS is connected to a different BS and each BS is connected to a separate ASN.

6.3.Summary

In this chapter we described all the processing times for WEIRD's phase 2 architecture.

In the one hand, we conclude that the resource allocation at the WiMAX equipment at this second phase is done in a more properly way, which give us more acceptable values than for first phase of the project.

On the other hand we evaluate the MIHF processing times, which are totally accordingly with the requirements of a mobility architecture: fast to provide a seamless handover to the users.

We also explained a possible scenario to exploit mobility advanced questions, but due to unavailability of the remaining modules, it was not possible to evaluate this scenario in the timeframe of the Thesis.

7.Conclusion

7.1.Final Conclusion

The work presented in this Thesis addressed key aspects of an architecture which is able to bring 802.16 technologies into play for the future next generation networks in compounded wireless environments, to perform end-to-end Quality of Service (QoS) and seamless mobility over heterogeneous networks: WiFi, WiMAX, 3GPP or 3GPP2.

Some of key aspects of the next generation networks were depicted in WEIRD (WiMAX Extension to Isolated Research Data networks) project and have been matter of concern all along the Thesis. In this Thesis, it was specified, developed, implemented and evaluated part of a network architecture with end-to-end QoS and mobility support over IEEE 802.16.

In this Thesis, it was evaluated the support of real-time services, such as VoIP and IPTV, over IEEE 802.16 in different modes of operation for the IEEE 802.16 system: point-to-point and point-to-multipoint. Thus, with the two different modes of operation, several tests with different characteristics were exploited, not only with Best Effort traffic but also establishing different service classes, in order to obtain the real capacities of RedMAX equipment at resource allocation. We concluded that our RedMAX's equipment can sustain C = 50 emulated bidirectional Speex-encoded VoIP calls within the same WiMAX cell and 3 simultaneous emulated IPTV streams with negligible packet loss, adequate application-level throughput, and one way delays within proper bounds. Finally, VoIP aggregation appears to be a powerful method to improve performance and increase capacity utilization in a point-to-point scenario.

This Thesis also evaluated the QoS architecture of the first phase of the WEIRD project in order to control the resource allocation in the WiMAX equipment. This evaluation consisted on the processing times of all modules involved, the end-to-end time required for the establishing of a IEEE 802.16's service flow, and the QoS achieved with the architecture. We concluded that the QoS specification done by the WEIRD software, for a specific application, is established correctly at the equipment. Unlike the point-to-point scenario, which gave us acceptable values for the signalling in the resource allocation at the WiMAX equipment, the point-to-multipoint scenario didn't work in the correct manner in the WEIRD project.

The next phase of the Thesis was the specification and implementation of the central unit of IEEE 802.21 architecture called Media Handover Independent Function (MIHF), which was integrated in the WEIRD mobility architecture. This implementation was the materialization of the research work, in order to obtain seamless mobility support in next generation real environments. Moreover, it was demonstrated the correct functionality and flexibility of MIHF. Several tests were conducted to evaluate the enhancements provided by the mobility-enabled architecture with QoS and resource allocation support. We

concluded that the MIHF processing times in the forward of the messages are totally accordingly to the requirements of a mobility architecture, providing fast processing.

The experiments accomplished along the project confirm expectations relating to the IEEE 802.16 technology in terms of performance, with real-time services and mobility support, and a variety of usage scenarios.

This Thesis shows that it is possible to integrate IEEE 802.16 technologies into new generation networks with seamless handover between different access networks, enabling end users to enjoy an "Always Best Connected" experience. The combination of these capabilities makes IEEE 802.16 attractive for a wide diversity of users and entities, not only for operators and wireless ISPs (Internet Service Provider), but also for many vertical markets and local authorities.

WiMAX is a technology with potential to succeed and it will soon become one of the most powerful wireless technologies in the market due to its several possible applications.

7.2.Future work

As future work, some improvements could be done in MIHF, such as, the implementation of all the messages related to the IEEE 802.21 standard.

Moreover, the advanced mobility scenario developed in this Thesis need to be integrated with the overall architecture to evaluate its performance.

Finally, the MIHF solution should implement the required functionalities to integrate with all possible access technologies, specifying the interfaces of communication between MIHF and lower layers.

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9.Annex 1 – WEIRD phase 1 software installation and configuration

To successfully demonstrate the effectiveness of WEIRD's phase 1 architectural solution in managing WiMAX resources it was developed a testbed.

This section resumes the different steps required to install and configure all the WEIRD's phase 1 software. The software must be described according the different components of the WEIRD architecture, namely, the MS, the ASN, and the CSN.

9.1.Developed Architecture

Figure 36 describes the WEIRD's phase 1 architecture. As we can see, this architecture contains a set of modules (each one described in chapter 4). What is going to do is to test the proper communication between the different modules in order to determine the correct allocation of resources, for example, in a video streaming.

9.2.MS

- **Running NSIS**

For pre-requisites, we have to install sun-java5.0.

First we have to configure the IP for GIST in the nsis/conf/gist.conf file. This interface address corresponds to the IP address where the NSIS must run.

Second we have to configure the local IP address and the network for QoSNSLP by editing the nsis/conf/qosnslp.conf file.

To run this module we have to start the following scripts: nsis/start_gist.sh, nsis/start_qosnslp.sh and, finally, nsis/start_nsisatt.sh, on this order. Note that GSIT must be run as sudo.

Note that GIST and QoSNSLP generate logs, respectively the nsis/logs/gist.log and nsis/logs/qosnslp.logs files.

- **Running CSC_MS**

For pre-requisites, we have to install sun-java5.0 and mysql5.0.

First we have to configure the options in the CSC_MS/csc.conf file. Note that NSIS must be started before the running of CSC_MS and it is running when we start CSC_MS/start_csc_ms.sh.

Note that CSC_MS generates output which can be redirected to a log file.

- **Running Weird Agent**

For pre-requisites, we have to install apache2.0, php5.0 and mysql5.0.

First we have to configure the options in the weird_agent/conf/conf-wa.php file, changing the values of CSC_MS_IP, CSC_MS_PORT and the variables to connect to the database server.

Second we have to create the weird_agent database by running the weird_agent/WA_db.sql script with mysql command, using the user "root" and the password "weird".

Third we have to populate the table with the QoS characteristics of applications by running weird_agent/populateWADB.sql with mysql command.

Next we have to configure apache2.0 to run with PHP support and with an alias to directory where the WA is installed. This can be done at the file /etc/apache2/sites-available/default.

Finally we have start apache2.0, use the web browser and navigate to the URL configured in apache2: http://10.240.2.4/wa/.

Note that CSC_MS must be running before the running of WEIRD Agent.

Note that apache2.0 generates output which can be redirected to a log file.

9.3.CSN

- **Running NSIS**

For pre-requisites, we have to install sun-java5.0.

First we have to configure the IP for GIST in the nsis/conf/gist.conf file. This interface address corresponds to the IP address where the NSIS must run.

Second we have to configure the local IP address and the network for QoSNSLP by editing the nsis/conf/qosnslp.conf file.

To run this module we have to start the following scripts: nsis/start_gist.sh, nsis/start_qosnslp.sh and, finally, nsis/start_nsisatt.sh, on this order. Note that GSIT must be run as sudo.

Note that GIST and QoSNSLP generate logs, respectively the nsis/logs/gist.log and nsis/logs/qosnslp.logs files.

- **Running CSC_CSN**

For pre-requisites, we have to install sun-java5.0 and mysql5.0.

First we have to configure the options in the CSC_CSN/csc.conf file. Note that NSIS must be running before the running of CSC_CSN and it is running when we start CSC_CSN/start_csc_csn.sh.

Note that CSC_CSN generates output which can be redirected to a log file.

- **Running AAA**

For pre-requisites, we have to install sun-java5.0 and mysql5.0.

First we have to configure the AAA with the IP address of the localhost. For this we have to change in AAA/aaa/bin/conf/server_JDiameter.xml the value of the tag "transport_mngt,identity" with the IP address of the localhost.

Second we have to create and populate the users database by running the AAA/aaa/db/UsersDB.sql script with mysql command.

Third we have o configure the AAA to connect to the database. For this is necessary to change in AAA/aaa/bin/conf/AAAConfiguration.xml the values of the tag "db,users", "db,pwd", "db,host" with the username, password and IP address of the databases.

To run this module we have use the following command: java –jar AAAServer.jar in AAA/aaa/bin folder.

Note that AAA generates logs, respectively the AAA/aaa/bin/logs/aaa.log.log and AAA/aaa/bin/logs/aaa_verbose.log files.

9.4.ASN

- **Running NSIS**

For pre-requisites, we have to install sun-java5.0.

First we have to configure the IP for GIST in the nsis/conf/gist.conf file. This interface address corresponds to the IP address where the NSIS must run.

Second we have to configure the local IP address and the network for QoSNSLP by editing the nsis/conf/qosnslp.conf file.

To run this module we have to start the following scripts: nsis/start_gist.sh, nsis/start_qosnslp.sh and, finally, nsis/start_nsisatt.sh, on this order. Note that GSIT must be run as sudo.

Note that GIST and QoSNSLP generate logs, respectively the nsis/logs/gist.log and nsis/logs/qosnslp.logs files.

- **Running CSC_ASN**

For pre-requisites, we have to install sun-java5.0 and mysql5.0.

First we have to configure the file CSC_ASN/conf/client_JDiameter.xml with the IP Address of the AAAServer (CSN) and the AAAAtendant (ASN).

Second we have to change populateDB.sql file accordingly with our network configuration.

Next we have to configure the options in the CSC_ASN/csc.conf file. Note that NSIS must be running before the running of CSC_ASN and it is running when we start CSC_ASN/start_csc_asn.sh.

Note that CSC_CSN generates output which can be redirected to a log file.

- **Running RC**

First we have to open the ASN_GW/RC/WIMAX_topology.cfg file and write the CSC_ASN IPv4 address, as well as the WiMAX network topology (Base Station and Subscriber Stations MAC/IPv4 addresses).

Second we have to compile the RC using the makefile located on folder ASN_GW/RC.

Next we have to just type on a Linux Terminal the following "./rc".

Note that CSC_ASN must be started before the running of RC.

- **Running Generic Adapter**

First we have to compile the Generic Adapter, located on folder Generic_Adapter, using the following command: gcc –o generic_adapter generic_adapter.c -lpthread.

Second we have to check the configurations from "AI.h" and "GASAI.h" files to confirm that the IP and port numbers are correctly set for AI and GASAI interfaces.

Next we have to just type on a Linux Terminal the following: "./generic_adapter".

Note that RC shall be started before the running of Generic Adapter.

- **Running Redline Adapter**

First we have to compile the Redline Adapter using the makefile located on folder ASN_GW/Adapter/Redline_Adapter.

Next we have to just type on a Linux Terminal the following: "./RedlineAdapter GenericAdapterIPAddress".

Note that Generic Adapter must be started before the running of Redline Adapter.

9.5.Important information

All modules of the WEIRD's architecture, necessaries for the testbed running, and described so far, are available by WEIRD project [4] . These folders are: nsis, CSC_MS, weird_agent, CSC_CSN, AAA, CSC_ASN, ASN_GW/RC, Generic_Adapter, ASN_GW/Adapter/Redline_Adapter. If there is a problem with any script, open it and make "set ff = unix".

10.Annex 2 – WEIRD phase 2 software installation and configuration

To successfully demonstrate the mobility mechanisms provided by WEIRD through a restricted mobility scenario including MIH and MIP it was developed a testbed.

This section resumes the different steps required to install and configure all the WEIRD's phase 2 software. The software must be described according the different components of the WEIRD architecture, namely, the MS, the ASN, and the CSN.

10.1.Developed architecture

Figure 54 describes the WEIRD's phase 2 architecture. As we can see, this architecture contains a set of modules (each one described in chapter 5). What is going to do is to test the proper communication between the different modules in order to determine the correct behaviour in a mobility scenario including MIP and MIH.

10.2.MS

- **Running NSIS**

For pre-requisites, we have to install sun-java5.0.

First we have to configure the IP for GIST in the nsis/conf/gist.conf file. This interface address corresponds to the IP address where the NSIS must run.

Second we have to configure the local IP address and the network for QoSNSLP by editing the nsis/conf/qosnslp.conf file.

Next we have to configure the nsis/conf/mihnslp.conf file with the IP addresses of MIHF's and the communication ports.

To run this module we have to start the following scripts: nsis/start_gist.sh, nsis/start_qosnslp.sh, nsis/start_nsisatt.sh, nsis/run_mihnslp.sh, on this order. Note that GIST must be run as sudo.

Note that GIST and QoSNSLP generate logs, respectively the nsis/logs/gist.log and nsis/logs/qosnslp.logs files.

- **Running MIHF**

First we have to open the MIHF/MIHF.cfg file and fill with the neighbour MIHFs, as well as with the LLCs and MIHUs information.

Second we have to compile the MIHF using the makefile located on folder MIHF.

Next we have to just type on a Linux Terminal the following "./main".

Note that NSIS must be started before the running of MIHF.

- **Running CSC_MS**

For pre-requisites, we have to install sun-java5.0 and mysql5.0.

First we have to configure the options in the CSC_MS/csc.conf file. Note that NSIS and MIHF must be started before the running of CSC_MS and it is running when we start CSC_MS/start_csc_ms.sh.

Note that CSC_MS generates output which can be redirected to a log file.

- **Running Weird Agent**

For pre-requisites, we have to install apache2.0, php5.0 and mysql5.0.

First we have to run the script weird_agent/java_server/start_wa.sh after ran CSC_MS.

Second we have to configure the options in the weird_agent/conf/conf-wa.php file, changing the values of CSC_MS_IP, CSC_MS_PORT and the variables to connect to the database server.

Third we have to create the weird_agent database by running the weird_agent/WA2_db.sql script with mysql command, using the user "root" and the password "weird".

Fourth we have to populate the table with qhe QoS characteristics of applications by running weird_agent/populateWADB.sql with mysql command.

Fifth we have to configure apache2.0 to run with PHP support and with an alias to directory where the WA is installed. This can be done at the file /etc/apache2/sites-available/default.

Finally we have start apache2.0, use the web browser and navigate to the URL configured in apache2 : http://10.240.2.4/wa/.

Note that LLA must be running before the running of WEIRD Agent.

Note that apache2.0 generates output which can be redirected to a log file.

- **Running LLC**

For pre-requisites, we have to install sun-java5.0.

The LLC can be configured by setting the parameters into the configuration XML file confParameters.xml in the folder LowLevelAgent/conf.

The steps to be performed are:

1. Configure the parameters related to the Ethernet interface (e.g. IP_Address, MAC_Address).

2. Configure the parameters related to the WiFi interface (e.g. IP_Address, MAC_Address).

3. Configure the parameters related to the Access Routers.

4. Configure the port number used to establish the connection with the MIHF (see tag MIHF_Configuration).

Note that CSC_MS must be started before the running of LLC and it is running when we start LowLevelAgent/start_LowLevelAgent.sh.

- **Running Mobile Node Agent**

Dynamics Mobile IPv4 release includes different files explaining the operations necessary to make working the software. These files can be found in the folder dynamics-0.8.1 and dynamics-0.8.1/doc (e.g. INSTALL, README, Dynamics-HUT-Mobile-IP-HOWTO)

The pre-requisites to install Dynamic MIPv4 are described in the file README into the folder dynamics-0.8.1. They can be classified in: Kernel requirements, Hardware requirements and Software requirements.

Dynamics MIPv4 has been tested in WEIRD by using the Linux release called Ubuntu. This operating system requires the installation of some libraries to compile the software. They are named: libgmp3-dev, libgmp3c2, libc6-dev, texinfo, automake and autoconf.

We have to install the libraries necessary to compile Dynamics MIPv4, compile the software and configure the Mobile Node Agent considering the network configuration. The compilation can be performed by using the following commands:

- ./configure
- make
- make install

from the folder dynamics-0.8.1.

The Mobile Node Agent has to be configured using the tools provided by Dynamics MIPv4. These tools are automatically generated after the compilation of the software into the folders /user/local/sbin (./dynamics-mn-setup) and /user/local/etc (dynmnd.conf).

To make working Dynamics MIPv4 three agents (Home Agent, Foreign Agent and Mobile Node) has to be lauched on three different nodes with the following order: Home Agent (./dynhad) , Foreign Agent (./dynfad) and Mobile Node (./dynmnd). The default folder in which these commands has to be executed is /user/local/sbin.

10.3.CSN

- **Running NSIS**

For pre-requisites, we have to install sun-java5.0.

First we have to configure the IP for GIST in the nsis/conf/gist.conf file. This interface_address corresponds to the IP address where the NSIS must run.

Second we have to configure the local IP address and the network for QoSNSLP by editing the nsis/conf/qosnslp.conf file.

To run this module we have to start the following scripts: nsis/start_gist.sh, nsis/start_qosnslp.sh, nsis/run_mihnslp.sh, on this order. Note that GIST must be run as sudo.

Note that GIST and QoSNSLP generate logs, respectively the nsis/logs/gist.log and nsis/logs/qosnslp.logs files.

- **Running CSC_CSN**

For pre-requisites, we have to install sun-java5.0 and mysql5.0.

The CSC_CSN is located in SVN on folder CSN/CSC_CSN.

First we have to change the nsis.conf file according to the network topology, i.e it should include address and netmask of the MS, ASN and CSN

Second we have to change the createdb.sql and populatedb.sql script according to topology and network configuration

Third we have to change the csc.conf file with the right path of the scripts (createdb.sql and populatedb.sql)

Note that NSIS must be running before the running of CSC_CSN and it is running when we start CSN/CSC_CSN/start_csc_csn.sh.

Note that CSC_CSN generates output which can be redirected to a log file.

- **Running AAA**

For pre-requisites, we have to install sun-java5.0 and mysql5.0.

The AAA is located in SVN on folder AAA.

The AAA database can be created and populated by running the AAA/AAA_DB/create_aaaDB.sql script with a mysql command.

The AAA Server can be configured by setting some parameters into the configuration files having an XML format. These files are included in the folder AAA/conf.

- server_JDiameter.xml – Diameter Server Configuration

1. The IP address of the AAA Server has to be indicated both in the tag "transport_mngt, identity" and in "peer_table, peer1, hostname".

2. The realm related to the AAA Server has to be indicated both in the tag "route_table, route1, realm" and in "route_table, default_route, realm".

- client_JDiameter.xml – Diameter Client Configuration

1. The IP address of the AAA Server has to be indicated both in the tag "transport_mngt, identity" and in "peer_table, peer1, hostname".

2. The realm related to the AAA Server has to be indicated both in the tag "route_table, route1, realm" and in "route_table, default_route, realm".

- relay_RRTable.xml - Relay Agent Configuration

1. The realm related to the foreign AAA Server has to be indicated in the tag "record, realm_name" (e.g. 192.168.4.2, weird2.org)

2. The 'security_id' parameter related to the foreign AAA Server has to be indicated in the tag "record, security_id". The format of this parameter is: 'IP_Address, Port Number, Transport Layer'.

- AAAConfiguration.xml – AAA database connection configuration

1. The AAA Server has to be configured to be connected to the AAA database. The values of the tag "db, users", "db, pwd", "db, host" have to be updated with the username, password and IP address of the AAA database.

Note that AAA is running when we start AAA/start_aaaServer.sh.

AAA generate logs, respectively the aaa/bin/logs/aaa.log and aaa/bin/logs/aaa_verbose.log files.

10.4.ASN

- **Running NSIS**

For pre-requisites, we have to install sun-java5.0.

First we have to configure the IP for GIST in the nsis/conf/gist.conf file. This interface_address corresponds to the IP address where the NSIS must run.

Second we have to configure the local IP address and the network for QoSNSLP by editing the nsis/conf/qosnslp.conf file.

Next we have to configure the nsis/conf/mihnslp.conf file with the IP addresses of MIHF's and the communication ports.

To run this module we have to start the following scripts: nsis/start_gist.sh, nsis/start_qosnslp.sh, nsis/start_nsisatt.sh, nsis/run_mihnslp.sh, on this order. Note that GIST must be run as sudo.

Note that GIST and QoSNSLP generate logs, respectively the nsis/logs/gist.log and nsis/logs/qosnslp.logs files.

- **Running MIHF**

First we have to open the MIHF/MIHF.cfg file and fill with the neighbour MIHFs, as well as with the LLA and MIHU's information.

Second we have to compile the MIHF using the makefile located on folder MIHF.

Next we have to just type on a Linux Terminal the following "./main".

Note that NSIS must be started before the running of MIHF.

- **Running CSC_ASN**

For pre-requisites, we have to install sun-java5.0 and mysql5.0.

First we have to configure the file CSC_ASN/conf/client_JDiameter.xml with the IP Address of the AAAServer (CSN) and the AAAAtendant (ASN).

Second we have to change populateDB.sql file accordingly with our network configuration.

Next we have to configure the options in the CSC_ASN/csc.conf file. Note that NSIS and MIHF must be started before the running of CSC_MS and it is running when we start CSC_ASN/start_csc_asn.sh.

Note that CSC_CSN generates output which can be redirected to a log file.

- **Running RC**

First we have to open the ASN_GW/RC/WIMAX_topology.cfg file and write the CSC_ASN IPv4 address, as well as the WiMAX network topology (Base Station and Subscriber Stations MAC/IPv4 addresses).

Second we have to compile the RC using the makefile located on folder ASN_GW/RC.

Next we have to just type on a Linux Terminal the following "./rc".

Note that CSC_ASN must be started before the running of RC.

- **Running Generic Adapter**

The Generic Adapter is located in SVN on folder ASN_GW/Adapter/ Generic_Adapter/.

First we have to check the configurations from GASAI.h file to confirm that the IP and port numbers are correctly set for GASAI interface.

Second we have to set MAX_VENDOR_ADAPTERS [1/2/3/4] corresponding to the amount of VSAs to be connected to the Generic Adapter..

Next we have to just type on a Linux Terminal the following : ./generic_adapter [rc=0/1] [mih=0/1] [cnms= 0/1] [gasai=0/1].

Note that RC and MIHF must be started before the running of Generic Adapter.

GA will wait until the amount of MAX_VENDOR_ADAPTERS VSAs have sent their GASAI setup messages. After that the GA delivers the GASAI setup acknowledgement message to each VSA.When wanted enable the debug printouts with DEBUG flag.

- **Running Redline Adapter**

The Redline Adapter is located in SVN on folder ASN_GW/Adapter/ Redline_Adapter/.

Next we have to just type on a Linux Terminal the following : ./RedlineAdapter GenericAddr BsAddr TrapReceiverAddr TrapReceiverPort.

Note that Generic Adapter must be started before the running of Redline Adapter.

- **Running Home Agent**

Dynamics Mobile IPv4 release includes different files explaining the operations necessary to make working the software. These files can be found in the folder dynamics-0.8.1 and dynamics-0.8.1/doc (e.g. INSTALL, README, Dynamics-HUT-Mobile-IP-HOWTO)

The pre-requisites to install Dynamic MIPv4 are described in the file README into the folder dynamics-0.8.1. They can be classified in: Kernel requirements, Hardware requirements and Software requirements.

Dynamics MIPv4 has been tested in WEIRD by using the Linux release called Ubuntu. This operating system requires the installation of some libraries to compile the software. They are named: libgmp3-dev, libgmp3c2, libc6-dev, texinfo, automake and autoconf.

We have to install the libraries necessary to compile Dynamics MIPv4, compile the software and configure the Mobile Node Agent considering the network configuration. The compilation can be performed by using the following commands:

- ./configure
- make
- make install

from the folder dynamics-0.8.1.

The Home Agent has to be configured using the tools provided by Dynamics MIPv4. These tools are automatically generated after the compilation of the software into the folders /user/local/sbin (./dynamics-ha-setup) and /user/local/etc (dynhad.conf).

To make working Dynamics MIPv4 three agents (Home Agent, Foreign Agent and Mobile Node) has to be lauched on three different nodes with the following order: Home Agent (./dynhad) , Foreign Agent (./dynfad) and Mobile Node (./dynmnd). The default folder in which these commands has to be executed is /user/local/sbin.

10.5.AP

- **Running Foreign Agent**

Dynamics Mobile IPv4 release includes different files explaining the operations necessary to make working the software. These files can be found in the folder dynamics-0.8.1 and dynamics-0.8.1/doc (e.g. INSTALL, README, Dynamics-HUT-Mobile-IP-HOWTO)

The pre-requisites to install Dynamic MIPv4 are described in the file README into the folder dynamics-0.8.1. They can be classified in: Kernel requirements, Hardware requirements and Software requirements.

Dynamics MIPv4 has been tested in WEIRD by using the Linux release called Ubuntu. This operating system requires the installation of some libraries to compile the software. They are named: libgmp3-dev, libgmp3c2, libc6-dev, texinfo, automake and autoconf.

We have to install the libraries necessary to compile Dynamics MIPv4, compile the software and configure the Mobile Node Agent considering the network configuration. The compilation can be performed by using the following commands:

- ./configure
- make
- make install

from the folder dynamics-0.8.1.

The Home Agent has to be configured using the tools provided by Dynamics MIPv4. These tools are automatically generated after the compilation of the software into the folders /user/local/sbin (./dynamics-fa-setup) and /user/local/etc (dynfad.conf).

To make working Dynamics MIPv4 three agents (Home Agent, Foreign Agent and Mobile Node) has to be lauched on three different nodes with the following order: Home Agent (./dynhad) , Foreign Agent (./dynfad) and Mobile Node (./dynmnd). The default folder in which these commands has to be executed is /user/local/sbin.

10.6.Important information

All modules of the WEIRD architecture, necessaries for the testbed running, and described so far, are available in folders on the server SVN. These folders are: CSC_MS, weird_agent, LowLevelAgent, nsis, MIHF, CSC_ASN, ASN_GW/RC, ASN_GW/Adapter/Generic_Adapter, ASN_GW/Adapter/Redline_Adapter, dynamics-0.8.1. If there is a problem with any script, open it and make “set ff=unix”.

11.Annex 3 – MIHF Implementation

This chapter resumes the detailed information necessary to MIHF implementation.

11.1. Messages sent by LLC

- **Link_Up message**

2:1:3:13:25:19:0:0:0:0:8:0:6:0:23:49:199:143:70:0:0:8:0:6:0:19:96:132:210:48:16:9:8:0:6:0:12:41:39:141:247	
2	(SID: Event service)
1	(MIH_Link_up)
3	(Operation code: Indication)
13	(Link Identifier)
25	(Length of Link Identifier)
Link-ID	
19:0:0:0	(Link type)
0	(Choice Link Address -> MAC address)
8	(Length of Link Address)
0:6	(Mac Address family)
0:23:49:199:143:70	(MAC address of the interface)
Choice	
0	(Choice PoA Address) (if 1 -> no PoA address)
0	(Choice Link Address -> MAC address)
8	(Length of Link Address)
0:6	(Mac Address family)
0:19:96:132:210:48	(MAC address of the PoA)
16	(Mac new Access Router)
9	(Length of Acces router address)
8	(Length of Link Address)
0:6	(Mac Address family)
0:12:41:39:141:247	(Access Router MAC)

Table 18 - LLC Link_Up message

- **Link_Down message**

2:2:3:13:15:19:0:0:0:0:8:0:6:0:23:49:199:143:70:1:20:1:0	
2	(SID: Event service)
2	(MIH_Link_down)
3	(Operation code: Indication)
13	(Link Identifier)
15	(Length of Link Identifier)
19:0:0:0	(Link type)
0	(Choice Link Address -> MAC address)
8	(Length of Link Address)
0:6	(Mac Address family)
0:23:49:199:143:70	(MAC address of the interface)
1	(Choice -> no PoA address in message)
20	(Link down reason code)
1	(Length)
0	(Reason: no resource)

Table 19 - LLC Link_Down message

- **Link_Going_Down**

2:3:3:13:25:19:0:0:0:0:8:0:6:0:23:49:199:143:70:0:0:8:0:6:0:19:96:132:210:48:21:2:50:0:22:1:20:23:1:1:24:2:1:0	
2	(SID: Event service)
3	(MIH_Link_going_down)
3	(Operation code: Indication)
13	(Link Identifier)
25	(Length of Link Identifier)
19:0:0:0	(Link type)
0	(Choice Link Address -> MAC address)
8	(Length of Link Address)
0:6	(Mac Address family)
0:23:49:199:143:70	(MAC address of the interface)
0	(Choice PoA Address) (if 1 -> no PoA address)
0	(Choice Link Address -> MAC address)
8	(Length of Link Address)
0:6	(Mac Address family)
0:19:96:132:210:48	(MAC address of the PoA)
21	(Time interval)
2	(Length)
50:0	(50 in network byte order)
22	(Confidence level)
1	(Length)
20	(Value in percents)
23	(Link going down reason)
1	(Length)
1	(Reason: link parameter degrading)
24	(Unique event identifier)
2	(Length)
1:0	(1 in network byte order)

Table 20 - LLC Link_Going_Down message

11.2.NSIS Mobility NSLP

Figure 90 shows an example of the NSIS usage to transport MIH Messages [5]. It presents the interaction between the MIHF and the NSIS framework and the transport of MIH Messages between a Source and a Destination MIHF. In this scenario, the Middle MIHF also intervenes by receiving the message exchanged due to the intercept NSIS feature.

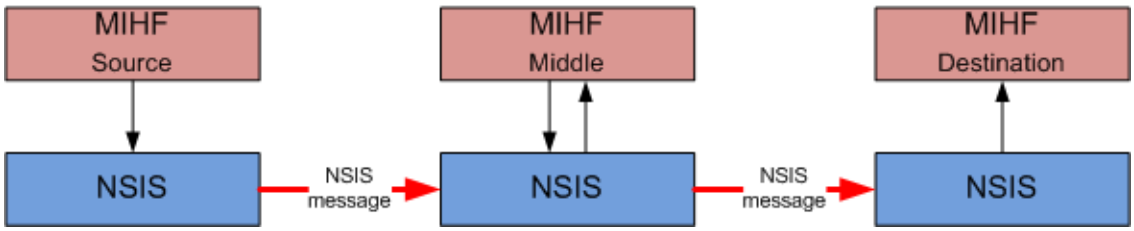

Figure 90 - NSIS usage to transport MIH Messages

To be able to transport the MIH Messages, NSIS requires the destination network address of the MIHF Destination. However, MIH entities only handle MIHF Identifiers (ID) to identify the remote MIHF. Therefore, there is the need to perform the mapping between the MIHF ID and the correspondent network addresses, which is under NSIS responsibility.

One of the MIH NSLP functionalities is to handle the mapping between MIHF ID and network addresses, since GIST is able to provide all the required functionalities required by the MIH specification for MIH Message transport. This functionality is currently being performed through the usage of a configuration file.

Figure 91 shows the procedure to send MIH Messages to the remote MIHF when the remote MIHF IP Address is available, either through the cache mechanisms or resorting to the mapping procedure.

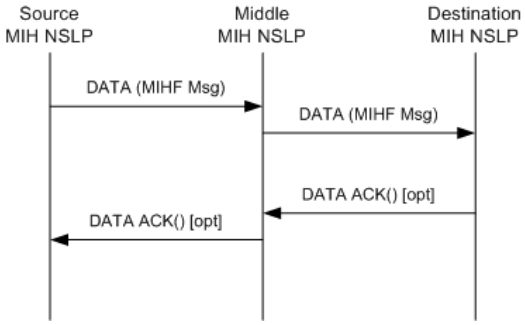

Figure 91 - Message transport between two MIH NSLP

In this figure the MIHF Message needs to be sent from the Source MIH NSLP to the Destination MIH NSLP. To send the MIHF Message, the MIH NSLP creates a MIH NSLP DATA message with the MIHF Message as one of its components.

During the message exchange, the DATA message is intercepted in the Middle MIHF. After the Middle MIHF message processing the MIH NSLP must forward the DATA message to the Destination MIH NSLP.

When a DATA message reaches the destination, the MIHF Message is forwarded to the local MIHF for processing. The MIH Message information is transparent to the MIH NSLP. The MIHF processing is defined in the IEEE 802.21 Draft Standard for Media Independent Handover Services.

Optionally, a DATA ACK message can be sent to the Source MIH NSLP when the DATA message arrives to the Destination MIH NSLP. This feature can be requested by the Source MIH NSLP and should depend on the transfer attributes requested to GIST (reliable and/or secure).

A MIHF response to the received MIH Message is treated as a new request by the MIH NSLP. The MIH NSLP does not handle states for the MIH Messages.

11.3.MIHF Primitives

11.3.1.MIHF_LINK_SAP Interface

- **Link_Up.indication**

Table 21 describes the Link_Up.indication primitive parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
LLC	MIHF	Link Identifier	LINK_TUPLE_ID	Identifier of the link associated with the event
		MAC Old Access Router	MAC_ADDRESS	(Optional) MAC Address of old Access Router
		MAC New Access Router	MAC_ADDRESS	(Optional) MAC Address of new Access Router
		IP Renewal Flag	IP_RENEWAL_FLAG	(Optional) Indicates whether the MN shall change IP Address in the new PoA
		Mobility Management Support	IP_MOBILITY_MGMT	(Optional) Indicates the type of Mobility Management protocol supported by the new PoA

Table 21 - Link_Up.indication primitive parameters

- **Link_Down.indication**

Table 22 describes the Link_Down.indication primitive parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
LLC	MIHF	Link Identifier	LINK_TUPLE_ID	Identifier of the link associated with the event
		MAC Old Access Router	MAC_ADDRESS	(Optional) MAC Address of old Access Router
		Reason Code	LINK_DOWN_REASON	Reason why the link went down

Table 22 - Link_Down.indication primitive parameter

- **Link_Going_Down.indication**

Table 23 describes the Link_Going_Down.indication primitive parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
LLC	MIHF	Link Identifier	LINK_TUPLE_ID	Identifier of the link associated with the event
		Time Interval	UNSIGNED_INT(2)	Time interval (in milliseconds) in which the link is expected to go down. The link connectivity is expected to be available at least for the time specified
		Confidence Level	PERCENTAGE	The confidence level (%) for link to go down within the specified time interval
		Link Going Down Reason	LINK_GOING_DOWN_REASON	The reason why the link is going to be down
		Unique Event Identifier	UNSIGNED_INT(2)	Used to uniquely identify the event. To be used in case of event rollback

Table 23 - Link_Going_Down.indication primitive parameters

- **Link_Action.request**

Table 24 describes the Link_Action.request primitive parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	LLC	PoAMACAddress	MAC_ADDRESS	(Optional) The PoA MAC address is included when the DATA_FORWARDING_REQUEST action is requested
		LinkAction	LINK_ACTION	Specifies the suggested action
		ExecutionDelay	UNSIGNED_INT(2)	Time (in ms) to elapse before the action needs to be taken. A value of 0 indicates that the action shall be taken immediately. Time elapsed shall be calculated from the instance the request arrives until the time when the execution of the action is carried out

Table 24 - Link_Action.request primitive parameters

11.3.2.MIHF_NET_SAP Interface

- **MIH_Register.request**

Table 25 describes the MIH_Register request message parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	**MIHF**	Source Identifier	MIHF_ID	This identifies the local MIHF which is the source of this request
		Destination Identifier	MIHF_ID	This identifies a remote MIHF which will be the destination of this request
		RequestCode	REG_REQUEST_CODE	Registration request code. Depending on the request code, the MIH User can choose to either register or re-register with the local or remote MIHF

Table 25 - MIH_Register.request primitive parameters

- **MIH_Register.response**

Table 26 describes the MIH_Register response message parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	**MIHF**	Source Identifier	MIHF_ID	This identifies the local MIHF which is the source of this response
		Destination Identifier	MIHF_ID	This identifies a remote MIHF which will be the destination of this response
		Valid Time Interval	UNSIGNED_INT(4)	Time interval in seconds during which the registration is valid. Parameter applicable only when the status parameter indicates a successful operation. A value of 0 indicates an infinite validity period.
		Status	STATUS	Status of operation

Table 26 - MIH_Register.response primitive parameters

- **MIH_Event_Subscribe.request**

Table 27 describes the MIH_Event_Subscribe request message parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	**MIHF**	Source Identifier	MIHF_ID	This identifies the local MIHF which is the source of this request
		Destination Identifier	MIHF_ID	This identifies a remote MIHF which will be the destination of this request
		Link Identifier	LINK_TUPLE_ID	Identifier of the link for event subscription. For local event subscription, PoA link address need not be present if the link type lacks such a value
		Requested MIH Event List	MIH_EVENT_LIST	List of MIH events that the endpoint would like to receive indications for, from the Event Source

Table 27 - MIH_Event_Subscribe.request primitive parameters

- **MIH_Event_Subscribe.response**

Table 28 describes the MIH_Event_Subscribe response message parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	**MIHF**	Source Identifier	MIHF_ID	This identifies the local MIHF which is the source of this response
		Destination Identifier	MIHF_ID	This identifies a remote MIHF which will be the destination of this response
		Link Identifier	LINK_TUPLE_ID	Identifier of the link for the event subscription
		Response MIH Event List	MIH_EVENT_LIST	List of MIH events.
		Status	STATUS	Status of the operation.

Table 28 - MIH_Event_Subscribe.response primitive parameters

- **MIH_Link_Up.indication**

Table 29 describes the MIH_Link_Up indication message parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	**MIHF**	Source Identifier	MIHF_ID	This identifies the local MIHF which is the source of this indication
		Destination Identifier	MIHF_ID	This identifies a remote MIHF which will be the destination of this indication.
		Link Identifier	LINK_TUPLE_ID	Identifier of the link associated with the event.
		Mac Old Access Router	MAC_ADDRESS	(Optional) MAC Address of old Access Router
		Mac New Access Router	MAC_ADDRESS	(Optional) MAC Address of new Access Router
		IP Renewal Flag	IP_RENEWAL_FLAG	(Optional) Indicates whether the MN shall change IP Address in the new PoA
		Mobility Management Support	IP_MOBILITY_MGMT	(Optional) Indicates the type of Mobility Management protocol supported by the new PoA

Table 29 - MIH_Link_Up.indication primitive parameters

- **MIH_Link_Down.indication**

Table 30 describes the MIH_Link_Down indication message parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	**MIHF**	Source Identifier	MIHF_ID	This identifies the local MIHF which is the source of this indication
		Destination Identifier	MIHF_ID	This identifies a remote MIHF which will be the destination of this indication
		Link Identifier	LINK_TUPLE_ID	Identifier of the link associated with the event
		Mac Old Access Router	MAC_ADDRESS	(Optional) MAC Address of old Access Router
		Reason Code	LINK_DOWN_REASON_CODE	Reason why the link went down

Table 30 - MIH_Link_Down.indication primitive parameters

- **MIH_Link_Going_Down.indication**

Table 31 describes the MIH_Link_Going_Down indication message parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	**MIHF**	Source Identifier	MIHF_ID	This identifies the local MIHF which is the source of this indication
		Destination Identifier	MIHF_ID	This identifies a remote MIHF which will be the destination of this indication
		Link Identifier	LINK_TUPLE_ID	Identifier of the link associated with the event
		Time Interval	UNSIGNED_INT(2)	Time Interval (in milliseconds) specifies the time interval in which the link is expected to go down. The link connectivity is expected to be available at least for the time specified
		Confidence Level	PERCENTAGE	The confidence level (%) for link to go down within the specified time interval
		Link Going Down Reason	LINK_GOING_DOWN_REASON	The reason why the link is going down
		Unique Event Identifier	UNSIGNED_INT(2)	Used to uniquely identify the event. To be used in case of event rollback

Table 31 - MIH_Link_Going_Down.indication primitive parameters

- **MIH_Get_Information.request**

Table 32 describes the MIH_Get_Information.request message parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	**MIHF**	Source Identifier	MIHF_ID	This identifies the local MIHF which is the source of this indication
		Destination Identifier	MIHF_ID	This identifies a remote MIHF which will be the destination of this indication
		InfoQueryBinaryDataList	LIST(INFO_QUERY_BINARY_DATA)	(Optional) A list of binary queries. The order of the queries in the list identifies the priority of the query. The first query has the highest priority to be processed by MIIS
		InfoQueryRDFDataList	LIST(INFO_QUERY_RDF_DATA)	(Optional) A list of RDF queries. The order of the queries in the list identifies the priority of the query. The first query has the highest priority to be processed by MIIS
		InfoQueryRDFSchemaURL	NULL	(Optional) An RDF Schema URL query
		InfoQueryRDFSchemaList	LIST(INFO_QUERY_RDF_SCHEMA)	(Optional) A list of RDF schema queries. The order of the queries in the list identifies the priority of the query. The first query has the highest priority to be processed by MIIS
		MaxResponseSize	UNSIGNED_INT (2)	(Optional) This field specifies the maximum size of Info Response parameters (i.e., Info Response Binary Data List, Info Response RDF Data List, Info Response RDF Schema URL and Info Response RDF Schema List) in MIH_Get_Information response primitive in octets. If this field is not specified, the maximum size is set to 65,535. The actual maximum size forced by the IS server may be smaller than that specified by the IS client

Table 32 - MIH_Get_Information.request primitive parameters

- **MIH_Get_Information.response**

Table 33 describes the MIH_Get_Information.response message parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	MIHF	Source Identifier	MIHF_ID	This identifies the local MIHF which is the source of this indication
		Destination Identifier	MIHF_ID	This identifies a remote MIHF which will be the destination of this indication.
		InfoResponseBinaryDataList	LIST(INFO_RSP_BINARY_DATA)	(Optional) A list of binary query responses. The list may be sorted from most preferred first to least preferred last
		InfoResponseRDFDataList	LIST(INFO_RSP_RDF_DATA)	(Optional) A list of RDF query responses. The list may be sorted from most preferred first to least preferred last
		InfoResponseRDFSchemaURLList	LIST(INFO_RSP_RDF_URL)	(Optional) A list of RDF Schema URL. The list may be sorted from most preferred first to least preferred last
		InfoResponseRDFSchemaList	LIST(INFO_RSP_RDF_SCHEMA)	(Optional) A list of RDF schema query responses. The list may be sorted from most preferred first to least preferred last
		Status	STATUS	Status of operation.The response lists contains meaningful data if and only if the status is '0'

Table 33 - MIH_Get_Information.response primitive parameters

- **MIH_ Link_Action.request**

Table 34 describes the MIH_Link_Action.request primitive parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	MIHF	Source Identifier	MIHF_ID	This identifies the local MIHF which is the source of this indication
		Destination Identifier	MIHF_ID	This identifies a remote MIHF which will be the destination of this indication
		Link Actions List	LINK_ACTION_REQ	Specifies the suggested actions

Table 34 - MIH_Link_Action.request primitive parameters

11.3.3.MIH_SAP Interface

- **MIH_Register.request**

Table 35 describes the MIH_Register.request primitive parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHU	MIHF	Destination Identifier	MIHF_ID	This identifies the local MIHF or a remote MIHF which will be the destination of this request
		Request Code	REG_REQUEST_CODE	Registration request code. Depending on the request code, the MIH User can choose to either register or re-register with the local or remote MIHF

Table 35 - MIH_Register.request primitive parameters

- **MIH_Register.confirm**

Table 36 describes the MIH_Register.confirm primitive parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	**MIHU**	Source Identifier	MIHF_ID	This identifies the invoker of this primitive which is a remote MIHF
		Valid Time Interval	UNSIGNED_INT(4)	Time interval in seconds during which the registration is valid. Parameter applicable only when the status parameter indicates a successful operation. A value of 0 indicates an infinite validity period
		Status	STATUS	Status of operation

Table 36 - MIH_Register.confirm primitive parameters

- **MIH_Event_Subscribe.request**

Table 37 describes the MIH_Event_Subscribe.request primitive parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MM/GUI	**MIHF**	Destination Identifier	MIHF_ID	This identifies the local MIHF or a remote MIHF which will be the destination of this request
		Link Identifier	LINK_TUPLE_ID	Identifier of the link for event subscription. For local event subscription, PoA link address need not be present if the link type lacks such a value
		Requested MIH Event List	MIH_EVENT_LIST	List of MIH events that the endpoint would like to receive indications for, from the Event Source

Table 37 - MIH_Event_Subscribe.request primitive parameters

- **MIH_Event_Subscribe.confirm**

Table 38 describes the MIH_Event_Subscribe.confirm primitive parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	**MIHU**	Source Identifier	MIHF_ID	This identifies the invoker of this primitive which can be either the local MIHF or a remote MIHF
		Link Identifier	LINK_TUPLE_ID	Identifier of the link for the event subscription
		Response MIH Event List	MIH_EVENT_LIST	List of MIH events
		Status	STATUS	Status of the operation

Table 38 - MIH_Event_Subscribe.confirm primitive parameters

- **MIH_Link_Up.indication**

Table 39 describes the MIH_Link_Up.indication primitive parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	MIHU	Source Identifier	MIHF_ID	This identifies the invoker of this primitive which can be either the local MIHF or a remote MIHF
		Link Identifier	LINK_TUPLE_ID	Identifier of the link associated with the event
		Mac Old Access Router	MAC_ADDRESS	(Optional) MAC Address of old Access Router
		Mac New Access Router	MAC_ADDRESS	(Optional) MAC Address of new Access Router
		IP Renewal Flag	IP_RENEWAL_FLAG	(Optional) Indicates whether the MN shall change IP Address in the new PoA
		Mobility Management Support	IP_MOBILITY_MGMT	(Optional) Indicates the type of Mobility Management protocol supported by the new PoA

Table 39 - MIH_Link_Up.indication primitive parameters

- **MIH_Link_Down.indication**

Table 40 describes the MIH_Link_Down.indication primitive parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	MIHU	Source Identifier	MIHF_ID	This identifies the invoker of this primitive which can be either the local MIHF or a remote MIHF
		Link Identifier	LINK_TUPLE_ID	Identifier of the link associated with the event
		Mac Old Access Router	MAC_ADDRESS	(Optional) MAC Address of old Access Router
		Reason Code	LINK_DOWN_REASON_CODE	Reason why the link went down

Table 40 - MIH_Link_Down.indication primitive parameters

- **MIH_Link_Going_Down.indication**

Table 41 describes the MIH_Link_Going_Down.indication primitive parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	**MIHU**	Source Identifier	MIHF_ID	This identifies the invoker of this primitive which can be either the local MIHF or a remote MIHF
		Link Identifier	LINK_TUPLE_ID	Identifier of the link associated with the event
		Time Interval	UNSIGNED_INT(2)	Time Interval (in milliseconds) specifies the time interval in which the link is expected to go down. The link connectivity is expected to be available at least for the time specified
		Confidence Level	PERCENTAGE	The confidence level (%) for link to go down within the specified time interval
		Link Going Down Reason	LINK_GOING_DOWN_ REASON	The reason why the link is going down
		Unique Event Identifier	UNSIGNED_INT(2)	Used to uniquely identify the event. To be used in case of event rollback

Table 41 - MIH_Link_Going_Down.indication primitive parameters

- **MIH_Get_Information.request**

Table 42 describes the MIH_Get_Information.request message parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHU	**MIHF**	Destination Identifier	MIHF_ID	The local MIHF or a remote MIHF which will be the destination of this request
		InfoQueryBinaryDataList	LIST(INFO_QUERY_BINARY_DATA)	(Optional) A list of binary queries. The order of the queries in the list identifies the priority of the query. The first query has the highest priority to be processed by MIIS
		InfoQueryRDFDataList	LIST(INFO_QUERY_RDF_DATA)	(Optional) A list of RDF queries. The order of the queries in the list identifies the priority of the query. The first query has the highest priority to be processed by MIIS
		InfoQueryRDFSchemaURL	NULL	(Optional) An RDF Schema URL query.
		InfoQueryRDFSchemaList	LIST(INFO_QUERY_RDF_SCHEMA)	(Optional) A list of RDF schema queries. The order of the queries in the list identifies the priority of the query. The first query has the highest priority to be processed by MIIS
		MaxResponseSize	UNSIGNED_INT(2)	(Optional) This field specifies the maximum size of Info Response parameters in MIH_Get_Information response primitive in octets. If this field is not specified, the maximum size is set to 65,535. The actual maximum size forced by the IS server may be smaller than that specified by the IS client

Table 42 - MIH_Get_Information.request primitive parameters

- **MIH_Get_Information.confirm**

Table 43 describes the MIH_Get_Information.confirm message parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHF	MIHU	Source Identifier	MIHF_ID	Shall contain the MIHF ID of the node that invoked MIH_GET_Information.response
		InfoResponseBinaryDataList	LIST(INFO_RSP_BINARY_DATA)	(Optional) A list of binary query responses. The list may be sorted from most preferred first to least preferred last
		InfoResponseRDFDataList	LIST(INFO_RSP_RDF_DATA)	(Optional) A list of RDF query responses. The list may be sorted from most preferred first to least preferred last
		InfoResponseRDFSchemaURLList	LIST(INFO_RSP_RDF_URL)	(Optional) A list of RDF Schema URL. The list may be sorted from most preferred first to least preferred last
		InfoResponseRDFSchemaList	LIST(INFO_RSP_RDF_SCHEMA)	(Optional) A list of RDF schema query responses. The list may be sorted from most preferred first to least preferred last
		Status	STATUS	Status of operation.The response lists contains meaningful data if and only if the status is '0'

Table 43 - MIH_Get_Information.confirm primitive parameters

- **MIH_Link_Action.request**

Table 44 describes the MIH_Link_Action.request primitive parameters.

Source Module	Destination Module	Parameter Name	Parameter Type	Parameter Description
MIHU	MIHF	Destination Identifier	MIHF_ID	This identifies the local MIHF or a remote MIHF which will be the destination of this request
		Link Actions List	LINK_ACTION_REQ	Specifies the suggested actions

Table 44 - MIH_Link_Action.request primitive parameters