Universidade de Aveiro
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Departamento de Electrónica, Telecomunicações e Informática

João Monteiro Soares

Desempenho de Redes de Acesso Heterogéneas com Suporte de Mobilidade

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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 Telecomunicações, realizada sob a orientação científica da Prof. Dra. Susana Sargento, Professora auxiliar do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro e do Prof. Dr. Francisco Fontes, Professor auxiliar convidado do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro.

O júri

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Palavras-chave

Handover, IEEE802.21, IEEE.802.16, IEEE802.11, 3GPP, NS-2, Qualidade de Serviço, Mobilidade, Wi-Fi, WiMAX, UMTS, handovers entre redes heterogéneas.

Resumo

O desenvolvimento crescente da Internet e das tecnologias sem fios levou à necessidade de estarmos sempre ligados, onde quer que estejamos, dentro de casa ou fora, estacionários ou em movimento. O protocolo IEEE 802.21, desenvolvido pelo grupo IEEE, surge como um mecanismo independente da tecnologia de acesso que visa optimizar os processos de handover.

Esta dissertação apresenta mecanismos de mobilidade independentes entre as tecnologias de WiFi, WiMAX e UMTS. São descritos os processos de handover entre as diferentes tecnologias para efectuar mobilidade transparente, e optimização do processo de mobilidade através do suporte de servidores com informação dinâmica da rede.

Posteriormente é analisado o simulador de redes, ferramenta utilizada na avaliação do desempenho dos handovers em redes heterogéneas através dos mecanismos apresentados pelo protocolo IEEE 802.21, e são feitas alterações a estes mesmos mecanismos de forma a optimizar os handovers.

Com a criação de cenários com suporte das diferentes tecnologias de acesso sem fios, foram realizados, testados e analisados handovers entre as diversas tecnologias, com e sem suporte de servidores com informação dinâmica da rede.

Através da análise dos resultados obtidos pode-se constatar que as alterações propostas, em termos da integração do IEEE 802.21 com as diferentes tecnologias e de disponibilização de informação dinâmica na rede, apresentam melhorias significativas no processo, e consequente tempo de handover.

Keywords

Handover, IEEE802.21, IEEE.802.16, IEEE802.11, 3GPP, NS-2, Quality of Service, Mobility, Wi-Fi, WiMAX, UMTS, handovers between heterogeneous networks.

Abstract

The growing development of the Internet and the wireless access technologies lead us to the need of being always connected, wherever we are, at home or outside, stationary or moving. The IEEE 802.21 protocol, developed by the IEEE group, comes up as a mechanism independent from the access technology, with the purpose of improving the handover process.

This thesis presents possible independent mobility mechanisms between WiFi, WiMAX and UMTS technologies. It is described the handover process between the different technologies to have transparent mobility, and the optimization of the mobility process through the support of dynamic information servers.

Later, it is analyzed the network simulator, tool used to evaluate the performance of the handovers between heterogeneous networks through the mechanisms presented in the IEEE 802.21 protocol, and are made modifications to the same mechanisms in order to improve the handovers.

With the creation of scenarios supporting several wireless access technologies, were made, analyzed and tested handovers between the different technologies, with and without the support for servers in the network with dynamic information.

Through the analysis of the obtained results it is possible to see that the modifications presented, regarding the IEEE 802.21 integration with the different technologies and the availability of dynamic information in the network, present significant improvements to the process, and consequent handover time.

Contents

List of Figures

List of Tables

Nomenclature

1G	First Generation
2G	Second Generation
4G	Fourth generation
ACTS	Advanced Communications Technology and Services
AR	Access router
ARQ	Automatic repeat request
ATM	Asynchronous transfer mode
BE	Best Effort
BSA	Basic Service Area
BSS	Basic Service Set
BWA	Broadband Wireless Access
CPS	Common Part Sub-layer
CRNC	Controlling RNC
CS	Convergence Sub-layer
DCH	Dedicated Transport Channel
DL	Downlink
DRNC	Drifting RNC - DRNC
DS	Distribution System
DSCH	Downlink Shared Channel
DSS	Distribution system service
EDGE	Enhaced Data rates for GSM Evolution
ESS	Extended service set
ETSI	European Telecommunications Standards Institute
FACH	Forward link Access Channel
FBA	Fast Binding Acknowledge
FBU	Fast Binding Update

FMIPv6 Fast MIPv6

FMIPv6 Fast MIPv6

FNA Fast Neighbor Advertisement

FRAMES Future Radio Wideband Multiple Access System

GERAN GSM/EDGE Radio Access Network

GPRS General Packet Radio Service

GSM Global System for Mobile communication

HARQ Hybrid Automatic Repeat Request

HAWAII Handoff-Aware Wireless Access Internet Infrastructure

HI Handover Initiated

HiperMAN High Performance Radio Metropolitan Area Network

HMIPv6 Hierarchical MIPv6

HSDPA High Speed Downlink Packet Access

IBSS Independent BSS

IE Information Element

IEEE Institute of Electrical and Electronics Engineers

IETF Internet Engineering Task Force

IP Internet Protocol

Iur Internal interface

LMA Local Mobility Anchor

LOS Line-of-sight

MAG Mobile Access Gateway

MAP Mobile Application Part

MAP Mobility Anchor Point

MBMS Multimedia Broadcast Service

ME Mobile Equipment

MICS Media Independent Command Service

MIES Media Independent Event Service

MIH Media Independent Handover

MIHF MIH Function

MIIS Media Independent Information Service

MIMO multiple-input and multiple-output

MIP Mobile IP

MIPv4 MIP version 4

MIPv6	MIP version 6
MN	Mobile Node
MS	Mobile station
NAR	New Access Router
ND	Node
NLOS	Non-line-of sight
nrtPS	Non-Real-Time Polling Services
OFDM	Orthogonal Frequency-Division Multiplexing
OSI	Open Systems Interconnection
PAN	Personal Area Network
PAR	Previous Access Router
PMIP	Proxy Mobile IP
PMP	Point to multi-point
PoA	Point of Attachment
PoS	Point of Service
QoS	Quality of Service
RACH	Random Access Channel
RNC	Radio Network Controller
RNS	Radio Network Subsystem
RSNA	Robust security network association
rtPS	Real-Time Polling Services
SAP	Service Access Point
SDU	Service Data Unit
SMS	Short Message Service
SRNC	Serving RNC
SS	Station Service
SS	Subscriber station
STA	Station
TCP	Transmission Control Protocol
TDMA	Time division multiple access
UE	User equipment
UGS	Unsolicited Grant Services
UL	Uplink
USIM	UMTS Service Identity Module

UTRAN UMTS Terrestrial Access Network

WAN Wide Area Network

WCDMA Wideband Code Division Multiple Access

Chapter 1

Introduction

1.1 Motivation

Over the last decades, the telecommunications area has been one of the most or maybe the most growing area.

In the last years we have witnessed a huge grow of this area, particularly in the wireless technologies. Since the beginning of the twentieth century, when the wireless telephone was issued, this area never stopped developing. After the invention of wireless cells for telephones around 1950 until the discover of the wireless cells that provide the exchange of data packets was just a small step.

Nowadays we have available several types of wireless technologies with different attributes and main purposes, but all of them with a common purpose, the capability to provide connection to the user whether this connection is a phone or Internet connection. The common user can choose which tecnology suits best his purposes according to: his location, the purpose of the connection, his access permissions, or even its device capability.

A few years ago, the companies and schools were the main market for this kind of technologies, however today not only these but also the common user has developed a hunger of being always connected. We can be whether at home connected to a Wi-Fi network, go out to the street and connect to a 3G, GPRS or GSM network and most recently to a WiMAX network which is a technology that is seeing increased adoption rates lately. Whatever is the technology which gives the user the access, it doesn't matter since it provides its needs. Of course, there are costs associated to the technologies and to the operator to which the network belongs, but mainly the user wants:

- Permanent Internet access (which includes of course Mobility)
- Real-time access
- High speed rates
- Low costs

The market today provides devices with several wireless interfaces, such as laptops or pdas, allowing the user to connect to almost any wireless technology in current use. There is a need of having a media independent mobility mechanism to take advantage of the capability of these multi-interface devices considering always the different requirements of each user: more broadband (e.g. to watch a high quality video) or more mobility (e.g. avoid being offline or change to a better network).

The IEEE 802.21 working group started developing in March 2004 a mobility optimization framework, independent from the access network or technology. After several companies joined this group and eight drafts, the first standard was released in January of 2009, IEEE 802.21-2008.

This recent release will provide mechanisms that allow seamless handovers, whether horizontal handovers (between networks of the same technology) or vertical handovers (networks of different technologies). This standard provides information allowing mobility to and from cellular GSM, GPRS, Wi-Fi, Bluetooth, 802.11 and 802.16 networks through different handover mechanisms. Despite the

IEEE 802.21 (draft 14) provides only the interaction between itself and some access technologies, the interaction can probably be extended to other technologies, through the analysis of their standards.

1.2 Objectives

The aim of this thesis is to evaluate the performance of different acess technologies using the IEEE 802.21 mobility optimization protocol. We also intend to evaluate the mobility performance for each technology presented. The study of the technologies focused on the aspects of mobility with the support of multimedia services with different types of requirements and experiencing several types of handover. In order to perform these evaluations, it was used the simulator NS-2 (nework simulator 2). Furthermore, the simulator and will be introduced with more detail as well as the work evolving it.

Summarizing, an analysis of mobility features with Quality of Service (QoS) in UMTS, WiMAX and Wi-Fi networks was made based on measures such as jitter, packet delay, handover preparation time and handover latency. We also present a new upgrade to the IEEE 802.21 standard, with the purpose of making the handover process more efficient.

1.3 Organization of the Thesis / Document Outline

The present thesis is organized as follows:

- Chapter 2 provides a short overview on the wireless technologies in study (UMTS, Wi-Fi, WiMAX), as well as on some mobility mechanisms with special emphasis on IEEE 802.21.
- Chapter 3 provides a more detailed description on the IEEE 802.21 protocol. This chapter also presents a solution for the procedures that are necessary to support IEEE 802.21 functionality from and to UMTS, Wi-Fi and WiMAX networks. It are also presented some changes to the current standard, that we consider to be an improvement of the handover process.
- Chapter 4 provides a brief description of the simulator used to obtain the handover results, describes which features it already had for this purpose, as well as detailed information about the implementation done to improve it.
- Chapter 5 shows the scenarios studied and the discussions on the measured results obtained for the several handover processes.
- Chapter 6 presents the conclusions of this work, as well as the improvements that could be done to the implementation in the future.

Chapter 2

Background

As we know, there has been a growth of the wireless solutions to provide any type of service. In this chapter, technologies such as Wi-Fi, WiMAX and UMTS will be first described. After, mobility mechanisms regarding MIP will be briefly described. For last, the recent IEEE 802.21 protocol for the optimization of handovers will be presented. This chapter also presents a brief summary in its end.

2.1 Broadband Wireless Technologies

The need for wireless data transmission became a reality in the final decades of the twentieth century. After the installation of fixed Internet networks in several places all over the globe and its large expansion, the need for wireless access became more important, and with no surprise today it is deployed worldwide.

Common users need whatever the market has to offer them, and as techologies evolve, better services are provided. Today, having high bandwidth is an essential requirement for any user. Video on Demand (VOD), peer-to-peer sharing, tele-working and high definition TV (HDTV) are just an example of services that need these high bandwidths.

Since the 1970s many wireless technologies had large utilization, being GSM (Global System for Mobile communication) the most successful until now. GSM is a technology mainly used for voice transmission in addition to low-speed data transmission such as the Short Message Service (SMS). Evolutions of the GSM were developed, such as GPRS (General Packet Radio Service) and EDGE (Enhanced Data rates for GSM Evolution) with the purpose to facilitate relatively high-speed data communication in GSM-based networks.

In addition to GSM, third-generation (3G) cellular systems, originally European and Japanese UMTS (Universal Mobile Telecommunication System) technology and originally American cdma2000 technology are already deployed and are promising wireless communication systems. Cellular systems must cover wide areas, sometimes as large as countries. The use of wireless access networks is another approach. These networks were initially proposed for Local Area Networks (LANs) but can also be used for Wide Area Networks (WAN).

Nowadays there is a large number of different types of wireless data networks available, and others under design. These technologies can be classified according to a network scale:

- Personal Area Network (PAN) - Ex: Bluetooth (IEEE 802.15.1)
- Local Area Network (LAN) - Ex: Wi-Fi (IEEE 802.11 and variants)
- Metropolitan Area Network (MAN) - Ex: WiMAX (IEEE 802.16-2004 version)
- Wide Area Network (WAN) - Ex: Cellular networks (second and third generation), WiMAX (IEEE 802.16e version)

Wireless technologies can also be categorized into those requiring line-of-sight (LOS) and those that can operate in non-line-of-sight (NLOS) conditions. The technologies evaluated here can operate in both categories, having however a better performance with LOS. Those technologies are:

- Wi-Fi
- WiMAX
- UMTS

2.1.1 IEEE

The Institute of Electrical and Electronics Engineers (IEEE) is an international non profit organization for the advancement of technology. Being a leading developer of international standards in a broad-range of industries, including Telecommunications, and Information Technologies, the standardization efforts for the local area data networks started in 1979 in the IEEE. In the beginning of the 80s the IEEE 802 working group (or committee) was founded, dedicated to the definition of IEEE standards for LANs and MANs. The protocols and services specified in IEEE 802 map to the lower layers (Data Link and Physical) of the Open Systems Interconnection (OSI) networking reference model.

Several subcommittees of IEEE 802 have since then been created.

2.1.2 IEEE 802.11

IEEE 802.11 is a set of standards carrying out WLAN communication. In the year of 1997, the 802.11 working group released its first standard (IEEE 802.11-1997). After two years of clarification and review of this first standard, a new standard was defined, IEEE 802.11a-1999. While the first standard allows to operate at a rate of 1 or 2 Mbps over the unlicensed 2.4GHz, the second one can achieve data rates up to 54Mbps at a frequency of 5GHz.

After this first versions of the IEEE 802.11 others came out such as: IEEE 802.11b operating at bit rates up to 11Mbps at the 2.4GHz band; IEEE 802.11g operating also at the 2.4GHz but being able to achieve up to 54Mbps as the IEEE 802.11a-1999. Both the 802.11a and g in order to achieve their high bit rates use the Orthogonal Frequency-Division Multiplexing (OFDM) technique . The use of these frequencies is a big advantage because it allows transmitters to achieve ranges of 30 meters indoor and up to 450 meters outdoor and still, operate at low power.

Recently, the IEEE 802.11 working group has been working on a new specification called the IEEE 802.11n. This version is expected to get rates up to 300Mbps by introducing multiple antennas at both the transmitter and receiver (MIMO - multiple-input and multiple-output).[8]

When the IEEE 802.11 technology entered the market, it raised many problems. Products from different vendors could not work together, and this situation was a major problem for the consumers. Regarding this situation, the Wi-Fi Alliance was created, which is a global non-profit industry association of hundreds of leading companies devoted to the proliferation of Wi-Fi technology across devices and market segments. With technology development, market building, and regulatory programs, the Wi-Fi Alliance has enabled widespread adoption of Wi-Fi worldwide.[9] Products based on the IEEE 802.11 standards are commonly known as Wi-Fi (trademark of the Wi-Fi Alliance) devices.

The IEEE 802.11 architecture consists of several components that interact to provide a WLAN that supports station (STA) mobility trasparently to upper layers:

- Basic Service Set (BSS) - is the basic building block of an IEEE 802.11 LAN
- Basic Service Area (BSA) - coverage area within which the STAs of a BSS may remain in communication.
- Independent BSS (IBSS) - the most basic type of IEEE 802.11 LAN. It can consist of only two STAs, when they are able to communicate directly. Since this type of connection is often formed without pre-planning and used only as long as it is necessary, it is often refered to as an ad hoc network.
- Distribution System (DS) - architectural component used to interconnect BSSs. Instead of existing independently, a BSS may also form a component of an extended form of network that is built with multiple BSSs. The DS enables mobile device support by providing the logical

services necessary to handle address to destination mapping and seamless integration of multiple BSSs.

- Extended service set (ESS) - union of BSSs connected by a DS. The ESS does not include the DS.

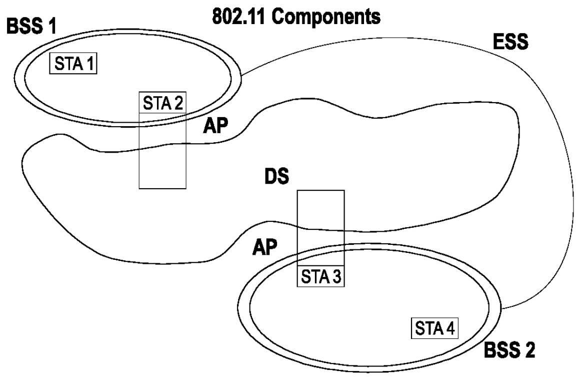

Figure 2.1: ESS[1]

- Robust security network association (RSNA) - defines a number of security features in addition to wired equivalent privacy (WEP) and IEEE 802.11 authentication.

There are two categories of IEEE 802.11 services: the station service (SS), which is the service provided by the stations (STAs), and the distribution system service (DSS), provided by the DS.

As to mobility, the Wi-Fi technology is limited mainly because of its range. Of course, Wi-Fi is very good for mobility, but in small areas. Technologies as WiMAX and UMTS are more suitable to mobility, as it is possible to see through figure 2.2.

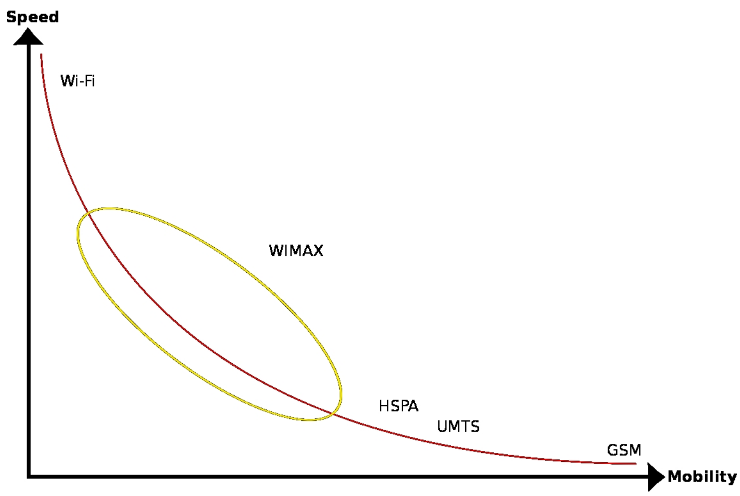

Figure 2.2: Speed vs. Mobility of wireless systems

The standard defines three types of transitions describing the mobility of STAs within a network:

- No-transition - contemplates two subclasses that are usually indistinguishable:
  - Static - no motion
  - Local movement - movement within the PHY range of the communicating STAs. In other words, the STA moves only within a BSA.

- BSS-transition - STA movement from one BSS in one ESS to another BSS within the same ESS.

- ESS-transition - STA movement from on BSS in one ESS to a BSS in another different ESS. Maintenance of upper-layer connections cannot be guaranteed by IEEE Std 802.11, in fact, disruption of service is likely to occur.[1]

2.1.3 IEEE 802.16

IEEE 802.16 is the working group of IEEE 802 dedicated to Broadband Wireless Access (BWA). Compared to the WLAN Wi-Fi, WiMAX networks have a much greater range. The working group was created in 1999 and divided into two working groups:

- 802.16a - This technology will be used by WiMAX with a center frequency within the interval 2-11 GHz.

- 802.16 - With a frequency value interval of 10.66 GHz.

The IEEE 802.16 BWA has two variants:

- IEEE 802.16-2004 - defines a fixed wireless access WMAN technology

- IEEE 802.16e-2005 - an amendment of 802.16-2004, which included mobility and fast handover, then becoming a Wireless WAN.

As stated in 802.16-2004, this standard revises and consolidate the previous ones: 802.16-2001, 802.16a-2003 and 802.16c-2002. Before getting to 802.16d-2004, a revision called 802.16d was started in 2003 with the objective of taking into account the European Telecommunications Standards Institute (ETSI) HiperMAN (High Performance Radio Metropolitan Area Network) BWA standard. This project was concluded later with the approval of the 802.16-2004 standard.

802.16-2004 was very useful, replacing a set of documents which described different parts of the same technology, with different modification directions. However, after being published, there was still the need of an upgrade, mainly for the inclusion of mobility features and also because other futures were needed and some errors had to be corrected. Under this requirements, with no surprise, the 802.16e was published in February 2006. However, this document is not a standalone document, it only proposes changes and additions to the 802.16-2004.[10]

2.1.3.1 MAC

IEEE 802.16 MAC, has a network topology of point to multi-point (PMP), with support for mesh network topology. It can work over either ATM (asynchronous transfer mode) or packet-based protocols, such as IP.

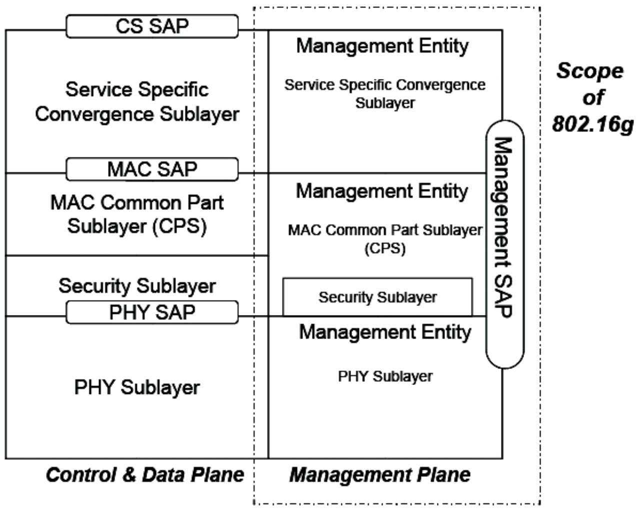

Figure 2.3: 802.16 reference model[2]

As it is possible to see through the above figure, there are three sub-layers in the MAC:

- Service Specific Convergence Sub-layer (CS) - entity that provides any transform action or mapping of external network data through CS SAP (CS service access point).
- MAC Common Part Sub-layer (MAC CPS) - classifies external network service data units (SDUs) and associates these SDUs to the proper MAC service flow and Connection Identifier (CID).
- Security Sub-layer - entity that supports authentication, secure key exchange, and encryption.

Unlike the typical MACs in the IEEE 802, the IEEE 802.16 MAC is connection oriented and similar to time division multiple access (TDMA). When a subscriber station (SS) enters the network, one ore more connections to the BS are created, performing also link adaptation and automatic repeat request (ARQ) functions to maintain the target bit error rate. Bandwidth is granted to SSs on demand since the BS controls the access to the medium. The BS schedules the uplink, and downlink grants to meet the negotiated QoS requirements at the beginning of each frame.

IEEE 802.16e MAC defines four types of service, providing QoS differentiation for different types of applications:

- Unsolicited Grant Services (UGS) - for constant bit rate (CBR) services, such as VoIP without silence suppression.
- Real-Time Polling Services (rtPS) - for real-time services that generate variable size of data packets on a periodic basis, such as MPEG video and VoIP with silence suppression.
- Non-Real-Time Polling Services (nrtPS) - for non-real-time service that require variable size data grant burst types on a regular basis.
- Best Effort Services (BE) - for typical data traffic such as Internet web browsing and FTP file transfer.

In order to re-distribute the granted capacity to all its connections, an SS scheduler must be implemented with each SS MAC. Note that the scheduling algorithms are specified by the manufacturers and not by the IEEE 802.16. The 802.16 MAC has a radio link control (RLC), similar to the concept cellular layer-2/3, to control PHY transition from one burst profile to another, in addition to traditional power control and ranging.

To suport mobility in Mobile WiMAX, IEEE 802.16e specifies a MAC layer handover procedure, while the exact handover decision algorithm is not specifically defined. There are two possible situations for the handover to happen: when the mobile station (MS) moves and needs (due signal fading, interference, etc) to change from the BS that is currently connected to another, in order to provide a better signal quality; when a another BS can provide higher QoS to the MS.

The process of handover in the IEEE 802.16e is devided into two phases:

- Network Topology Acquisition

  This process is achieved in three steps:

  - Network topology advertisement - a BS broadcasts information regarding the network topology, which might be obtained from the backbone.
  - MS scanning the neighboring BSs - BS can allocate time intervals to the MS (scanning interval). Once a BS is identified through the scanning, the MS may attempt to synchronize with its downlink transmission and estimate the quality of the physical channel. The serving BS may buffer the incoming data during the scanning interval until the exit of the scanning mode.
  - Association - it is an optional procedure during the scanning interval with respect to one of the neighboring BSs. It enables the MS to acquire and to record ranging parameters and service availability information for the purpose selection of the handover target.

- MS migration

  Migration from the air-interface provided by one BS to another. This process has five steps:

  - Cell re-selection - MS can use neighboring BS information or schedule scanning intervals to scan/range, in order to evaluate MS interests in handover to neighboring BS.
  - Handover decision and initiation - the MS or the serving BS originate the decision of processing the handover.
  - Synchronization to target BS downlink - the MS sychronizes to downlink transmissions of the target BS to obtain downlink (DL) and uplink (UL) transmission parameters. If the target BS has already received a handover notification from the serving BS through the backbone, the target BS can allocate a non-contention-based initial ranging opportunity.
  - Ranging - the target BS can get information from the serving BS through the backbone network. The MS and target BS will conduct either initial ranging or handover ranging to set up the correct communication parameters.
  - Termination of MS context - to terminate service at serving BS. The MS can terminate the handover any time prior to termination.

IEEE 802.16e-2005 supports both TDD and FDD, but in its early release TDD was the mode of operation mainly because it enables dynamic allocation of DL and UL radio resources to support asymmetric DL/UL traffic as it is common in Internet applications; DL and UL are in the same frequency channel, which provide better channel reciprocity and better support to link adaptation. MIMO techniques, and closedloop advanced antenna technique; a single frequency in DL and UL can provide more flexibility for spectrum allocation.

One of the features in Mobile WiMAX is the ranging, in which the MS acquires frequency, time and power ajustments, so that all MS transmissions can align the UL sub-frame received by the BS. This process starts with the MS transmistting a signal to the BS, and the BS responding with the required adjustments, which is a closed loop control process critical to OFDMA comunications in Mobile WiMAX. This operation happens for inital and handoff ranging, periodic ranging, and BW request ranging.[11]

2.1.4 UMTS

2.1.4.1 The "G's"

Nowadays, as far as it concerns to mobile cell communications, there are three generations, and a fourth one coming soon. The first one (1G), refers to the analogue and semi-analogue mobile networks established in the mid-1980s, offering basic services for users with emphasis on the speech and speech-related services. The 1G was developed with a national scope, being the main technical requirements agreed between the governmental telecommunication operator and the domestic industry. Due to this "local" agreements, there were no wider publications of the specifications, and so, we can say that each country was free to create its own specific 1G network. This "freedom" brought incompatibility between networks. However this was just the beginning.

With an increased need of mobile communications and its standardization, the second generation (2G) appeared. Compatibility and international transparency was the emphasis of the 2G, allowing the users to access it almost everywhere within the region. Besides the service provided by the 1G (speech service), these networks were also able to provide some data services and with it extra services. The globalization issue was not completely overcome due to the regional nature of standardization, and so there is not only one second generation network, however we can say the most famous and successful one is the GSM.

The so called 3G, is the expected generation to complete the globalization process of mobile communication. The 3G is based on GSM technical solutions, mainly because the GSM at the time already dominated the market and by using it, a bigger investment was being avoided. This generation adds to the previous services provided by the 1G and 2G greater mobility, multimedia services and all its components, and it separates the technology platform from the services using the platform. 3G has developed to a level where traditional telecommunication and Internet Protocol (IP) technologies are combined in the same package, and is still developing. The concept of a global mobile communication system creates a lot of political desires, and so, the term 3G has regional synonyms as in Europe, UMTS.

Specifications for a fourth generation (4G) have already started, however it is still hard to define where the 3G ends and the 4G starts. We can only say that the 4G will be a more sophisticated system bringing more capacity and services to the users. [12]

2.1.4.2 Standardization process/Specification process

UMTS came up as a development of the GSM, and as so, inherited several of its elements and functional principles. One of the most considerable developments is related to the radio access part of the network, where UMTS brings into the system an advanced wideband type of radio access implemented using Wideband Code Division Multiple Access (WCDMA).

Before a worldwide standardization came up, several pre-standardization research projects were founded. It started between 1992 and 1995 when a modeling technique describing the function allocation between the radio access and core parts of the network was developed in order to compare mobility management solutions such as Intelligent Network (IN) and GSM Mobile Application Part (MAP). Apart from this, discussions on the broadband versus the narrowband ISDN, and ATM versus B-ISDN as fixed transmission techniques were other issues discussed in this very first phase of the UMTS, named the MoNet project. Advanced Communications Technology and Services (ACTS) Future Radio Wideband Multiple Access System (FRAMES) was the next project to be in force between 1995 and 1998, used mainly to select and develop a multiple access technology. TDMA and CDMA were the two technology considered: in Europe TMDA because it was also used by GSM, and the CDMA in US due to its early utilization in defense applications. During the 1998, it was decided that WCDMA would be the European and Japanese UMTS radio technology. In this same year, Europe and Japan decided to make a common UMTS standard, and after, the 3GPP organization was established and the determined UMTS standardization was started worldwide.

There are three main specification releases since the UMTS standardization started, the 3GPP Release 99, R4 and R5. In R99 the basis for the UMTS Terrestrial Access Network (UTRAN) is WCDMA radio access, while in the R4 and R5 is the EDGE, integrated in order to create the GSM/EDGE Radio Access Network (GERAN) as an alternative to building a UMTS mobile network.

This thesis was done based on the 3GPP Release 99, the current implementation of the UMTS technology.[12]

2.1.4.3 UTRAN

The UTRAN model is divided into subsystems, called Radio Network Subsystems (RNSs), that connect to each other over the access network internal interface (Iur). This interface provides not only macro diversity, but also an efficient radio resource management and mobility mechanisms. Each RNS is composed by two elements, the Node B (usually called Base Station) which is the radio element; and the Radio Network Controller (RNC), being this one responsible for the control.

The RNC can have three kinds of roles during radio connection: a serving role (Serving RNC - SRNC), that is responsible for the radio connection between the User Equipment (UE) and the UTRAN, and maintaining the Iu interface to the CN; a drifting role (Drifting RNC - DRNC), which has a logical role used when radio resources of the connection between the UTRAN and the UE need to use cells controlled by another RNC rather than the SRNC; and a controlling role (Controlling RNC - CRNC), having overall control of the logical resources of the access points.

It is also relevant to mention that the UE, that is the 3G system terminal, is separated into two parts: the Mobile Equipment (ME) and the UMTS Service Identity Module (USIM). USIM is an application that stores user subscriber information, authentication information and also provides storage space for extra information.

Regarding to the the 3G network itself, from the protocol structure and its responsibility point of view, the network is separated into two parts: the access stratum* that is responsible for the protocols between the UE and the access network, while the non-access stratum is responsible for the protocols between UE and the core network (packet switched - PS - domain and circuit switch - CS - domain).[12]
[1]

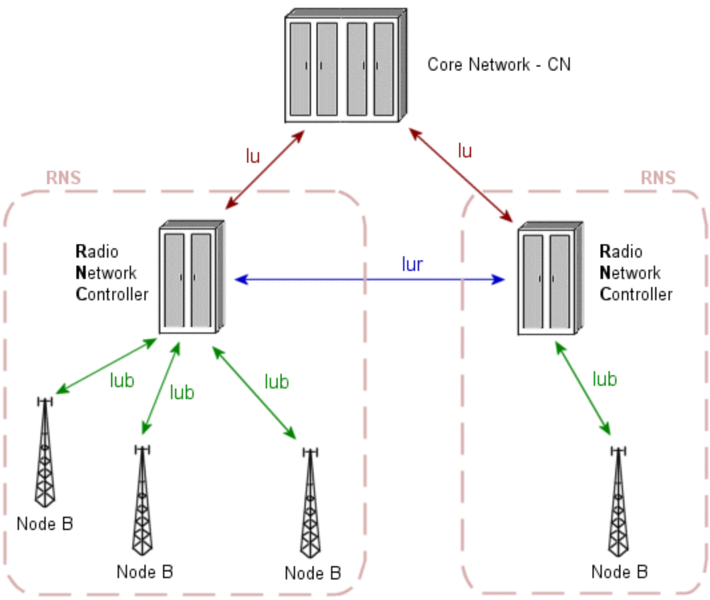

Figure 2.4: UTRAN architecture

In its early definition, UMTS was mainly thought of in terms of dedicated channel system, based on the 384-Kb/s max DCH (Dedicated Transport Channel). UMTS standard proposed other possibilities for shared channel transmission on FACH (Forward link Access Channel) or on the DSCH (Downlink Shared Channel). However these possibilities are limited. FACH was never intended for high bit rate, due to the lack of an efficient power control sheme and also because of the limitation of the uplink

[1] *stratum-way of grouping protocols related to one aspect of the services provided by one or several domains.

RACH (Random Access Channel, used in combination with the FACH). DSCH was never developed as a commercial solution due to its high complexity and the lack of real performance improvement.

Higher bit rate transmission on shared channel or shared group physical resources was introduced in UTRAN by HSDPA (High Speed Downlink Packet Access). From a radio interface perspective, HSDPA is based on a shared radio scheme and real time (every 2ms) evaluation as well as allocation of radio resources, allowing the system to quickly react to data bursts. It also implements a HARQ (Hybrid Automatic Repeat Request) which is a fast packet retransmission scheme located in NodeB as close as possible to the radio interface, allowing a faster adaptation to a change in radio transmission characteristics. HSDPA still relies on an associated dedicated channel used in downlink for power control commands. A dedicated physical channel is also present in uplink to carry HARQ indications and channel quality information. In practice, all three transmission schemes often co-exist with the same cell, set of cells, or geographical area. For circuit-based services requiring constant delay and bandwidth, transmission on DCH will still be applicable until HSDPA allows cost-efficient guaranteed bit rate solution. In addition, for low bit rate packet data service or MBMS (Multimedia Broadcast Service), transmission over the FACH will still be applied.[3]

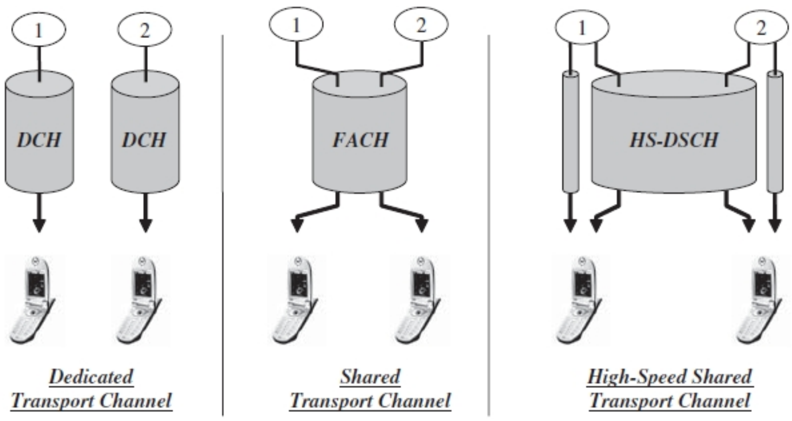

Figure 2.5: UTRAN Transport channels[3]

The data packets that are exchanged over transport channels (ex. DCH) are called transport blocks. A transport block comprises a certain quantity of data and several transport blocks of the same size can be transferred simultaneously per transport channel. This group of transport blocks is called a Transport Block Set (TBS). Transmission Time Interval (TTI) is the time by which a TBS must be transmitted , that can vary in length for each transport channel but must always be a multiple of the frame length 10ms. The size of the individual blocks and the number of blocks contained in a TBS is described by a Transport Format (TF). Precisely, the TF specifies what should happen with the TBS in the physical layer, however the transport channel does not allocate any TF: for each TBS the MAC layer can select a transport format from a group that is allocated to the transport channel, calling it Transport Format Set (TFS). TFS depends on the requested application, since it specifies in which the physical parameters of a connection are permitted to change. For example, a service that requires a constant data rate can only contain a single TF in the TFS, while a service with a variable data rate can have the possiblity of choosing from different TFs, being able to adpat the parameters of the physical layer quickly to the current data rate.

Different TFs that are used by different transport channels at a particular point in time are not compatible, because the available resources are limited. When there is an application that transmits data over a transport channel is guaranteed a high maximum data rate through the acceptance of a particular TF into the associated TFS. This same guarantee cannot be given for this same point in time to a second application that is using another transport channel. Regarding this situation, Transport Format Combinations (TFCs) were introduced. A TFC specifies, for example, that if having three transport channel and one requires 80% of the resources at a particular time, the other two channels can only jointly use a maximum of the 20% left. To clearly understand this part, see figure 2.6. [13]

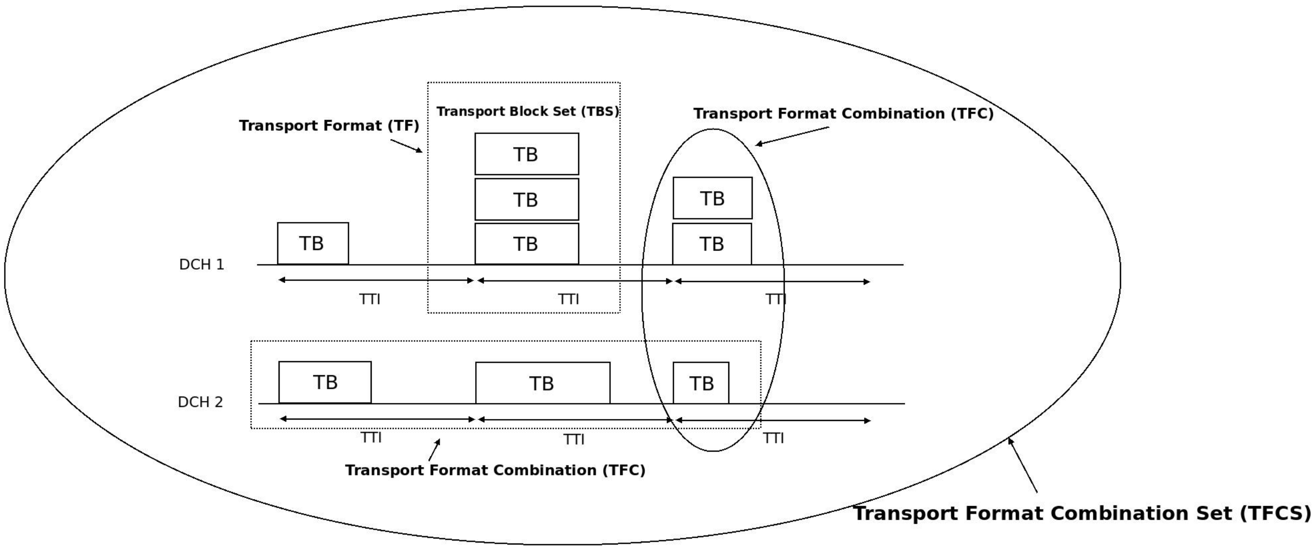

Figure 2.6: UMTS data transport over DCH channels

2.2 Mobility

A simple example of a mobility scenario is when a user is moving from one BS to a neighbor BS from the same operator. Therefore, for the two BSs, the same billing system and costumer care is applied. In this case, when a user is moving from one cell to a neighboring one it has to interrupt the session and start it again. This is considered nomadicity rather than mobility.

When we refer to mobility, we are referring to full mobility, when the user can move from one cell to another without breaking the session, whether this is a data session, a voice communication, or any other type of session. Sometimes mobility can me mistaken with portability, which is a user capability to move from one place to another, without concerning the user session. Mobility is portability, but it also concerns the user session, allowing the user to keep its session up while moving.

Early networks technologies assumed that the terminals would always be connected to their home network. With this concept in mind, the Internet infrastructure was built over certain protocols, such as the Transmission Control Protocol (TCP) and Internet Protocol (IP). IP requires the location of any terminal connected to the Internet to be identified by an unique IP address, and so, whenever there is a transaction to a new network, it is required a reconfiguration of the IP address and gateway based on the terminals current location which leads to a loss of connection.

It is critical that the support of mobility becomes available, since the next generation networks will provide an heterogeneous environment. The concept of stationary device is becoming outdated, mobile computing is widespread today and it requires constant network connectivity.

Today's technologies, like IEEE 802.11 and IEEE 802.16 support mobility at a link-layer level, allowing the user to move inside a subnet maintaining its IP address, though the problem of changing network continues. On the other hand, 3G networks such as UMTS are a bit more advanced in the matter of mobility, allowing the user to maintain connection while changing cells. The mobility in this case is specific to the access technology.

2.2.1 Mobile IP

Due to the need to introduce mobility in IP networks, Mobile IP (MIP) was the first presented mechanism to do so. MIP is a standard communication protocol designed to allow mobile devices to move from one network to another while maintaining a permanent IP address. It can also be applied for different types of transactions, between different administrative domains or changing the access technology. Despite solving the mobility issue to current IP networks, it misses several features to solve all the requirements of future all-IP networks. Therefore it was necessary to split this issue into two: macro-mobility and micro-mobility. The first one refers to the management of users moving between wide wireless access networks normally using Mobile IP, while the second is more focused on efficient local mobility within particular networks or domains. Since scalability and efficiency are two issues to take into account, several micro-mobility protocols were developed, such as Fast MIP, Cellular IP, HAWAII (Handoff-Aware Wireless Access Internet Infrastructure) and Hierarchical MIP. Still it is necessary to maintain a connection between global and local connection, therefore micro-mobility protocols are integrated in the MIP protocol.

2.2.1.1 MIPv4 and MIPv6

The original MIP protocol was named MIPv4, and with the development of the IPv6, it was created an upgrade of it, MIPv6. MIPv4 allows the Mobile Node (MN), to be reachable in every visited network, being able to use two distinguish global IP addresses: the home address, which is used by other hosts to communicate with the MN, and a different address given when the MN is visiting a foreign network. The purpose of the MIP protocol is to redirect the packets received in the home network to the one where the MN is visiting.

MIPv6, despite being an upgrade of MIPv4 and therefore based on the same principles, it has a better performance due to the features of the IPv6 protocol (it is no longer necessary a foreign agent), and also because it is no longer necessary for the packets to always pass trough the home network.

2.2.1.2 Fast MIPv6

This protocol is an extension to the MIPv6, with the aim of reducing the number of packets lost during a handover. FMIPv6 allows the MN to use its previous Care of Address while it is registering on the Care of Address of the new access network, and by doing it, the signaling delay also decreases. This is done by establishing a tunnel between the old and new access routers, allowing the MN to send or receive packets as if it was connected to its old access point, while in the meantime it is finishing the handover signaling with its new access point. The protocol is structured into three phases: handover initiation, tunnel establishment and packet forwarding. It is possible to have no lost packets, however, there will always be a loss of connectivity with the network.

Most of the existing protocols allow a MN to be connected to more than one link at the same time, which gives a better performance to the FMIPv6 by avoiding link layer disruption during handovers.

2.2.1.3 Hierarchical MIPv6

Hierarchical MIPv6 (HMIPv6) is another extension to the MIPv6 protocol with the purpose of locating the management of the handoffs which reduce the amount of signaling. At the same time, it also improves the MIPv6 performance in terms of handoff speed.

When a MN needs to connect with a new access point, the MN registers its care of address at a Mobility Anchor Point (MAP) which acts as a local home agent and is usually located near the current position of the MN, allowing a fast registration. This procedure benefits the MN with decrease of the signaling messages because it only needs to signal the MAP instead of the home agent and all correspondent nodes.

This protocol can also be seen as a complement to the FMIPv6 and it is also a good approach to handle mobility across heterogeneous access technologies and it is well suited to implement access control.

2.2.1.4 Local Mobility (netlmm - PMIPv6)

In the recent years new mobility protocols have been worked by the Internet Engineering Task Force (IETF) such as the Proxy Mobile IP (PMIP).

Movement between access routers (ARs) has three problems when using global mobility protocols: update latency, when the anchor point or CN is distant from the MN's access network; signaling overhead, that may negatively impact wireless bandwidth usage and real-time service performance; and location privacy, caused by the temporary change of the local address while the MN moves. Regarding the problems in these situations, it is preferable to use local mobility protocols that besides correcting the mentioned problems, can also provide a measure of local control, so mobility management can be tuned for specialized local conditions.

The PMIP, also called Network-based mobility management is a local mobility protocol. It provides similar functionality to MIP, however in PMIP the mobility is taken care of by the network without requiring the MN to be involved in the exchange of signaling messages between itself and the home agent. In this case, the signaling with the home agent and the mobility management is done by a specific agent, the proxy mobility agent. However, when the mobility involves different network interfaces, the host needs modifications similar to Mobile IP in order to maintain the same IP address across different interfaces.

Two entities are defined in the infrastructure of the PMIP:

- Local Mobility Anchor (LMA) - responsible for MN's reachability state, and is the topological anchor point for the MN's home network prefix(es).
- Mobile Access Gateway (MAG) - entity that performs the mobility management on behalf of the MN residing on the access link where the MN is anchored, responsible for detecting the MN's movements from and to the access link, and for initiating binding registrations to the MN's local mobility anchor.

When using PMIP, the mobile host enters the network, the MAG on that link ckecks the host authorization and the mobile host obtains an IP address. Then the MAG updates the LMA about the current location of the host and finally, both MAG and LMA create a bi-directional tunnel.

The PMIPv6 is being adopted as part of several wide-area wireless networks (e.g.: 3GPP, WiMAX) and local networks environments.

Note that when local mobility management is provided it is not strictly required that a MN supports global mobility management protocol. However, without global mobility the MN has a disruption in its traffic when moving beyond the border of the localized mobility management domain.[14]

2.3 IEEE 802.21

2.3.1 Scope

The large access technologies to the Internet, particularly the wireless ones, such as Wi-Fi, WiMAX, 3GPP LTE/UMTS, is becoming a regular option to all Internet users. The IEEE 802.21 (Media Independent Handover Services) standard has the purpose to optimize and facilitate both intra and inter-technology handovers, including wired and wireless technologies.

This standard allows mobile users to perform seamless handover whenever the network environment supports it. The IEEE 802.21 covers not only 802 access technologies such as Wi-Fi and WiMAX but also non 802 networks, as 3GPP LTE/UMTS by providing link layer intelligence and other related network information to upper layers.

2.3.2 Support

IEEE 802.21 tends to improve the users experience, whether the user is stationary or mobile. Handovers for mobile users can occur when there is a change in the wireless conditions (loosing signal and weak signal while moving, crowded network, better network detected), while on the other hand, handovers for stationary users can occur due to network surrounding environment changes, making one network preferential to another.

The standard supports another very important aspect, the user requirements. If a user is running an application which requires for example a higher data rate than the one available on the current link, there can be a link adaptation to provide the higher rate, or a handover can be initiated if the rate can not be provided by the current link. One of the most important aspects of this standard, is the capability to ensure the continuity of the connection so that the user, for example in a phone call, does not "feel" any interruption in the connection.

Cooperative use of both mobile terminals and network infrastructure is another aspect of the IEEE 802.21 standard. While the mobile terminal location allows it to detect available networks, the good position of the network infrastructure enables it to store overall network information, such as neighborhood cell lists, location of mobile devices and higher level service availability. Summarizing, both the mobile terminal and the network make decisions about connectivity. The support of multiple radio standards and simultaneously support of connections on more than one radio interface is also a capability shared by the terminal and the network point of attachment.

As said before, the IEEE 802.21 works with several technologies, from IEEE 802.16 to UMTS. These different technologies have different cell sizes, and are located according to their purpose (target), so overlapping coverage of cells is an usual situation, and also a desired one. If we are losing a connection to a network, and we don't want to have a break in our session, it is necessary to have a case of overlapping cells, so that we can change to a new cell before breaking the connection with the old one.

The 802.21 standard can be separated in the following four elements:

- A framework, which relies on the presence of a mobility management protocol stack within the network elements that support the handover so it can enable service continuity as the mobile node transacts between heterogeneous link-layer technologies.
- A set of handover-enabling functions within the protocol stacks of the network elements and a new entity called the MIH Function (MIHF) therein.
- A media independent handover Service Access Point (MIH_SAP) and associated primitives defined to provide MIH Users with access to the services of the MIHF.
- The definition of new link service access points (SAPs) and associated primitives for each link-layer technology, in order to help the MIHF to collect information and control link behavior during handovers. When applicable, these new SAPs are recommended as amendments to the standards for the respective link-layer technology.

2.3.3 MIHF Framework

The MIHF is a logical entity, whose definition has no implications on the way the MIHF is implemented on the mobile node or in the network. It is the central structure of the IEEE 802.21 standard, implemented between the link layer and the network layer (2.7).

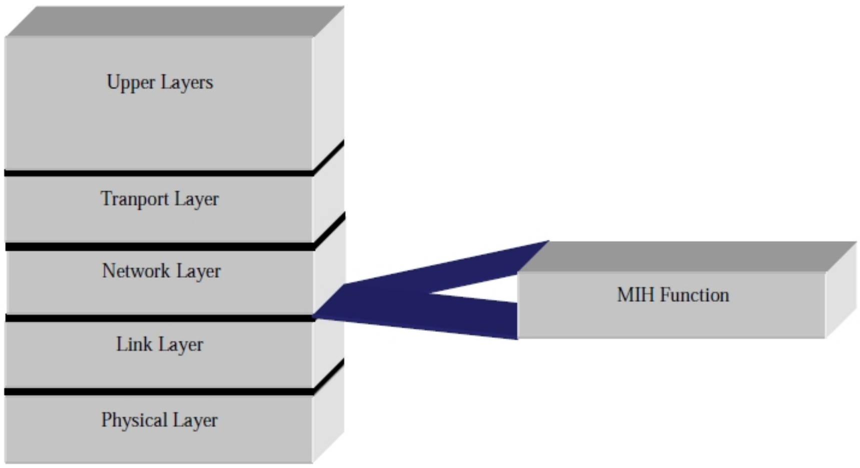

Figure 2.7: TCP/IP Model plus MIHF block[4]

The MIH network is composed by the following entities:

- Point of Attachment (PoA) - point where the MN connects to the access network.
- Point of Service (PoS) -point of communication MIH between the MN and the network operator. It can be placed in the same entity as the PoA.

- Non-Point of Service (Non-PoS) - point of communication MIH with the PoS. This entity does not exchange MIH messages with the MN.

The logical entity MIHF implements the three MIH Services: the Event Service (MIES), the Command Service (MICS), and the Information Service (MIIS).

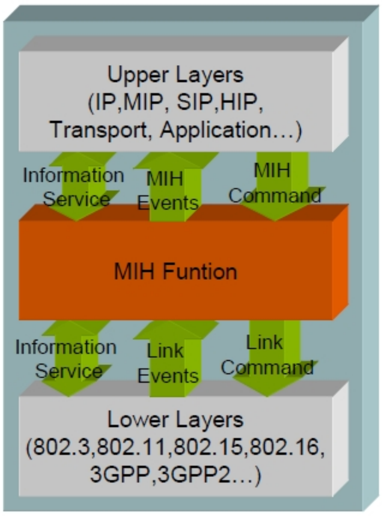

Figure 2.8: MIHF Framewok[4]

In a practical point of view, the MIHF receives Link Events from the lower layers and sends them to the upper layers as MIH Events. It also receives MIH Commands from the upper layers and forwards them to the lower layers as Link Commands. As to the Information Service, it is provided to the MIHF either by the upper layers or the lower ones.

The events delivered by the MIES may indicate changes in the state and the transmission of the physical, data link and logical link layers, or predict state changes of these layers. It can also be used to report management actions or command status on the part of the network or another management entity.

The MICS allows the control of the lower layers by the higher ones, being able to control the reconfiguration or selection of an appropriate link through a set of handover commands.

Both MIES and MICS can be local or remote (figure 2.9).

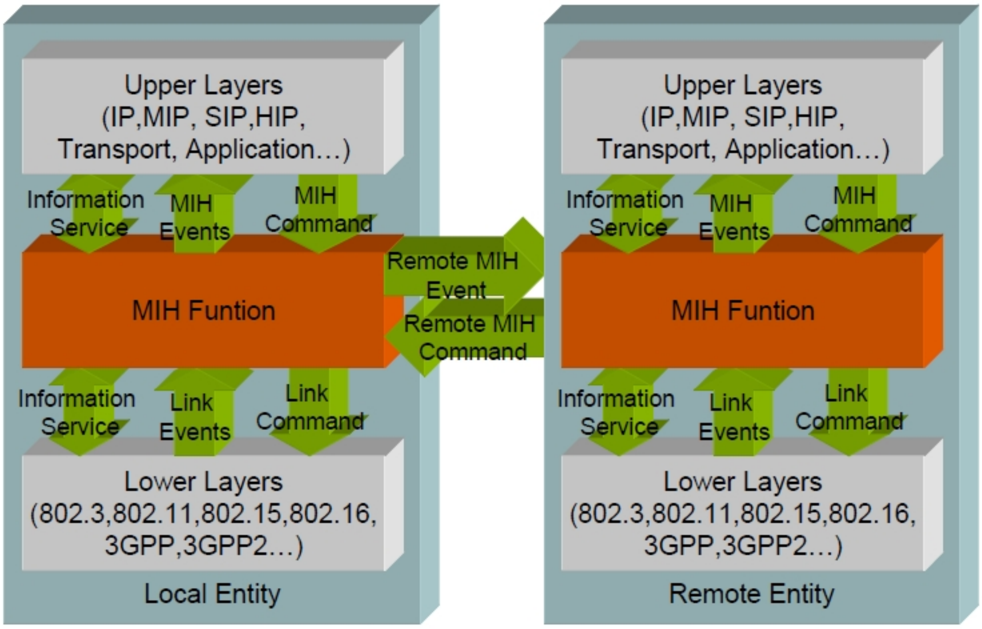

Figure 2.9: Relationship with MIHF peers[4]

To facilitate the handovers, the MIIS purpose is to provide a framework and corresponding mechanisms by which an MIHF entity can discover and obtain network information within a geographical area.

The MIHF can exchange either local or remote services, and for that, it has to communicate with the remote MIHFs using MIH protocol (figure 2.9). The exchange of information and messages with remote MIHFs is provided by MIH_NET_SAP interface.

2.3.4 MIHF services

2.3.4.1 Media Independent Event Service

This service is used to detect the need for handovers. For example, if the link that the MN is using will cease to carry MAC service data units (SDUs) at some point in the near future, an indication is received by MIH Users to prepare a new PoA, potentially reducing the time needed to handover between attachment points.

These events are treated as discrete, as such there is no general event state machine, but however in certain cases a particular event may have state information associated with it. For example, events may carry additional context data such as a layer 2 or 3 identifier. For example, a Link Up can also carry a new IP address acquisition that informs the upper layers of the need to initiate a layer 3 handover.

The MIES is divided into two categories, the Link Events which are originated from event source entities below the MIHF (technology) and may terminate at the MIHF, while the MIH Events are defined as events created within the MIHF, or Link Events that are forwarded to the MIHF Users by the MIHF. These events are notifications, and the recipient does not have to act on them.

Event notifications are generated asynchronously, however all MIH Users and MIHFs that wish to receive those, need to subscribe to particular events. By nature, all Link Events are local and propagate from the local lower layer to the local MIHF. Here, the MIHF creates the MIH Events that can be either local or remote. When the events are remote, the messages propagate from the MIHF in one protocol stack to the MIHF in the peer protocol stack. A protocol stack can be present in a MN while the other can be present in a fixed network entity, such as a point of attachment or any node not directly connected to the other protocol stack. From there, it is then sent to local MIH Users that have subscribed to the remote event. The event may also be sent to a remote MIH entity as a remote MIH Event.

These events can be created by the mobile node or by the network.[5]

2.3.4.2 Media Independent Command Service

The MICS enables the higher layers (MIHUs) to get information about the state of the radio channel and to control the access technology (physical, data link, and logical link layers). If a MIHF supports the command service, all MIH commands are mandatory. In other words, when a MIHF receives a command, it is always expected to execute the command.

The commands, as the events, are classified into two groups, Link and MIH Commands. The MIH Commands are sent from the MIHUs to the MIHF, either being local or remote. The local MIH Commands are sent to a MIHF located in the same node, while the remote ones are sent to the MIHF located on another node of the network. After reaching to the MIHF, the commands are propagated by the MIHF to the access technology. For example, the command service can be used by the policy engine of an entity in the network to request an MN to switch links.

Handovers are initiated by changes in the wireless environment that leads to the selection of a network that supports a different access technology other than the serving network. Network selection and handover initiation are outside the scope of mobility management protocols such as MIP. Only after the network selection and the handover initiation, the mobility management protocols act in packet routing aspects such as address update and transfer of packet delivery to the new network. During the network selection, the MN and the network need to exchange information about the available candidate networks and select the best network, and the MICS provide these exchanges.[5]

2.3.4.3 Media Independent Information Service

The MIIS provides a framework and corresponding mechanisms by which an MIHF located on a mobile terminal or in the network can discover and obtain information about the existing networks. The main purpose is to obtain information about all existing access technologies in a geographical area. The MIIS also supports a push mode wherein the information can be pushed to the MN by the operator. With the information provided by the MIIS, it is possible to initiate the process of selection of the network to process the handover. In order to do so, a new entity named Information Server (IS) is used by the MIIS to store information about the access networks. Therefore, the MIHFs can, whenever necessary, query the IS to know which networks are available for handover. The definition and indexing of such a local database, as well as the regime for maintaining it or accessing it, are outside the scope of the IEEE 802.21 standard.

The information provided by the MIIS is made available via both lower and higher layers (L2 and L3). At the L2, the information is available through both a secure port and also a non secure one, which allows a network selection decision to be made before incurring the overhead of authentication and the establishment of a secure L2 connection with the network. In some cases, L2 cannot access the information or the information available at its level is not enough to make an intelligent handover decision. When this happens, the information can be accessed via higher layers. Both information transport options, are expected to provide security, such as data integrity and data confidentiality for the IS.

MIIS typically provides static link layer parameters such as channel information, the MAC address and security information of a PoA. Also information about higher layer services in a network can be useful in a more effective handover decision.

In order to represent the information about different technologies, a standardized format such as XML or binary code is used.

Depending on how the MIIS service is implemented, it allows the access to information about all networks in a geographical area from any single L2 network. In matters of transport and security, the MIIS either relies on existing mechanisms or L3 mechanisms. In a heterogeneous network environment, the network selector or higher layer mobility will collect information from different media types and assemble a consolidated view to facilitate its inter-media handover.

Several networks, such as cellular and others already have means of detecting a list of neighborhood base stations within the vicinity of an area. However, the means to detect neighbor base stations are not the same for every technology. For cellular networks the detection is made via the broadcast control channel, while for some IEEE standards it is done via the broadcast of MAC management messages. Here, is where the MIIS is a major advantage, defining an unified mechanism to the higher layer entities to provide handover candidate information in a heterogeneous network environment by a given geographical location.[5]

2.4 Summary

In this chapter it was possible to get an overview about concepts such as mobility and broadband wireless technologies. A brief overview about Wi-Fi, WiMAX and UMTS was also provided, as well as the handover mechanisms of the IEEE 802.21 protocol. With the IEEE 802.21 we can process both homogeneous and heterogeneous handovers between the mentioned technologies, achieving less delay in the handover as well as a reduced latency and packet loss.

Being able to make handovers between different technologies ensuring the users requirements as most as possible, enhances the concept of mobility and the fact that a user can be “always connect”.

Chapter 3

Media Independent Handovers between Wi-Fi, WiMAX and UMTS

The following chapter presents the handover procedure defined by the IEEE 802.21, as well as its interaction with the different wireless access technologies. It is also presented the integration of the 802.21 protocol. Finally, a new concept is introduced regarding the availability of dynamic information in the network.

This chapter is organized in 4 sections. The first section describes the handover procedure as it is defined in the draft 14 of the IEEE 802.21 standard. As to the second, it shows in a more detailed way, the interaction between the UMTS, Wi-Fi and WiMAX technologies with the 802.21 protocol. The third section presents the integration of the 802.21 protocol. In the fourth and last section, a new concept of a MIIS is introduced.

Along the chapter, several message sequence charts (MSCs) are presented, to provide a more clear understanding of the several processes.

3.1 IEEE 802.21

The following table has a brief description of the messages mentioned in this section.

Messages	Service Category	Description
MIH_Get_Information	Command	Request to get information from repository
MIH_MN_HO_Candidate_Query	Command	Initiate MN query request for candidate network
MIH_Net_HO_Candidate_Query	Command	Initiate handover
MIH_N2N_HO_Query_Resources	Command	Query available network resouces
MIH_MN_HO_Commit	Command	Notify the serving network of the decided target network information
MIH_Net_HO_Commit	Command	Network has commited to handover
MIH_N2N_HO_Commit	Command	Notify target network that the serving network has commited to handover
MIH_MN_HO_Complete	Command	Initiate MN handover complete notification
MIH_N2N_HO_Complete	Command	Handover has been completed

Table 3.1: IEEE 802.21 Messages

3.1.1 Handover Procedure

In this section it is described the handover procedure. It is important to remind that according to the draft 14 of the IEEE 802.21 standard, an handover can be initiated either by the MN or by the network itself. The purpose of this work was to study handovers initiated by the MN, however it is also described in this section the process of a network initiated handover. A handover process can be split into 4 main steps:

- Handover Initiation
- Handover Preparation
- Handover Execution
- Handover Completion

3.1.1.1 Handover Initiation

This first phase of the handover process considers two sub-phases: the Network Topology Acquisition and the Resources Availability Check.

- MN-initiated Handover

  At this point (Handover initiation) the MN is connected to the serving network via current PoS which gives it access to the MIH Information Server. By sending a MIH_Get_Information Request to the PoS, the MN is requesting the IS to provide it with information about neighboring networks. When receiving an indication from the PoS, the IS will send the information required through a MIH_Get_Information Response message. With the information provided by the IS, the MN knows which PoAs it has to query about resources (Resources Availability Check).

  The Resources Availability Check is triggered by sending a MIH_MN_HO_Candidate_Query Request to the serving PoS with the information of the potential candidate networks. When the PoS receives the request, it will query all the candidate networks about their resources availability by sending MIH_N2N_HO_Query_Resources Request to each one. The candidate PoSs give the serving PoS the information about their availability resources by sending a MIH_N2N_HO_Query_Resources Response, and the serving PoS forwards this information to the MN through a MIH_MN_HO_Candidate_Query Response. A clear presentation of this process is presented in figure 3.1.

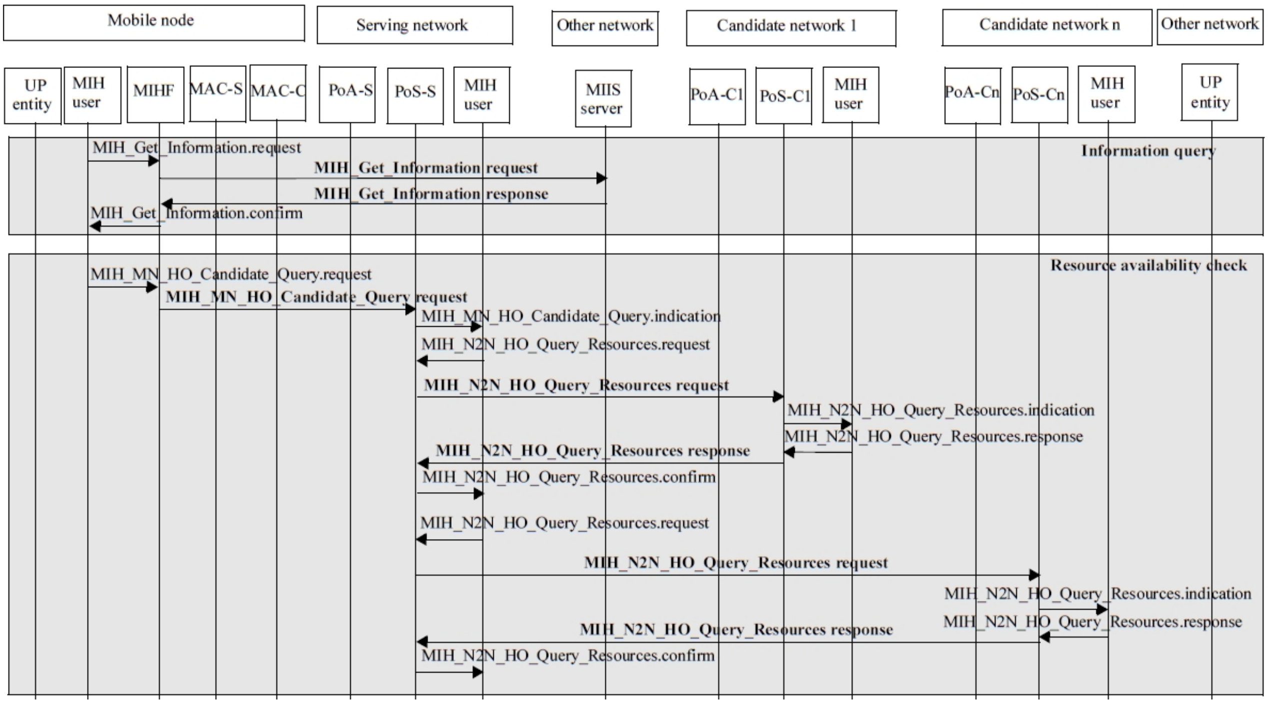

Figure 3.1: Mobile-initiated handover procedure - HO Initiation phase[5]

- Network-initiated Handover

  In this case, the network is the entity responsible for initiating the handover. As the MN Handover Initiation process, it starts by sending a MIH_Get_Information Request to the IS, but this time, the entity to send it is the serving PoS and not the MN.

  After receiving the information from the IS (MIH_Get_Information Response), the serving PoS sends an MIH_Net_HO_Candidate_Query Request message to the MN, that responds with a MIH_Net_HO_Candidate_Query Response message acknowledging about the handover and its preferred link and PoS lists. The serving PoS sends an MIH_N2N_HO_Query_Resources Request message to the candidate PoSs to check their availability of the resources. With the available resources given to the PoS through MIH_N2N_HO_Query Responses, the PoS decides which will be the target network. Figures 3.2 and 3.3 ilustrate this process.

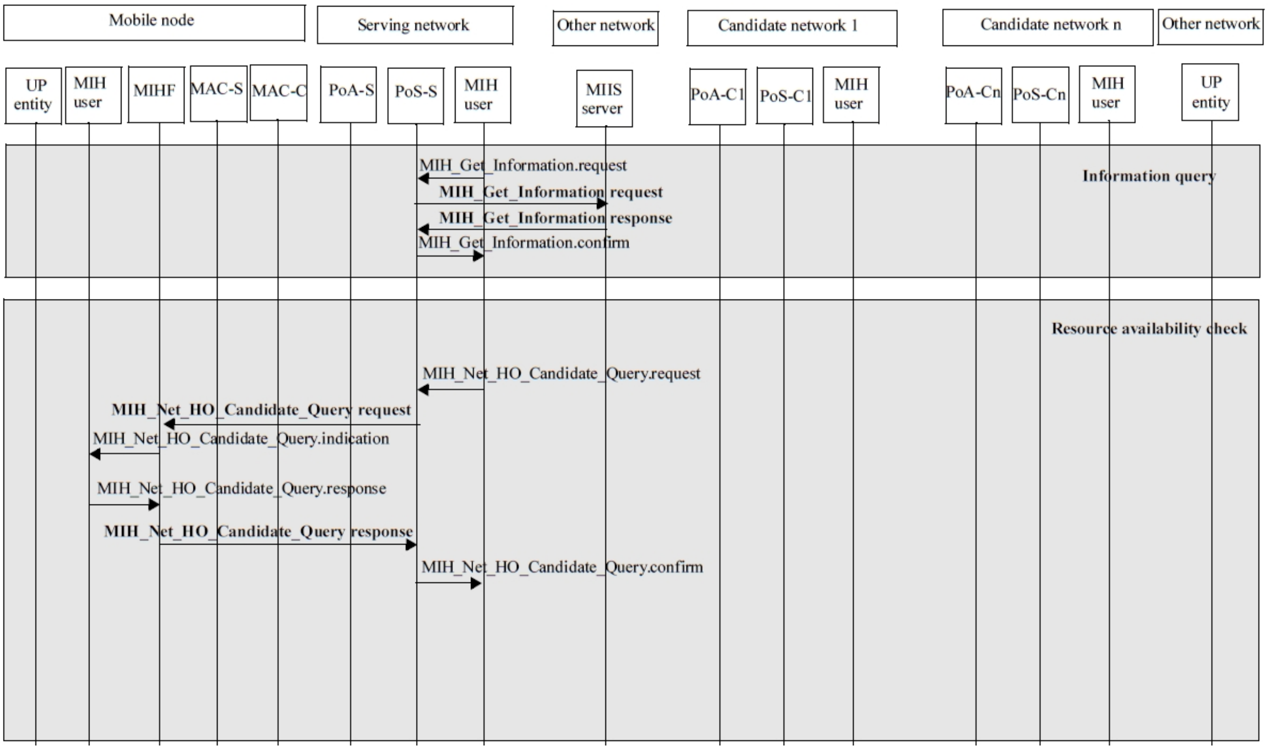

Figure 3.2: Network-initiated handover procedure - HO Initiation phase[5]

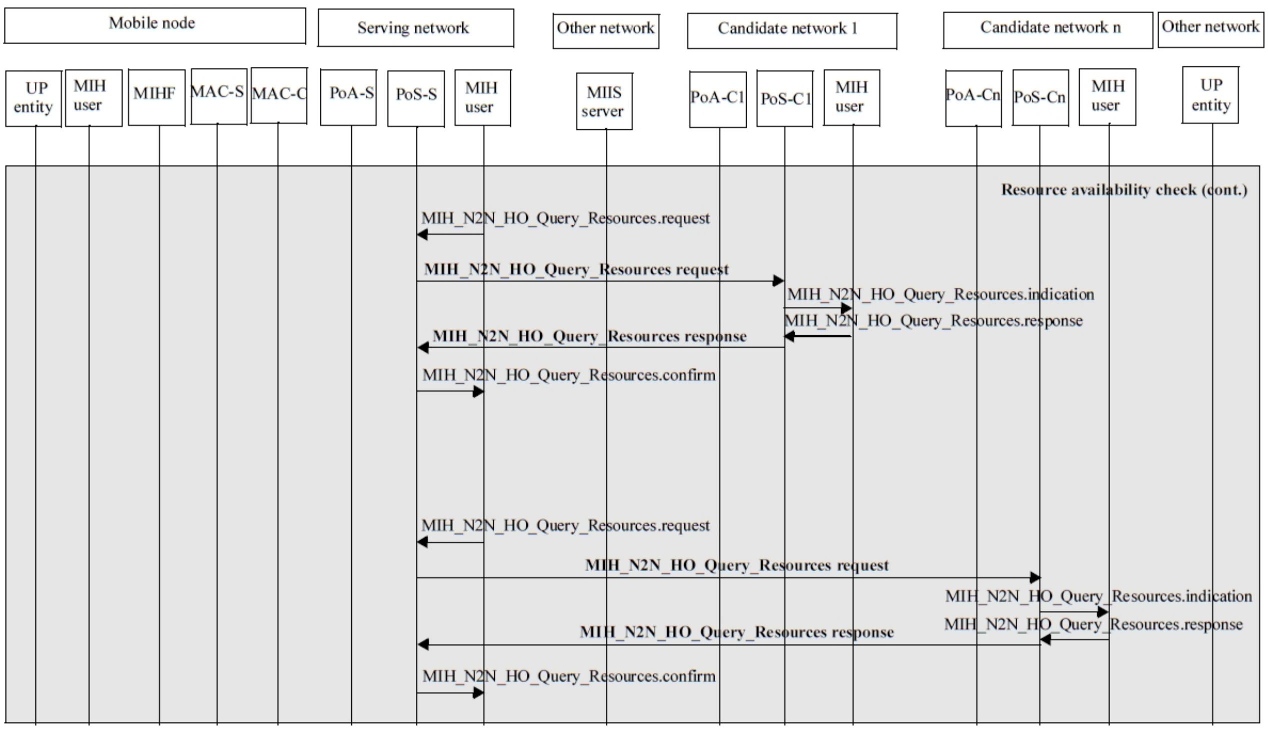

Figure 3.3: Network-initiated handover procedure - HO Initiation phase (cont.)[5]

3.1.1.2 Handover Preparation

The Handover Preparation is the phase responsible for preparing the QoS resources at the target network.

- MN-initiated Handover

  At this point, the MN already has information about the resources available on the possible target networks, and so it can decide which will be the target. As it is possible to see through figure 3.4, the request resource preparation is made by sending a MIH_Link_Handover_Imminent Indication to the serving PoS, that will send to the target PoS a MIH_N2N_HO_Commit Request. After, the serving PoS will receive a MIH_N2N_HO_Commit Response from the target PoS with the result of the resource preparation.

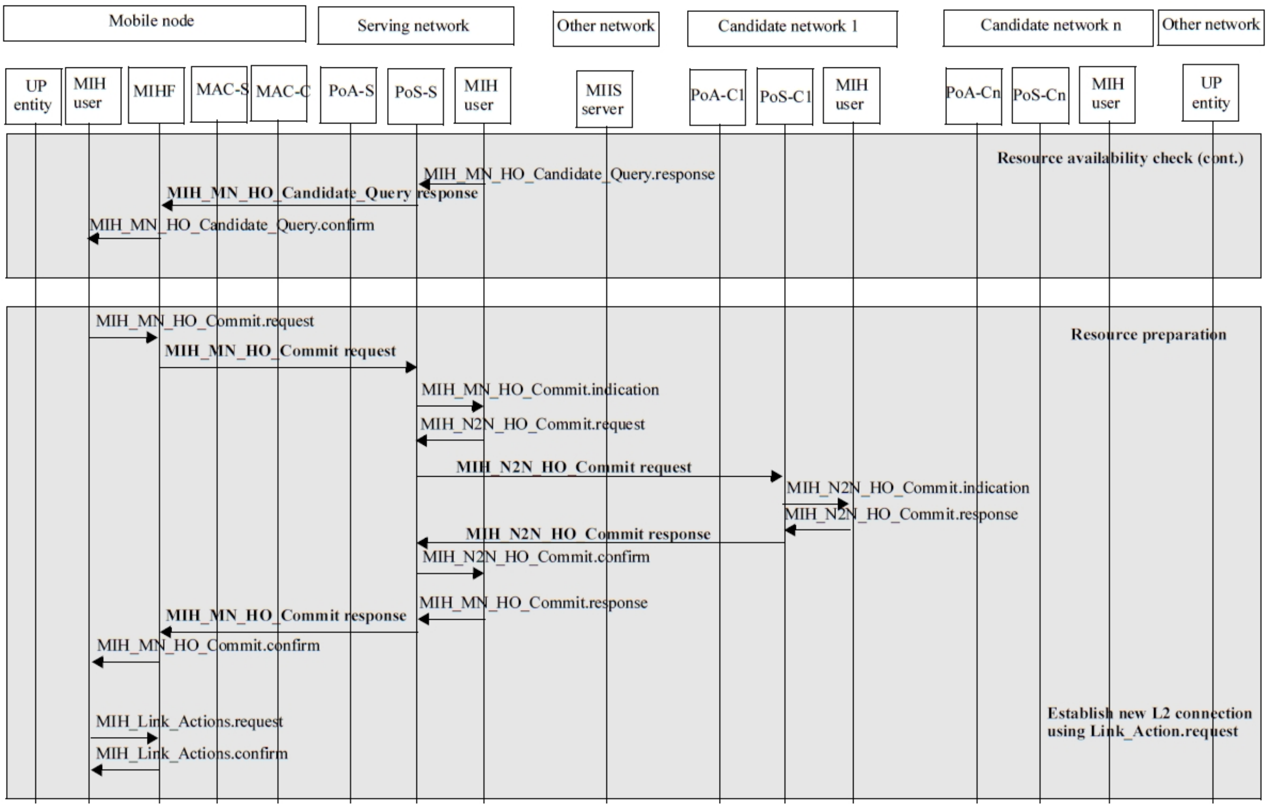

Figure 3.4: Mobile-initiated handover procedure - HO Preparation phase[5]

- Network-initiated Handover

  After deciding which will be the target network, the serving PoS sends a MIH_N2N_HO_Commit Request message to prepare the resources at the target network. The target PoS responds the result of the resource preparation by sending an MIH_N2N_HO_Commit response message. If the resource is successfully prepared, the serving PoS commands the MN to commit handover towards the specified network type and PoA through an MIH_Net_HO_Commit request message. When the new layer 2 connection is established, the MN sends an MIH_Net_HO_Commit response to the serving PoS, as figure 3.5 shows.

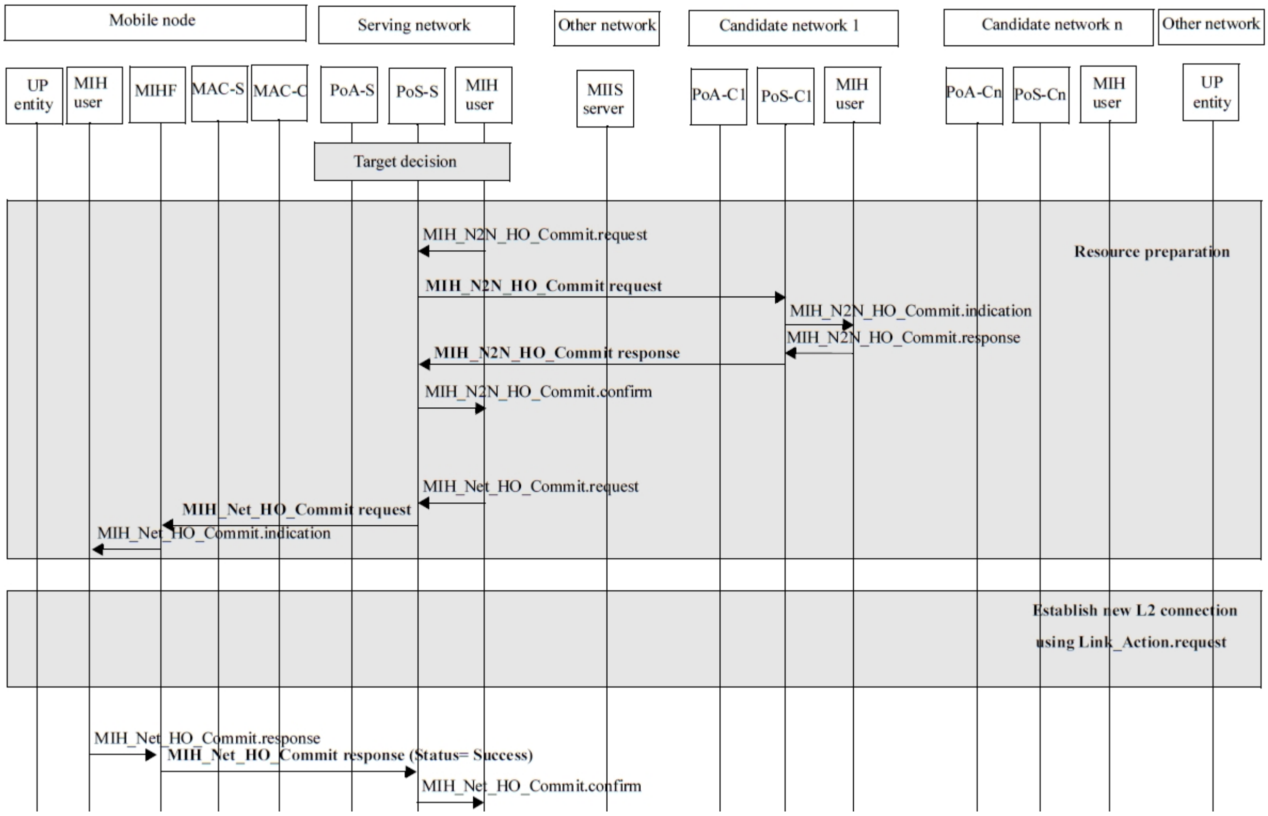

Figure 3.5: Network-initiated handover procedure - HO Preparation phase[5]

3.1.1.3 Handover Execution

In the MN Handover Initiation case, this phase is executed after the Handover Preparation, while in the Network Initiated Handover case is executed in the end of the preparation phase, since this phase is only completed after the serving PoS receives a MIH_Net_HO_Commit Response from the MN, which only happens after the new L2 connection is established.

At this point the MN is already connected to the target PoS.

3.1.1.4 Handover Completion

Handover Completion is the fourth and final phase of a handover process. It is responsible for releasing the resources from the previous target PoS. The MN sends an MIH_MN_HO_Complete Request message to the target PoS, which sends an MIH_N2N_HO_Complete Request message to the previous serving PoS to release the allocated resources by the MN. After successfully releasing the resources the MN receives an MIH_MN_HO_Complete Response message from the new serving PoS.

This process is similar to both MN and Network initiated Handover, as the figures below show.

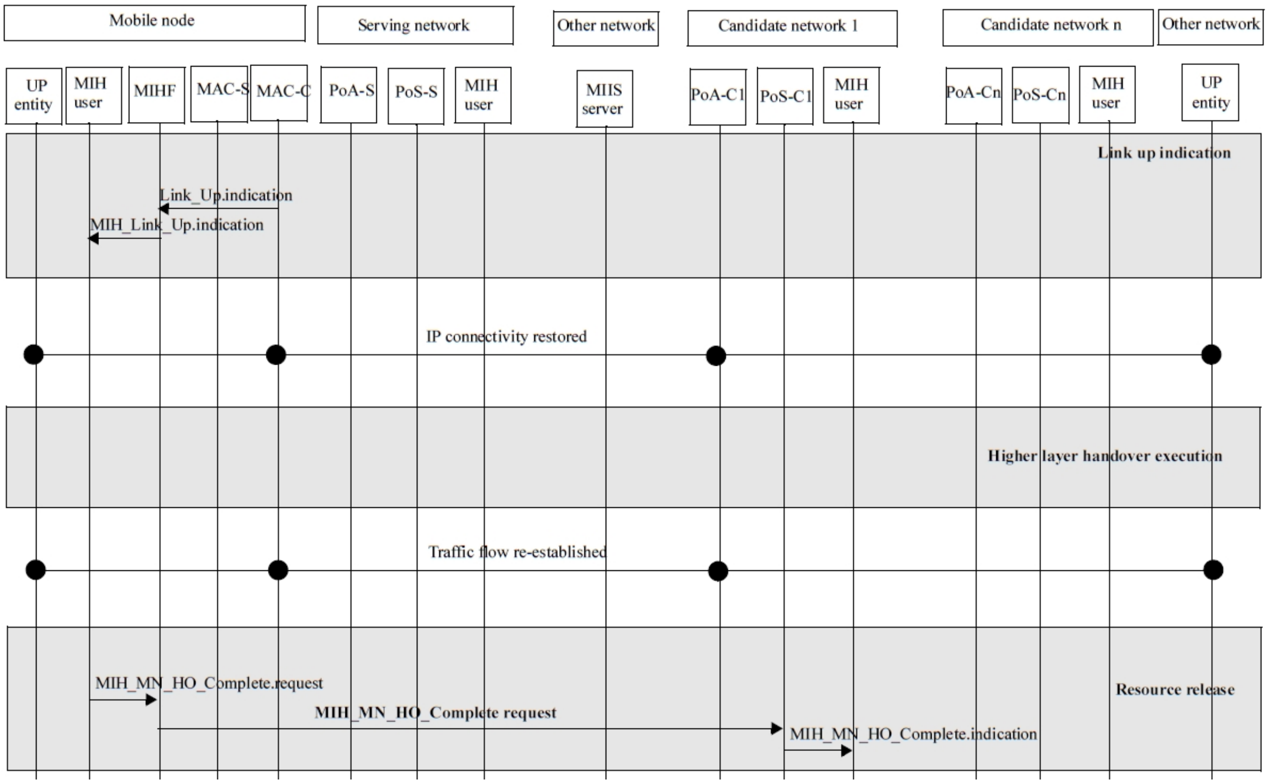

Figure 3.6: Mobile-initiated handover procedure - HO Completion phase[5]

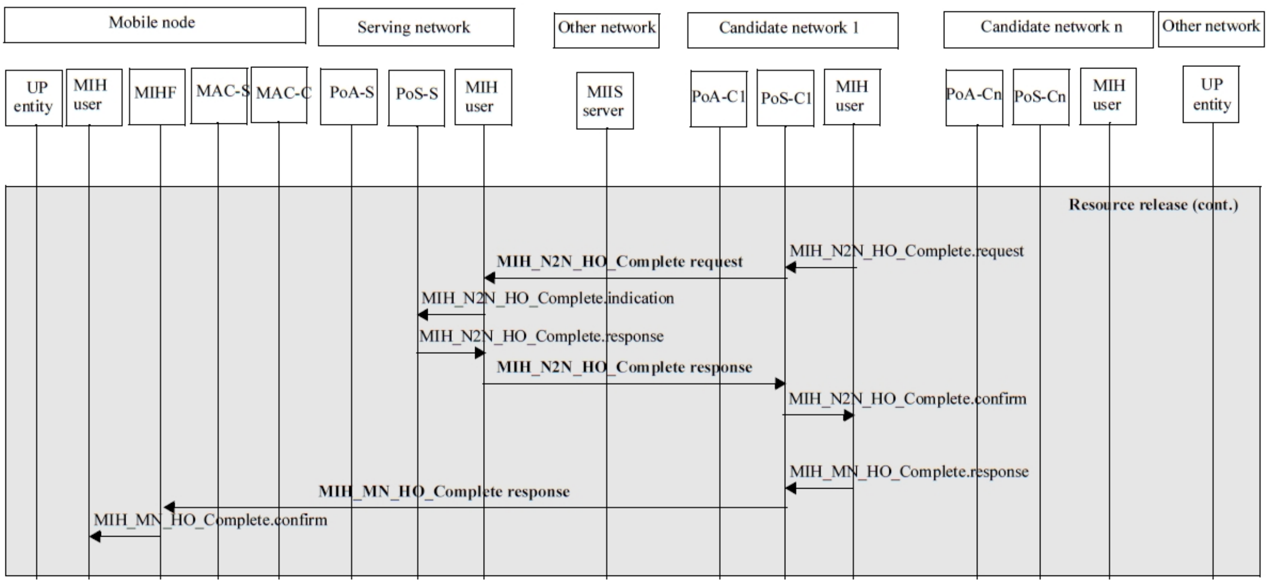

Figure 3.7: Mobile-initiated handover procedure - HO Completion phase[5]

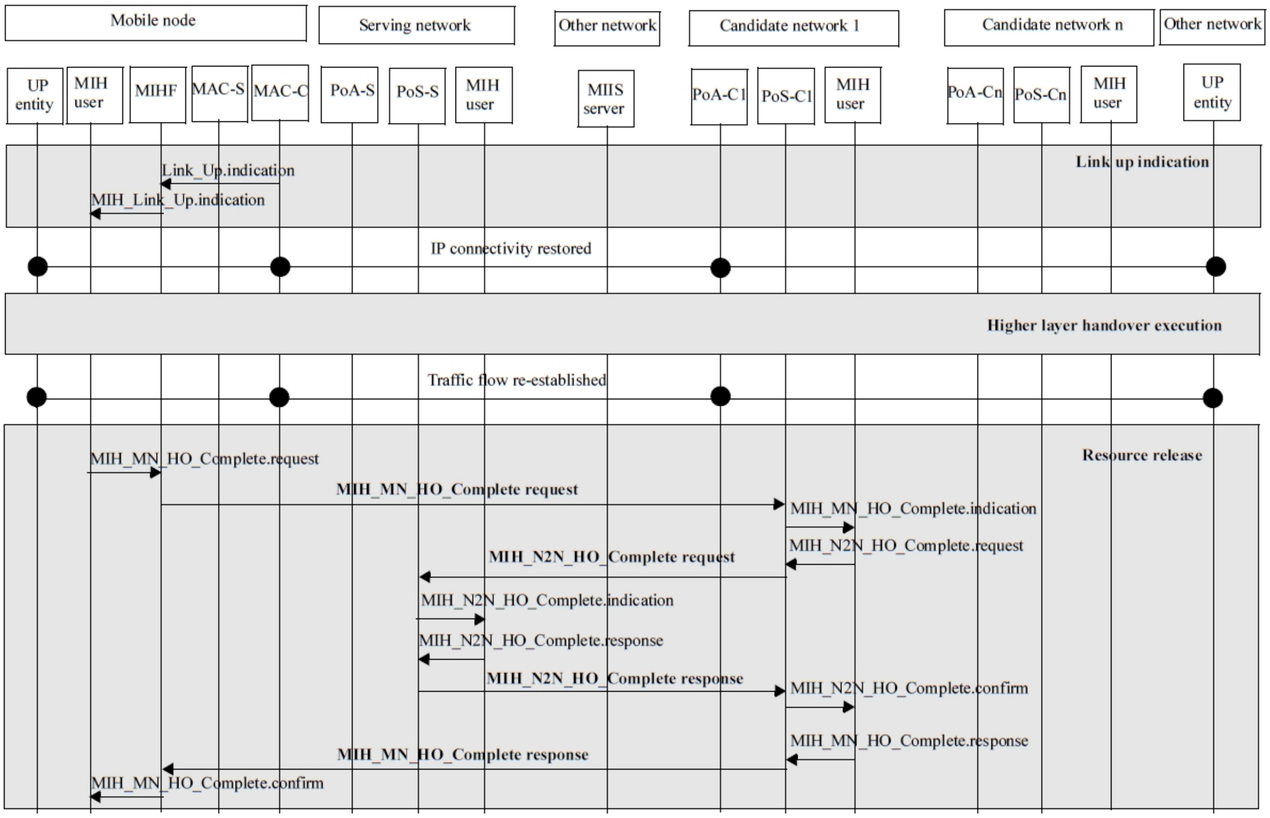

Figure 3.8: Network-initiated handover procedure - HO Completion phase[5]

3.2 IEEE 802.21 interaction with UMTS, Wi-Fi and WiMAX

The present section explains how the interaction between the IEEE 802.21 and the different wireless access technologies is made.

3.2.1 UMTS

This section provides a definition of the signaling exchange between the IEEE 802.21 protocol and the UMTS technology when a handover from or to UMTS is in process.

As mentioned in the previous section, the handover procedure is split into four main steps: Initiation, Preparation, Execution and Completion. Table 3.2 presents the mapping of the IEEE 802.21 and 3GPP messages.

HO Phase	Function	Primitives		Comment
		IEEE 802.21	3GPP	
HO Initiation	Configure UMTS thresholds	Link_Configure_Thresholds	SMREG-PDPMODIFY	Modify PDP Context
	Obtain UMTS link parameters information	Link_Parameters _Report.ind	RABMSM-MODIFY	Inform for QOS Profile parameter modification
	Notification of link going down	Link_Going_Down.ind	MEASUREMENT REPORT (Event Triggered)	Set quality thresholds have been passed
Handover Preparation	Activate UMTS interface	Link_Action (Scan)	POWER-ON	Power on UMTS interface
	Query resources in candidate UMTS network / establish RRC Conection	Link_Get_Parameters (HO Scan)	PAGING Type 1, MEASURE-MENT REPORT (Periodic)	Request for the UE to initiate RRC setup
	Establish L2 Connection	Link_Action (POWER_UP)	GMMREG-ATTACH	Activate GPRS attach procedure
	Resource Reservation	Link_Action (QOS_RESERVATION)	SMREG-PDPACTIVATE	Activate PDP context and set QOS requirements
	PDP Context Request			
HO Execution Phase	-	-	-	-
HO Completion Phase	Delete resources in previous serving UMTS network	Link_Action (QOS_DELETION)	SMREG-PDPDEACTIVATE	Close session and deactivate PDP context
	GPRS Mobility Management Detach		GMMREGDETACH	Activate GPRS Detach procedure
	Power-off the UMTS interface	Link_Action (POWER_DOWN)	POWER-OFF	Power down UMTS interface

Table 3.2: IEEE 802.21 and 3GPP mapping[6]

- Handover Initiation (from UMTS to another network):

  At this point, the QoS requirements thresholds are set via the SMREG-PDP-MODIFY.REQ primitive and if the set is successful, a SMREG-PDP-MODIFY.Conf is reported. When using UMTS, the MN periodically is provided with measurement parameters through the Measurement Control message sent by the UMTS RNC. A link going down message is triggered when the comparison of the measures provided by the RNC and the set thresholds reach a certain level. This process is shown in figure 3.9.

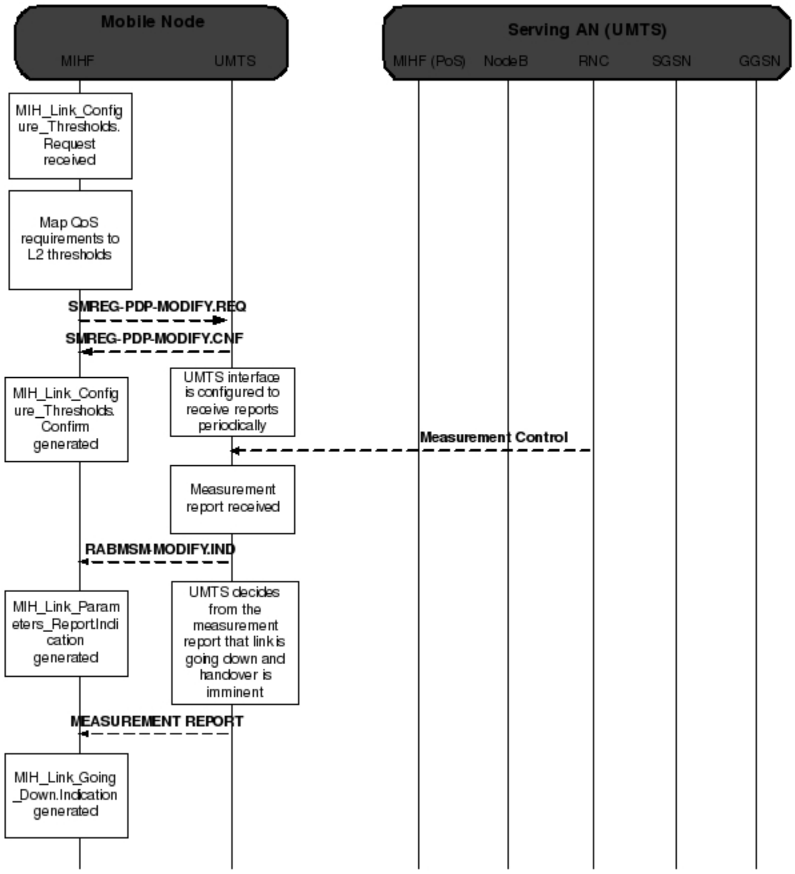

Figure 3.9: UMTS - Link unavailability - HO Initiation phase[6]

- Handover Preparation (to a UMTS network):
  - Power On & Scan

    This stage requires the MN to switch from DETACHED to IDLE mode so it can start communicating with the UMTS PoA. As it is ilustrated in figure 3.10, first the UMTS interface is switched on with a POWER-ON-REQ primitive and starts "listening" for the synchronization channel from the NodeB's in its vicinity. Through the analysis of the signals received, the MN chooses which NodeB has a better signal, and after it is synched with a NodeB, it turns to IDLE mode and informs the MIHF with a POWER-ON-CNF primitive.

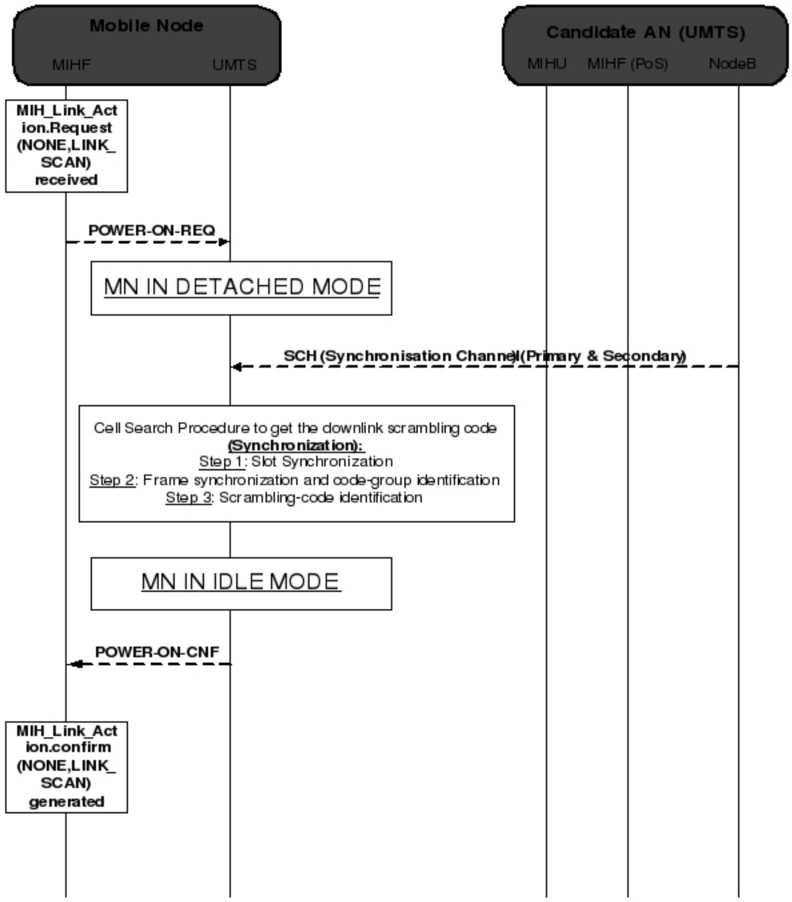

Figure 3.10: UMTS - Power On & Scan - HO Preparation phase[6]

– L2 connection establishment

The MN establishes an RRC connection with the RNC and attaches itself to the UMTS network. There is only one RRC connection between one MN and the RNC. After the RRC connection is established, the MN triggers the CONNECTED mode with a GMMREG-ATTACH-REQ primitive, creating a sequence of events which will result in a GMMREG-ATTACH-CNF primitive if the process is successful (see figure 3.11).

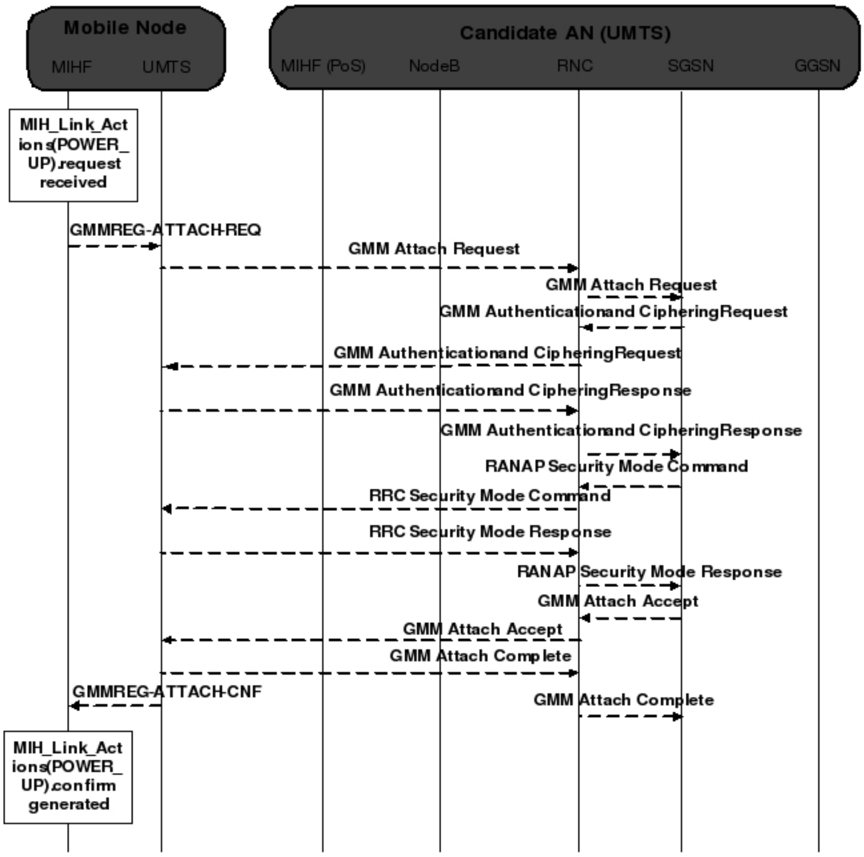

Figure 3.11: UMTS - L2 connection establishment - HO Preparation phase[6]

- Handover Completion (from UMTS to another network):

  This last stage of the handover process, has the purpose of releasing the resources on the previous access network. In the UMTS case, a SMREG-PDP-DEACTIVATE-REQ message is deployed which initiates the deactivation of the PDP Context at the SGSN and the GGSN. When the deactivation is complete, a SMREG-PDP-DEACTIVATE-CNF is received by the MN.

  After the PDP deactivation, the MN has to detach from the network and to do so it sends a GMM-DETACH-REQ. Once completed, a reply is sent back to the MN, GMM-DETACH-CNF.

  By sending a RABMAS-RAB-RELEASE-IND from the MN, we are releasing the MN from the RNC and any link between the RNC and the SGSN.

  Finally, the last step is to turn off the UMTS interface through a POWER-OFF-REQ. A reply by the interface is sent confirming the interface shut down with a POWER-OFF-CNF message.

  The exchange of messages in this phase is ilustrated in the figure below.

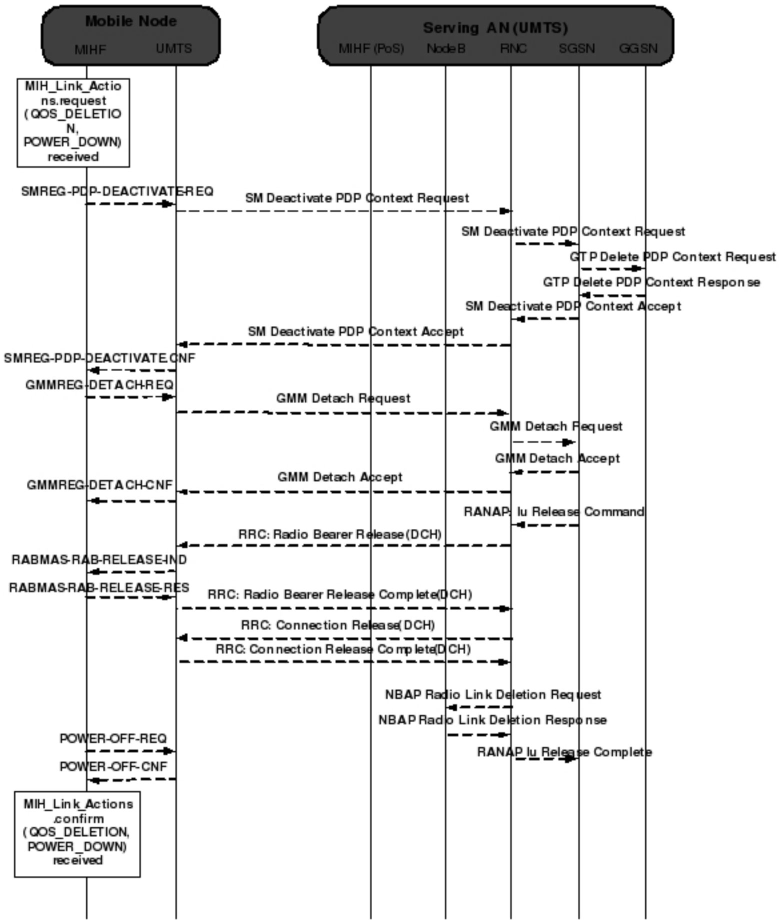

Figure 3.12: UMTS - Complete - HO Completion phase[6]

3.2.2 Wi-Fi

Now we explain how the interaction between the IEEE 802.21 and the Wi-Fi technology is performed. The following table helps understanding the exchange of messages in each phase.

HO Phase	Function	Primitives		IEEE 802.11u/802.11 Service
		IEEE 802.21	IEEE 802.11u/802.11	
HO Initiation	Configure 802.11 thresholds	Link_Configure_Thresholds	MLMEMEASURE. request or MLMEMRE-QUEST. request or MSGCF-Set-ESS-Link-Parameters	IEEE 802.11k (802.11) or Network configuration (802.11u)
	Obtain 802.11link parameters information	Link_Parameters_Report.ind	MLMEMEASURE. confirm or MLMEMRE-PORT. indication or MSGCF-ESS-Link-Threshold-report	IEEE 802.11k (802.11) or Network events (802.11u)
	Notification of link going down	Link_Going_Down.ind	MSGCF-ESS-Link- Going-Down	Status reporting (802.11u)
Handover Preparation	Scan the 802.11 Base Station	Link_Action (SCAN)	MSGCF-ESS-Link- Command (SCAN)	Network command (802.11u)
	Query resources in candidate 802.11 network	Link_Get_Parameters	MSGCF-Get-ESS-Link-Parameters	Network configuration (802.11u)
	Activate 802.11 interface	Link_Action (POWER_UP)	MSGCF-ESS-Link- Command (POWER_UP)	Network command (802.11u)
	Join in 802.11			
	Authentication in 802.11			
	Association in 802.11			
	Commit resources in target 802.11 network	Link_Action (QOS_RESERVATION)	MSGCF-ESS-Link- Command (QOS_RESERVATION)	Network command (802.11u)
	802.11 link is up	Link_Up.ind	MSGCF-ESS-Link-Up	Status reporting (802.11u)
HO Execution Phase	-	-	-	-
HO Completion Phase	802.11 link is down	Link_Down.ind	MSGCF-ESS-Link-Down	Status reporting (802.11u)
	Delete resources in previous serving 802.11 network	Link_Action (QOS_DELETION)	MSGCF-ESS-Link- Command (QOS_DELETION)	Network command (802.11u)
	Power-off the 802.11 interface	Link_Action (POWER_DOWN)	MSGCF-ESS-Link- Command (POWER_DOWN)	Network command (802.11u)

Table 3.4: IEEE 802.21 and IEEE 802.11 mapping[6]

- Handover Initiation (from Wi-Fi to another network):

  The procedures in this stage concern the QoS requirements mapping to Wi-Fi thresholds for each new application, measurement reports and handover estimation reports to higher layers. The QoS mapping is initiated by sending from the MIHF to the Wi-Fi Station Management Entity (SME) a MSGCF-Set-ESS-Link-Parameters.request message, and the result is reported back to the MIHF through MSGCF-Set-ESS-Link-Parameters.confirm. The measurement reports are generated each time the thresholds are crossed after setting the network parameters for the link. MSGCF-EES-Link-Threshold-Report message is reponsible for sending the measurements from the MSGCF to the MIHF. The MSGCF, based on predictive algorithms, has the capability to estimate when the handover is going to happen, sending this prediction through a MSGCF-ESS-Link-Going-Down.indication message (see figure 3.13) .

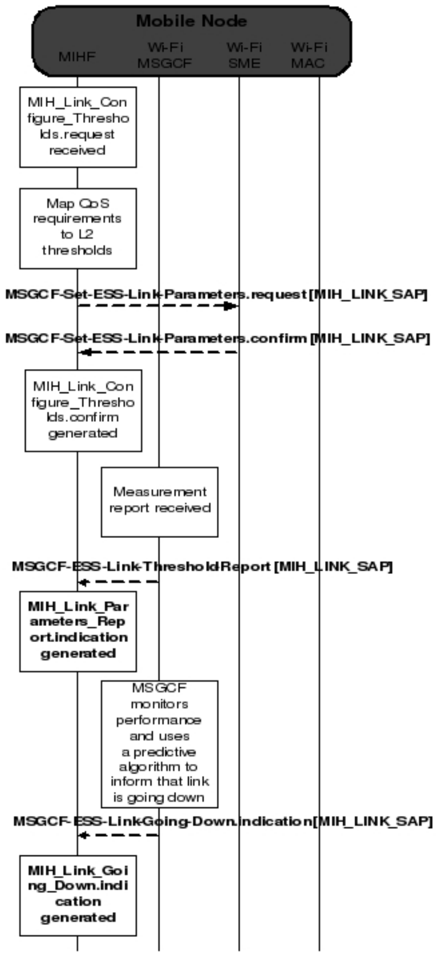

Figure 3.13: Wi-Fi - Link unavailability - HO Initiation phase[6]

- Handover Preparation (to a Wi-Fi network):

  - Power On & Scan

    In this stage (figure 3.14) , the Wi-Fi interface is powered on and performs a scan. By sending a MSGCF-ESS-Link-Command.request from the MIHF to the SME, two 802.11 primitives are deployed in the SME: MLM_POWER_ON.request/confirm for power on and MLME-SCAN to perform the scan (active and passive scan). This stage terminates when the MIHF receives a MSGCF-ESS-Link-Command.confirm with the scan results.

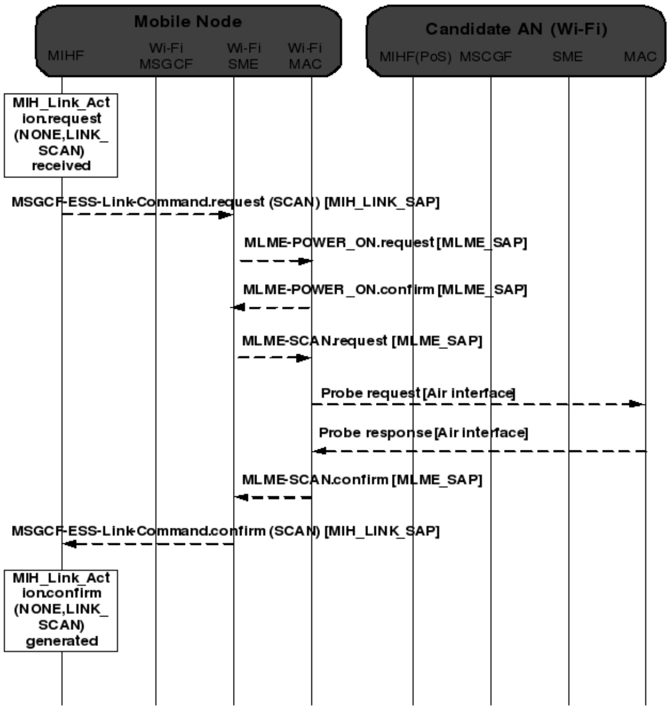

Figure 3.14: Wi-Fi - Power On & Scan - HO Preparation phase[6]

– Resource Check

The MIHF by sending a MSGCF-Get-ESS-Link-Parameters.request to the Wi-Fi SME checks for the available resources (see figure 3.17) .

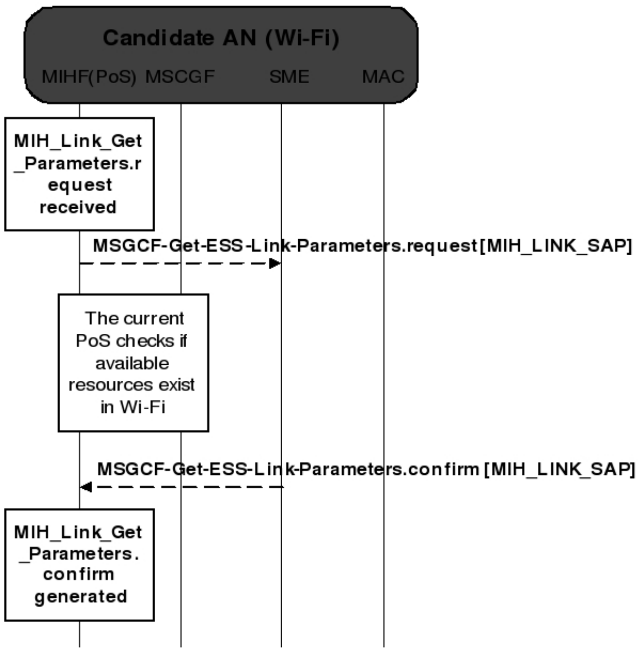

Figure 3.15: Wi-Fi - Resource Check - HO Preparation phase[6]

– L2 connection establishment

When the MN receives a MIH_Link_Actions.request (Power Up) message, the process of L2 connection establishment starts. This command is translated to power on and L2 connection establishment actions. If the interface is already on, the first step is skipped, if not, the interface is powered on (MSGCF-ESS-Link-Command.request) and the MN processes the authentication (MLME-AUTHENTICATE.request) and association. To start this process an MSGCF-ESS-Link-Command.request is sent to the SME, which will exchange MLME-JOIN messages with the MAC to perform the synchronization with the BS. After synchronization, the SME sends a MLME-AUTHENTICATE.request to the MAC and after receiving a confirm of the authentication, a MSGCF-ESS-Link-Command.confirm is sent to the SME to confirm the successful establishment of the L2 connection over Wi-Fi. This process is shown in figure 3.16.

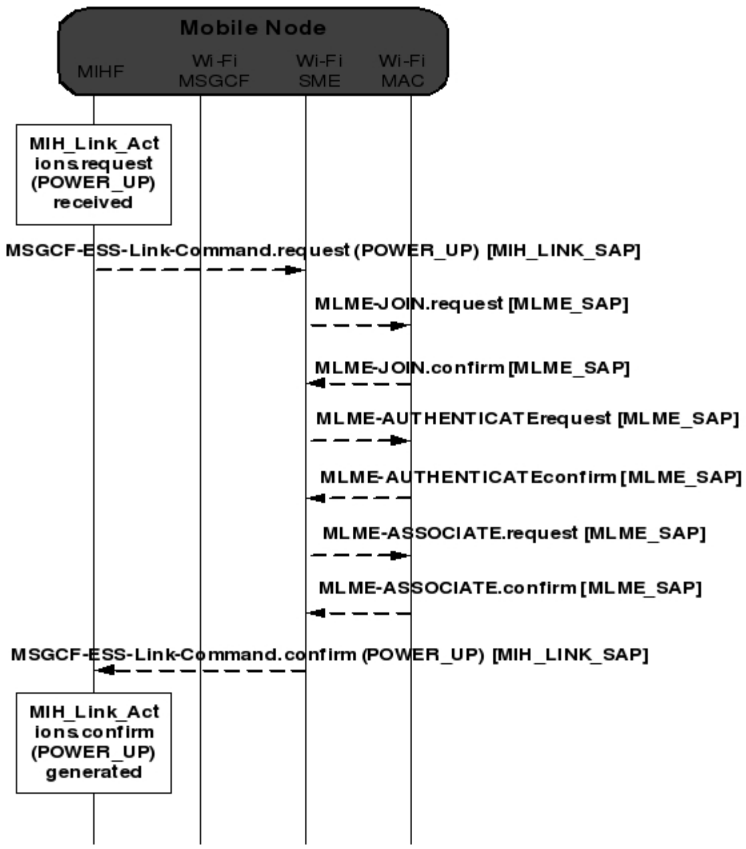

Figure 3.16: Wi-Fi - L2 connection establishment - HO Preparation phase[6]

– Resource Reservation

As the figure below shows (figure 3.17), the resources reservation is triggered by a MSGCF-ESS-Link-Command (QOS_RESERVATION), a new IEEE 802.11u primitive. When the SME receives this primitive, it launches the respective connection establishment procedures described in the IEEE 802.11 standard. If the reservation is sucessfull, the MIHF receives a MSGCF-ESS-Link-Command.confirm (QOS_RESERVATION) message.

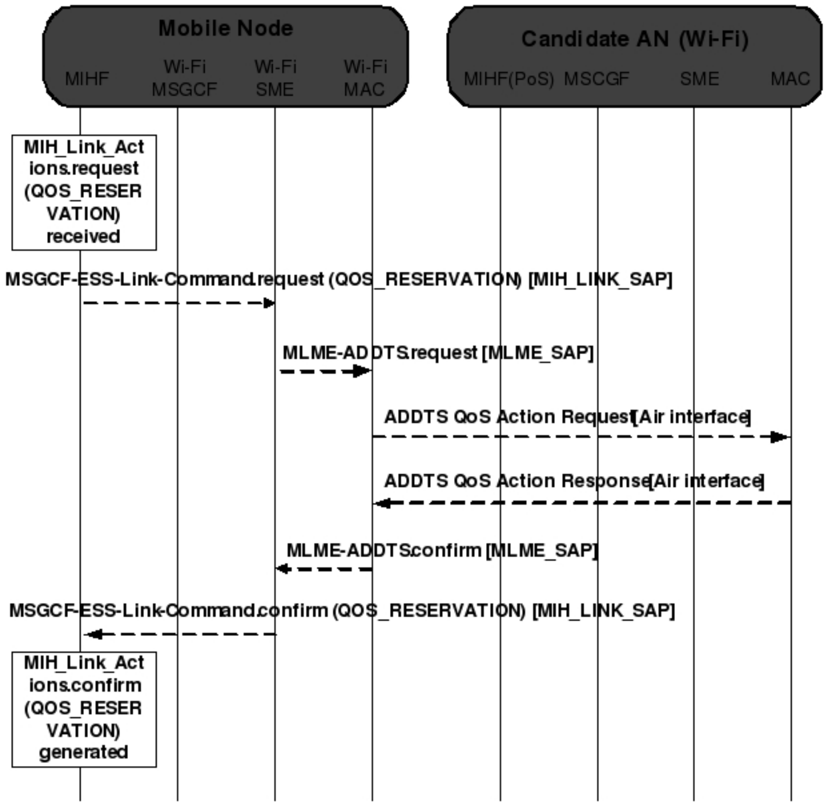

Figure 3.17: Wi-Fi - Resource Reservation - HO Preparation phase[6]

- Handover Completion (from Wi-Fi to another network):

  This final phase of a handover process releases the resources in the old access network (Wi-Fi), since the MN already connected to a new one. The process starts with the receipt of a MIH_Link_Actions.request (QOS_DELETION, POWER_DOWN) message, which will delete any QoS connection established over Wi-Fi through the exchange of a MSGCF-ESS-Link-Command (QOS DELETION) message between the MIHF and the Wi-Fi SME at the MN. Later, a MSGCF-ESS-Link-Command (POWER_DOWN) message is also exchanged in order to turn down the interface and terminate the process. The figure below ilustrates the completion process for Wi-Fi (figure 3.18) .

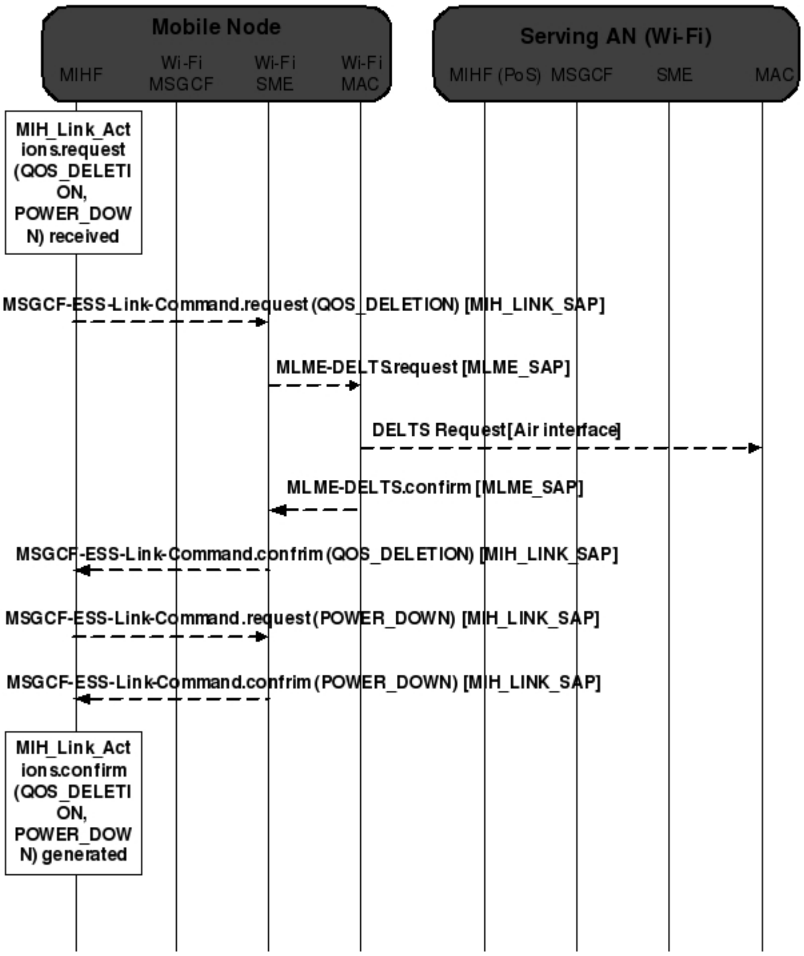

Figure 3.18: Wi-Fi - Complete - HO Completion phase[6]

3.2.3 WiMAX

In this sub-section, we detail how the IEEE 802.21 interacts with the WiMAX technology. To better understand the exchange of messages in each phase, the following table presents the IEEE 802.21 and WiMAX mapping.

HO Phase	Function	Primitives		IEEE 802.16g Service
		IEEE 802.21	IEEE 802.16g	
HO Initiation	Configure WiMAX thresholds	Link_Configure_Thresholds	C-HO-REQ/RSP (HO-SCAN)	Mobility Management (MM) Service
	Obtain WiMAX link parameters information	Link_Parameters _Report.ind	C-HO-IND (HO-SCAN) or C-HO-RSP (HO-SCAN)	Mobility Management (MM) Service
	Notification of link going down	Link_Going_Down.ind	C-HO-IND (HO SCAN)	Network Entry and Exit Management (NEM) Service
HO Preparation	Query resources in candidate WiMAX network	Link_Get_Parameters	C-RRM-REQ/RSP	Radio Resource Management (RRM) Service
	Commit resources in target WiMAX network	Link_Action (QOS RESERVATION)	C-SFM-REQ/RSP (CREATE)	Service Flow Management (SFM) Service
	Activate WiMAX interface	Link_Action (LINK_POWER_UP/SCAN)	M-SSM-REQ/RSP (POWER_ON)	Subscriber Station Management (SSM) Service
	Scan the WiMAX Base Station	Link_Get_Parameters (HO SCAN)	C-HO-REQ/RSP or C-NEM-IND (NETWORK_ATTACHED)	Mobility Management (MM) Service or Network Entry and Exit Management (NEM) Service
	Ranging in WiMAX	Link_Action (POWER_UP)	C-NEM-REQ/RSP (RANGING)	Network Entry and Exit Management (NEM) Service
	SS Basic Capability in WiMAX	Link_Action (POWER_UP)	C-NEM-REQ/RSP (SS BASIC CAPABILITY)	Network Entry and Exit Management (NEM) Service
	Registration in WiMAX	Link_Action (POWER_UP)	C-NEM-REQ/RSP (REGISTRATION)	Network Entry and Exit Management (NEM) Service
	WiMAX link is up	Link_Up.ind	C-NEM-RSP (REGISTRATION)	Network Entry and Exit Management (NEM) Service
HO Execution Phase	-	-	-	-
HO Completion Phase	WiMAX link is down	Link_Down.ind	C-NEM-RSP (DEREGISTRATION)	Network Entry and Exit Management (NEM) Service
	Delete resources in previous serving WiMAX network	Link_Action (QOS DELETION)	C-SFM-REQ/RSP (DELETE)	Service Flow Management (SFM) Service
	Power-off the WiMAX interface	Link_Action (LINK_POWER_DOWN)	M-SSM-REQ/RSP (POWER_DOWN)	Subscriber Station Management (SSM) Service

Table 3.6: IEEE 802.21 and IEEE 802.16g mapping[6]

- Handover Initiation (from WiMAX to another network):

  The MIHF receives a MIH_Link_Configure_Thresholds.request, and sends a C-HO-REQ to the WiMAX MAC to configure the thresholds values of the WiMAX link. The result of this function is notified back to the MIHF with a C-HO-RSP. After, the MIHF is periodically reported with the measurements of the link by receiving C-HO-RSP messages sent by the WiMAX MAC. Furthermore, the WiMAX MAC has the capability to predict when the link is going down, and reports it to the MIHF by sending a C-HO-IND message. The exchange of messages is shown in figure 3.19.

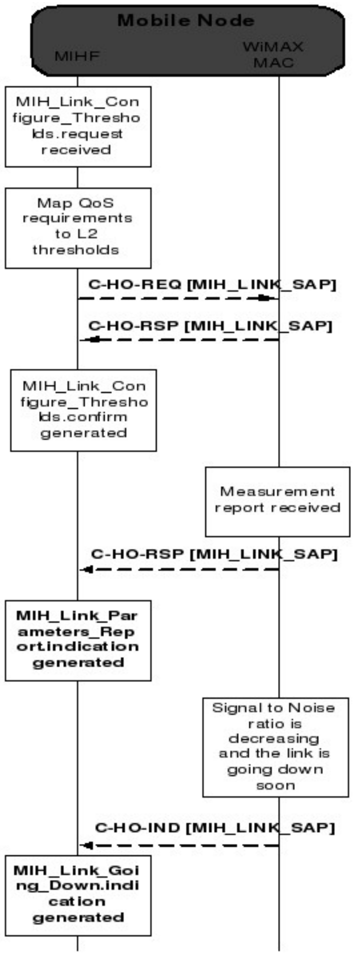

Figure 3.19: WiMAX - Link unavailability - HO Initiation phase[6]

- Handover Preparation (to a WiMAX network):

  - Power On & Scan

    The power on of the interface is done by the exchange of a M-SSM-REQ/RSP (Power-on) message between the MIHF and the WiMAX MAC. After the interface is up, through a C-HO-REQ (HO-SCAN), the WiMAX MAC starts scanning the air link. If there is a candidate network, DL_MAP, UL_MAP, DCD and UCD messages are received by the MN MAC coming from the candidate WiMAX BS MAC as a result of this scan. This results are reported to the MIHF with a C-HO-REQ (HO-SCAN) message (see figure 3.20).

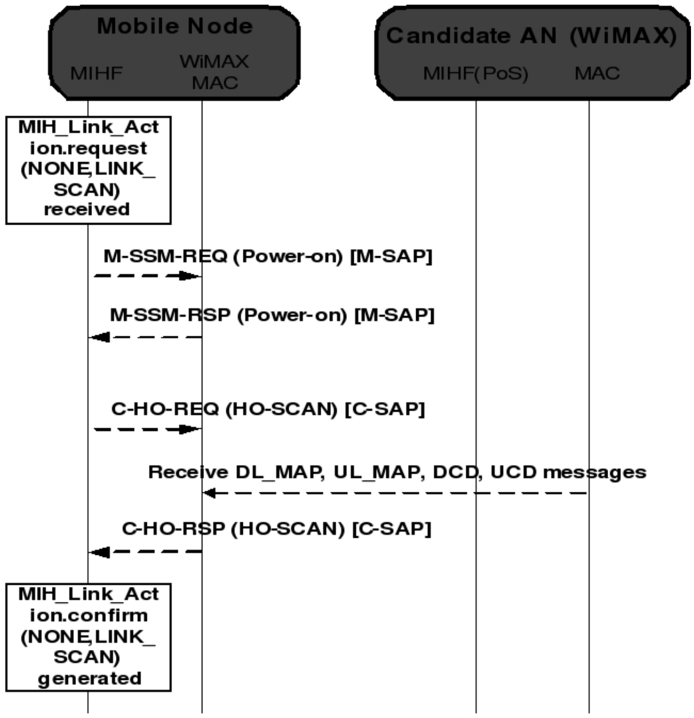

Figure 3.20: WiMAX - Power On & Scan - HO Preparation phase[6]

- Resource Check

  At this phase, when the MIHF of the WiMAX BS receives a MIH_Link_Get_Parameters.request it exchanges a C-RRM-REQ/RSP (Spare Capacity Report) message with its MAC to collect the available resources which will be sent to the MN through the MIH_Link_Get_Parameters.response. The process is showed in figure 3.21.

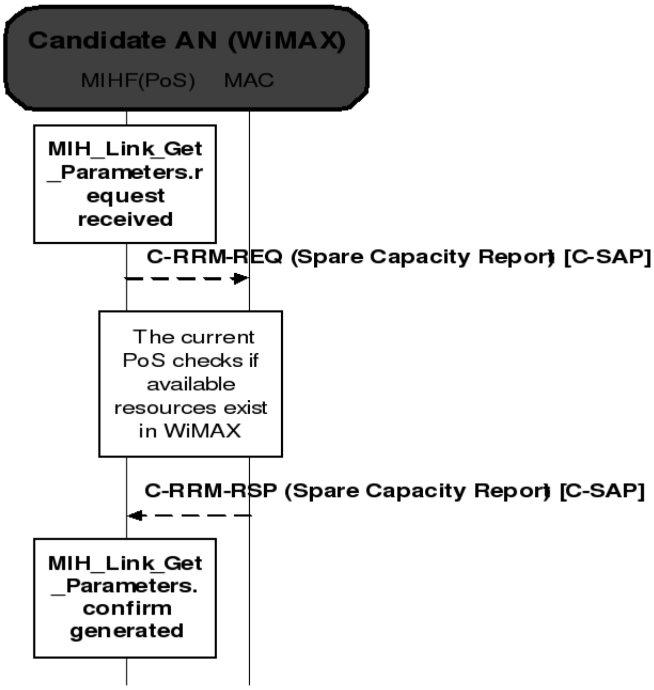

Figure 3.21: WiMAX- Resource Check - HO Preparation phase[6]

– L2 connection establishment

As a result of the reception of a MIH_Link_Actions.request (POWER_UP) message at the MN, the process of L2 connection establishment is initiated. In WiMAX, the MN is ordered to power on the interface and perform ranging, SS basic capability and registration procedures (figure 3.22).

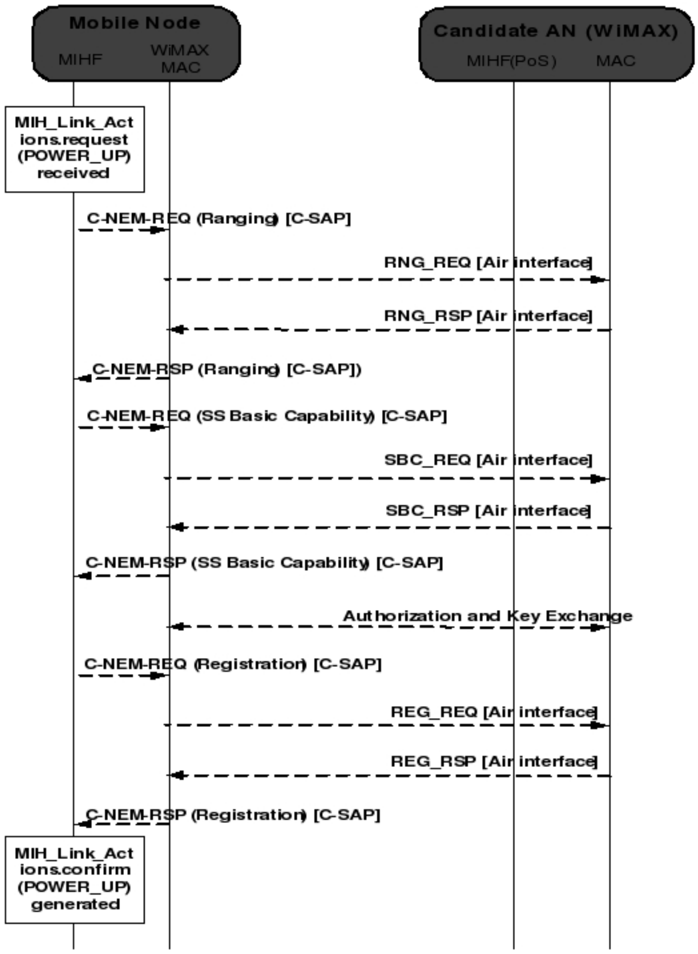

Figure 3.22: WiMAX- L2 connection establishment - HO Preparation phase[6]

– Resource Reservation

Reservation of resources in WiMAX networks, as in UMTS or Wi-Fi, starts with the reception of a MIH_Link_Actions.request (QOS_RESERVATION) at the MN MIHF from the MIH user. After receiving this message, a C-SFM-REQ (Create) is sent to the MN WiMAX MAC in order to reserve the resources at the WiMAX network. The WiMAC MAC will send a DSA-REQ to the WiMAX SS, and will receive a DSA-RSP if the resources were sucessfuly reservated. After, the WiMAX MAC will inform the MIHF of the reservation through a C-SF-RSP (Create), which will be forwarded to the MIH user through the MIH_Link_Actions.confirm (QOS_RESERVATION). Figure 3.23 shows the exchange of messages in this process.

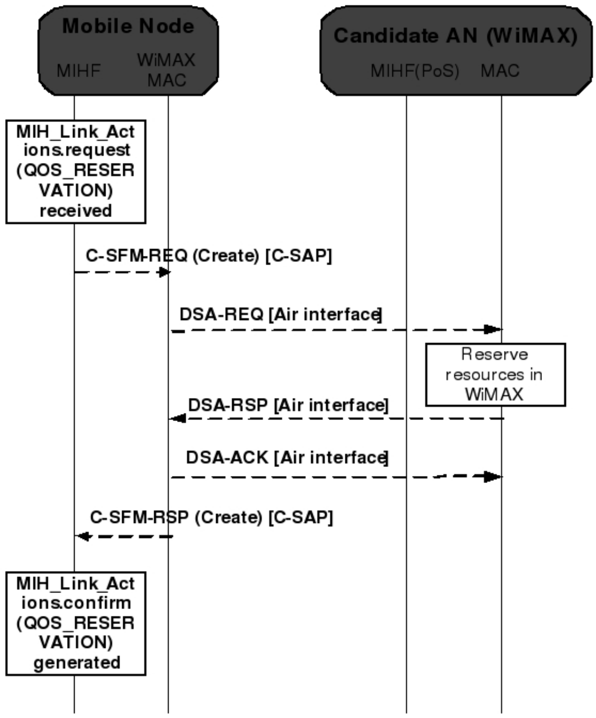

Figure 3.23: WiMAX- Resource Reservation - HO Preparation phase[6]

- Handover Completion (from WiMAX to another network):

  In this phase, the releases on the old access network (WiMAX) are released and the interface is powered down. As figure 3.24 shows, by receiving a MIH_Link_Actions.request (QOS_DELETION, POWER DOWN) message, the MIHF sends a C-SFM-REQ (Delete) message to the WiMAX MAC which will trigger the deletion of any QoS connection established over WiMAX. The result or the deletion will be reported to the MIHF through a C-SFM-RSP (Delete) message, and after, using a M-SSM-REQ/RSP (Power-down) the MN WiMAX interface is powered down.

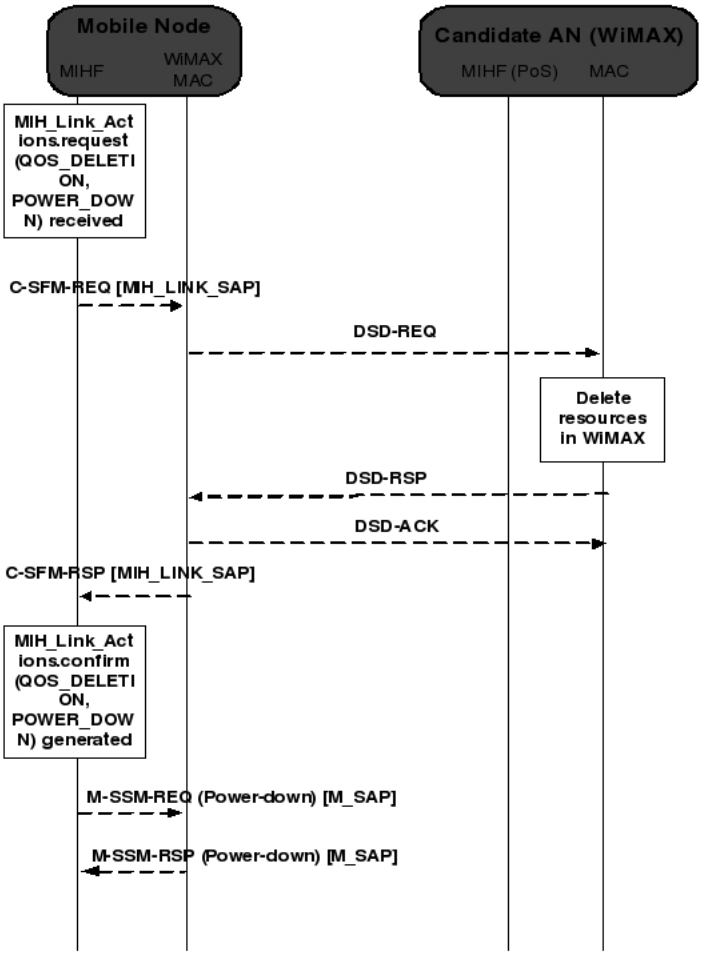

Figure 3.24: WiMAX- Complete - HO Completion phase[6]

3.3 Implemented HO Procedures

This section depicts the implemented handover procedure. The section is divided into four subsections, which represent the four steps of the process: Handover Initiation, Handover Preparation, Handover Execution and Handover Completion. In chapter 4, is presented the implementation done in NS-2, in order to create the procedure here presented.

In chapter 4, it is presented the already existing implementation regarding the handover procedures, as well as the modifications done to improve it.

3.3.1 Handover Initiation

3.3.1.1 Network Topology Acquisition

In this phase, the MN is connected to the serving network, and through it can access the IS and obtain information about candidate networks in the MN neighborhood. Figure 3.25 shows the messages exchanged in this process.

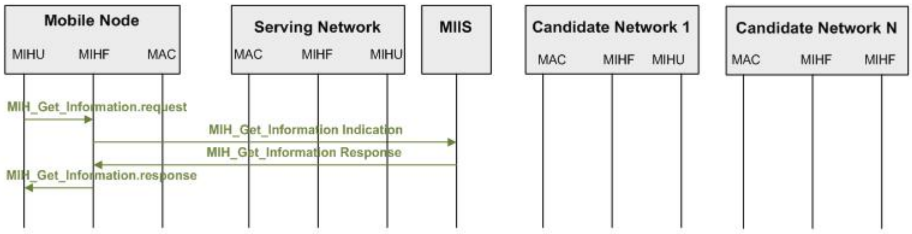

Figure 3.25: Network Topology Acquisition

3.3.1.2 Resources Availability Check

After acquiring the available networks in its range, the MN starts the Resource Availability Check by sending a MIH_MN_HO_Candidate_Query Request to his serving PoS. The serving PoS queries the networks about their available resources (MIH_N2N_HO_Query_Resources messages) and returns those values to the MN through a MIH_MN_HO_Candidate Response.

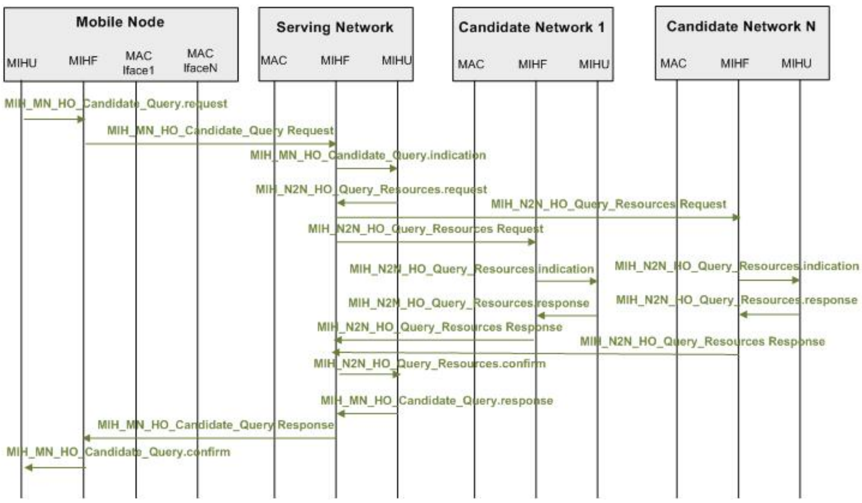

Figure 3.26: Resource Availability Check

3.3.2 Handover Preparation

Based on the information provided by the Resources Availability Check process, the MN decides which will be the target network. After the decision, the MN sends a MIH_MN_HO_Commit Request message to the serving PoS, and the PoS will prepare the resources at the target network by sending a MIH_N2N_HO_Commit Request. The target PoS responds with a MIH_N2N_HO_Commit Response, and the serving PoS notifies the MN of the reservation result through a MIH_MN_HO_Commit Response.

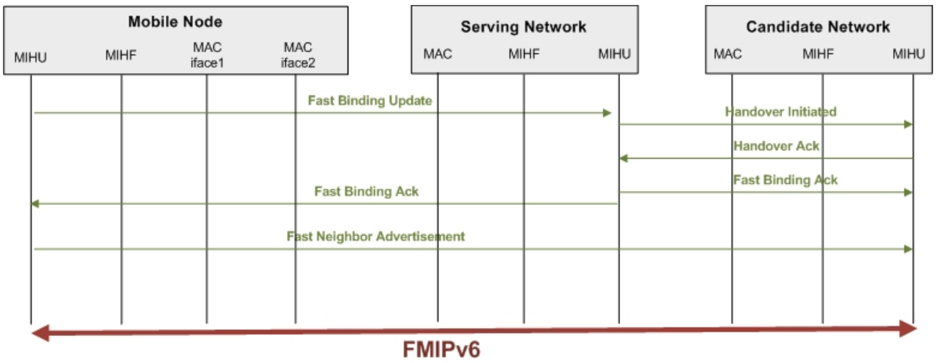

Figure 3.28: Handover Execution (FMIPv6)

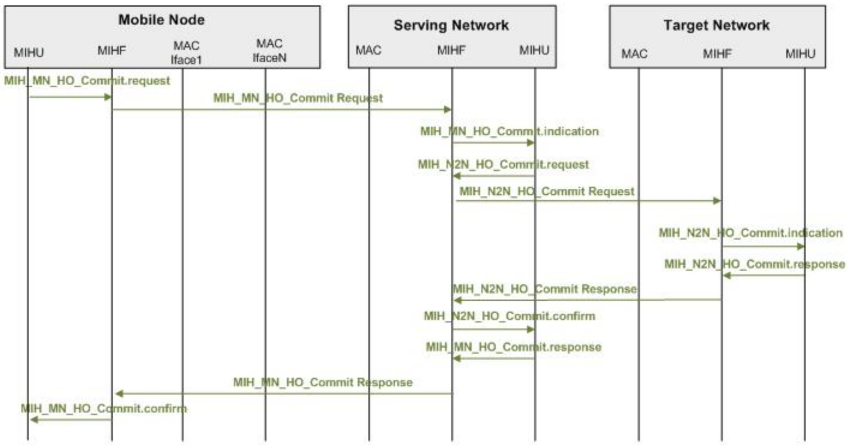

Figure 3.27: Handover Preparation

3.3.3 Handover Execution

In order to perform the Handover Execution, it is used the FMIP (section 2.2.1.2). The MN starts by sending a Fast Binding Update (FBU) message instructing its Previous Access Router (PAR), on his serving network, to redirect its traffic towards the New Access Router (NAR).

The PAR sends a Handover Initiated (HI) message to the NAR. After receiving the HI message, the NAR sends a Handover Acknowledge (HA) message confirming that it received the HI message.

After receiving the HA message, the PAR sends a Fast Binding Acknowledge (FBA) message to the MN and to the NAR warning them that he is already forwarding the MN packets to the NAR.

The MN receives a FBA on the previous link. This means that the packet tunneling is already in progress by the time the MN handovers to the NAR. The MN send a Fast Neighbor Advertisement (FNA) immediately after attaching to the NAR, so that arriving and buffered packets can be forwarded to the MN right away. Figure 3.28 shows the messages exchanged in the handover execution process. [4]

3.3.4 Handover Completion

In this final last step the MN will release the resources at the previous serving network by sending a MIH_MN_Complete Request through the net PoS.

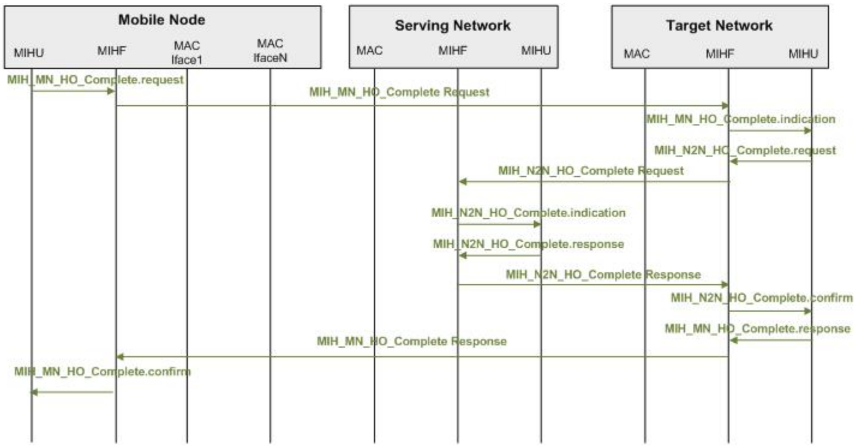

Figure 3.29: Handover Completion

3.4 Dynamic Media Independent Information Server

3.4.1 The idea/concept

The IEEE 802.21 standard defines the MIIS as a static information storage entity. This server can have information such as: the networks available in a given geographical area, the operator of the network, the service provider, the cost for service or network usage and QoS characteristics of the link layer. Almost all the information mentioned doesn't change, it's static, however, information such as the available QoS resources are not always the same. For example, at a certain moment, the Wi-Fi PoA has 11Mbps available, but later on it can have only 1Mbps. Therefore, it is important to store dynamic information in the IS.

This new concept intends to give the MIIS the capability to store dynamic information, with which it can provide the MN much more and much useful information for the handover decisions.

In order for the IS to have the information about the technologies, it is necessary that the technologies update it with their available resources. Nowadays, the access networks architecture, such as WiMAX or 3GPP, have gateways (GW) responsible for collecting and controlling a group of BSs of a certain type of access technology. As the GWs have permanent updated information about the resources, they can provide this information to the IS. Thereby, a new 802.21 message is implemented (MIH_Update_Information) with the purpose of providing the IS with the updated information.(figure3.30).

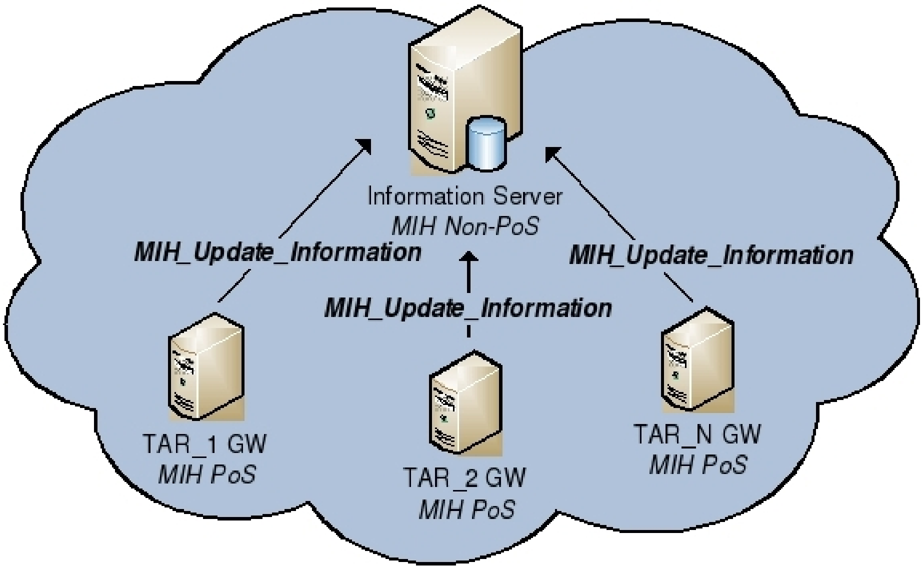

Figure 3.30: IS with dynamic information

The following table presents the description of the MIH_Update_Information message:

MIH Header Fields	Description
Source Identifier	source MIHF ID (PoS)
Destination Identifier	destination MIHF ID (MIIS)
InfoUpdateBinaryDataList	(Optional) Binary representation list of the Information Elements (IEs). The list is organized from the high to the less priority IE.
InfoUpdateRDFDataList	(Optional) List organized in the Resource Description Framework (RDF) format. The list is organized from the high to the less priority IE.
InfoUpdateRDFSchemaURLList	(Optional) List organized in the RDF Schema URL. The list is organized from the high to the less priority IE.
InfoUpdateRDFSchemaList	(Optional) List organized in the RDF Schema format. The list is organized from the high to the less priority IE.
UpdateNetworkType	Type of network which is doing the update of the resources to the IS

Table 3.7: MIH_Update_Information message fields

The frequency of the update messages sent to the IS depends on the load of the PoAs; in other words, if the PoA radio channel occupation is high the messages are more frequent than when the level of occupation is lower. When the occupation of the PoA is low, there is no need to send the update messages so frequently as when there are changes in the channel. The purpose of this procedure is to find out which are the candidate access networks for a handover, and with the resources information select the most suitable. These update messages should not interfere significantly in the network performance, since they are sent through cable connections of high bit rates.

According to this concept, a IS should be responsible for a specific topologic area, and a communication between ISs should be established.

Using this concept, the two different phases in the Handover Initiation, network topology acquisition and resources availability check, is only one. With a dynamic IS having the current information about the PoAs resources, it is possible to retrieve both the network topology and available resources in the same process.

3.5 Summary

As it was possible to see through this chapter, for each technology there is a different interaction with the IEEE 802.21. In a structural point of view of the handover process, it is clear that the main difference between the handover process defined in the IEEE 802.21 standard draft 14 and the proposed Dynamic MIIS is the exclusion of the Candidate Query process. With a Dynamic MIIS, the IS has current information about its networks, enabling it to retreive information regarding the networks resources to any MN associated to the IS in the Get Information process. Therefore, the Candidate Query process is no longer necessary.

Chapter 4

Implementation

Today's needs and demands make the telecommunications a constant growing area. New technologies take time to be ready for experimentation, and since the IEEE 802.21 standard was not finalized at the beginning of this Thesis, all extensions and integrations were done using the network simulator 2, in order to evaluate the performance of the protocol using diferent access technologies.

In this chapter, we describe the simulator used for performing the handovers in an heterogeneous environment. It is also presented two important add-ons made to the simulator which enhance its performance with the IEEE 802.21 protocol. The additions made to the simulator are presented in the third section of the chapter, detailing each change made to it in order to complete the missing parts of the handover process, including the dynamic MIIS, as well as to integrate the UMTS techonolgy with the MIH entities.

The chapter is organized in four main sections. Section 4.1 presents an overview of the simulator used and two add-ons already available for it, regarding the IEEE 802.21. As to section 4.2, it details which functions NS-2 already supports and those that are missing. Section 4.3 shows the modifications and new implementations done to the simulator in order to completly integrate the UMTS technology and create the MIIS structure. The last section is a brief summary regarding the chapter.

4.1 Network Simulator

The purpose of this thesis is to study handovers between heterogeneous technologies (Wi-Fi, WiMAX, UMTS) using the IEEE 802.21 standard. To evaluate the performance of our solution we have used the "Network Simulator 2" tool.

NS-2 is an open-source event-driven simulator designed specially for research in computer communication networks. Incepted in 1989 as NS and being under enhancement since then, today the NS-2 contains substantial support for simulation of TCP, routing, multicast protocols over wired and wireless (local and satellite) networks and others. Recent researches, such as 802.21 which has been under development over the last years can require previous simulation before real implementation. These recent researches are rarely implemented in NS-2. NS-2 is a very complex simulator and incorporating new modules into it requires profound understanding of NS-2 architecture. Unfortunately there is no guide book which can help the beginners to understand NS-2 architecture in depth. The lack of guidelines for extending NS-2 is perhaps its greatest obstacle.[15]

Nowadays, both academic and industry area resort to NS-2 for designing, testing and evaluating protocols as well as architectures. A new version of the NS, NS-3, is being developed and is already available but still very incomplete.

4.1.1 NIST add-on

4.1.1.1 Overview

Known between 1901 and 1988 as the National Bureau of Standards, the National Institute of Standards and Technology (NIST) is a measurement standards laboratory. It's purpose is to promote

U.S. innovation and industrial competitiveness by advancing measurement science standards, and technology in ways that enhance economic security and improve quality of life.[16]

The integration of UMTS (UTRAN), Bluetooth, 802.16 technologies are some of the upgrades provided by the NIST add-on. It also provides an implementation of the MIH framework based on the IEEE 802.21-draft 14 specifications; a generic design for nodes (network nodes, in this case a mobile node) with multiple interfaces; and the support for subnet discovery and change of address. All the wireless technologies allow heterogeneous handovers, including the 802.11 that was modified to support it.[7]

4.1.1.2 802.21 Implementation

In the NS-2 NIST add-on, the implementation of the entities is made with Agents, which enables the entities to send and receive layer 3 packets to and from remote MIHFs. The main agents defined are:

- MIHAgent - refers to the MIHF. The class handles the list of MIH Users and their registration information and also takes care of the communication with the remote MIHFs. Finally it has the list of the local interfaces to get their status and control their behavior through the media independent interface (MIH_SAP) and the media dependent interface (MIH_LINK_SAP and media specific primitives). The MIHAgent design is showed in the figure 4.1.

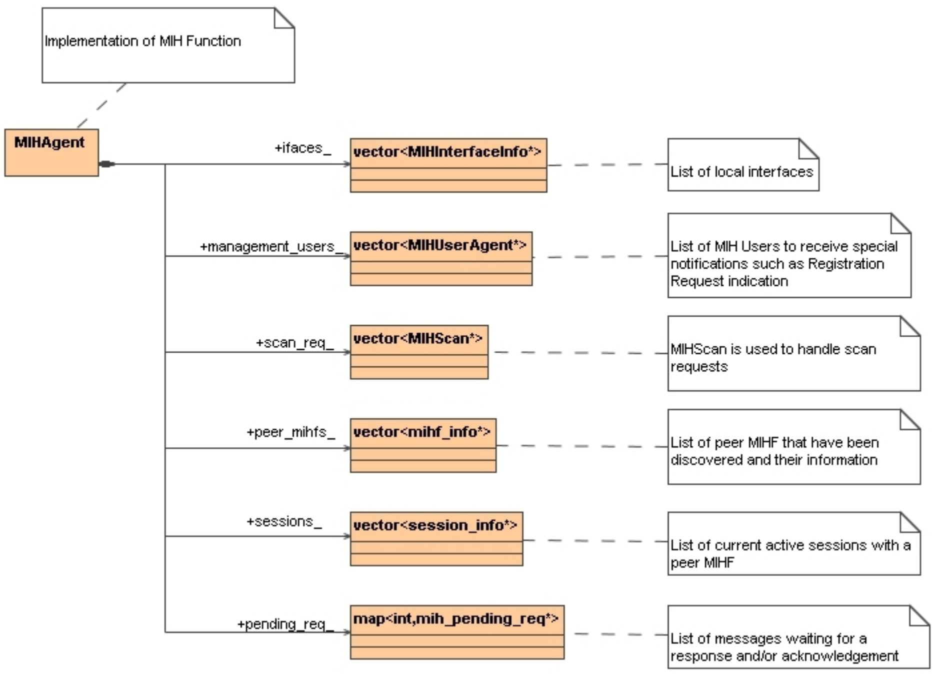

Figure 4.1: MIHF design [7]

- MIHUser - an Agent that needs to register itself with the MIHF in order to receive events from local and remote interfaces. The MIH Users are entities that make use of the MIHF fuctionalities in order to enhance user performances by optimizing handovers. Since there are an infinite number of implementations depending on the user preference or network policies, the implementation provides an abstract class MIHUser that can be easily extended. The class hierarchy of the MIHUser is showed in figure 4.2.

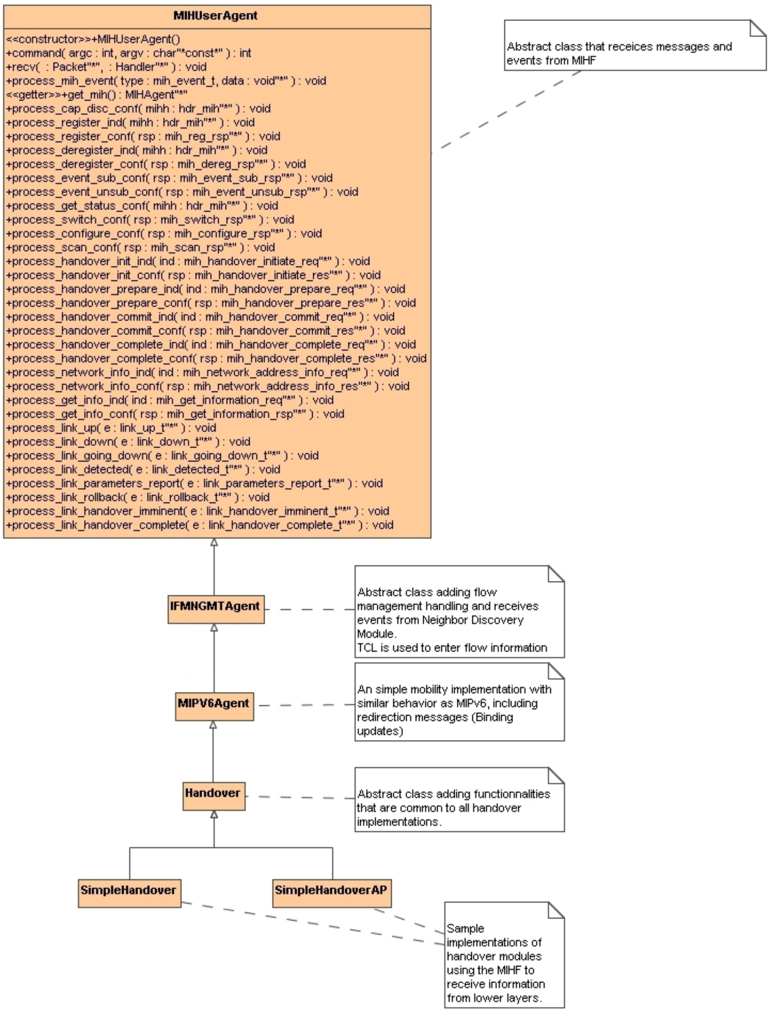

Figure 4.2: MIH User class hierarchy [7]

The interface between the MAC layers and the MIHF is done via Tool Command Language (TCL), the language used to create the simulations/scenarios.

To enhance usability, the MIH implementation also provides a series of abstract classes that contain commonly used functionality. The IFMNGMT (interface managment) provides flow management functions. Using the TCL, the user can register the flows that are being used in the node. This facilitates the handover module in finding the flows that it needs to redirect. It also receives events from the ND (node) agent when a new prefix is detected or when it expires. The MIPv6Agent adds the redirection capability to the MIH User. When a flow needs to be redirected, a message can be sent to the source node to inform him of the new address or interface to use. Finally, the Handover class provides a template for handover modules and computing a new address after successful handover.[7]

This add-on does not have an implementation of the MIH Users on the network, therefore there is no interaction between MIH Users from the network and MN. The figure bellow shows the MIH design overview from NIST.

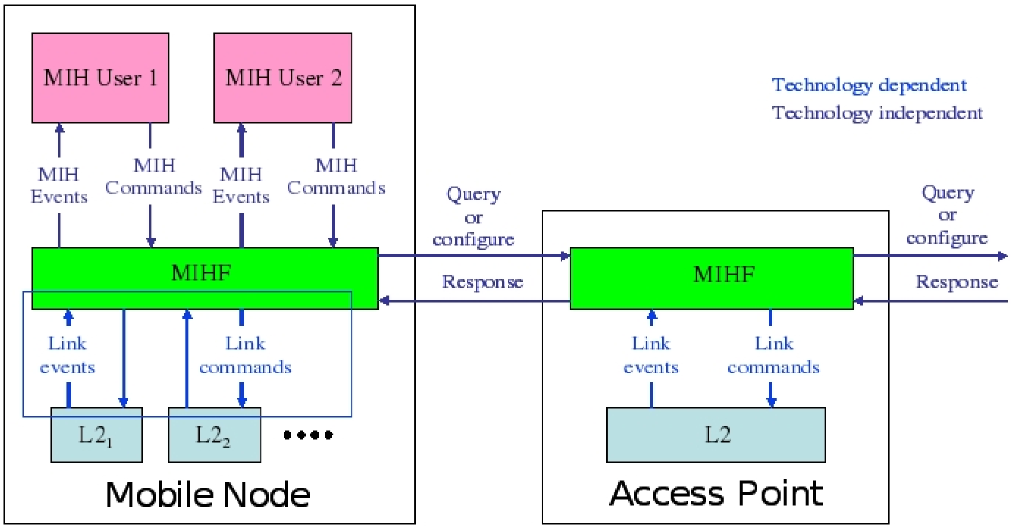

Figure 4.3: MIH design overview from NIST [7]

4.1.2 Basic Wi-Fi-WiMAX Handover Support

Other add-ons to NS-2 were done in 2008. Using the NIST add-on, he upgraded the 802.21 implementation that was still very incomplete. This upgrade was based on the draft 8 of the IEEE 802.21 protocol, with the purpose of simulating handovers between Wi-Fi-WiMAX and WiMAX-WiMAX networks. This work was focused essentially in the implementation of MIH Commands, however these commands only fit for Wi-Fi-WiMAX and WiMAX-WiMAX handovers. The implementation doesn't work for Wi-Fi-UMTS or WiMAX-UMTS handovers, and only supports one candidate network. The network's MIH User was also implemented in this upgrade.

Since the MIPv6 is not supported either by the original NS-2 nor the NIST add-on, it was not possible to implement the FMIPv6. The redirection of the flow is done through a redirect message.[4]

4.2 Analysis of the Simulator

4.2.1 Supported/Missed functions

This section enumerates the messages already implemented in the simulator related to the IEEE 802.21 protocol. In particular, we present the service management, events and command messages in table 4.1.

	Service Management Primitive	Description	Implemented by
√	MIH_Capability_Discover	Discover list of Events and Commands sup- ported by MIHF	NIST
√	MIH_Register	Register with a remote MIHF	NIST
√	MIH_DeRegister	Deregister with a remote MIHF	NIST
√	MIH_Event_Subscriber	Subscribe for MIH event notifications	NIST
√	MIH_Event_Unsubscribe	Unsubscribe from MIH event notifications	NIST

Table 4.1: Service Management Primitives implemented in the simulator

Every Link event has an MIH event associated, and so, the following table refers to both MIH and Link events.

	Event	Type	(L)ocal/(R)emote	Description	Implemented by
$\surd$	Link_Up	State Change	L/R	L2 connection has been established	NIST
$\surd$	Link_Down	State Change	L/R	L2 connectivity is lost	NIST
$\surd$	Link_Going_Down	Predictive	L/R	L2 connectivity is predicted to go down	NIST
$\surd$	Link_Detected	State Change	L/R	A new link is detected	NIST
$\surd$	Link_Param_Report	Link Parameters	L/R	Link parameters have crossed specified threshold	NIST
χ	Link_PDU_Transmit_Status	Link Transmissions	L	Indicate transmission status of a PDU	-
$\surd$	Link_Handover_Imminent	Link Synchronous	L/R	L2 handover is imminent	NIST
$\surd$	Link_Handover_Complete	Link Synchronous	L/R	L2 handover has been completed	NIST

Table 4.2: MIH/Link Events implemented in the simulator

Tables 4.4 and 4.6 refer to the link and MIH commands, showing those which are already implemented and those that are not (or incomplete).

	MIH Commands	(L)ocal/(R)emote	Description	Implemented by
$\surd$	MIH_Get_Link_Parameters	L,R	Get the status of link	NIST
$\surd$	MIH_Link_Configure_Thresholds	L,R	Configure link parameter thresholds	NIST
χ	MIH_Link_Actions	L,R	Control the behavior of a set of links	-
χ	MIH_Net_HO_Candidate_Query	R	Initiate handover	-
χ	MIH_MN_HO_Candidate_Query	R	Initiate MN query request for candidate network	[4]
χ	MIH_N2N_HO_Query_Resources	R	Query available network resources	[4]
χ	MIH_MN_HO_Commit	L	Notify the serving network of the decided target network information	[4]
χ	MIH_Net_HO_Commit	R	Network has committed to handover	-
χ	MIH_N2N_HO_Commit	R	Notify target network that the serving network has committed to handover	[4]
χ	MIH_MN_HO_Complete	R	Initiate MN handover complete notification	[4]
χ	MIH_N2N_HO_Complete	R	Handover has been completed	[4]

Table 4.4: MIH Commands implemented in the simulator

	Link Command	Description	Implemented by
χ	Link_Capability_Discover	Query and discover the list of supported link-layer events and link- layer commands.	-
$\surd$	Link_Event_Subscribe	Subscribe to one or more events from a link.	NIST
$\surd$	Link_Event_Unsubscribe	Unsubscribe from a set of link-layer events.	NIST
$\surd$	Link_Configure_Threshold	Configure thresholds for Link Parameters Report event.	NIST
$\surd$	Link_Get_Parameters	Get parameters measured by the active link, such as signal-to-noise ratio (SNR), BER, received signal strength indication (RSSI).	NIST
χ	Link_Action	Request an action on a link-layer connection.	-

Table 4.6: Link Commands implemented in the simulator

Table 4.7 presents the description regarding the MIH Information.

	MIH Information	Description	Implemented by
χ	MIH_Get_Information	Request to get information from repository	-
χ	MIH_Push_Information	Information Notify the mobile node of operator policies or other information	-

Table 4.7: MIH Information implemented in the simulator

As it is possible to see through the analysis of the previous tables, some messages from the 802.21 protocol are missing. The most relevant implementation missing is the Link Action command, because it is the one that allows the MIHF to command the interfaces. It would be a major value to be implemented in NS-2, however it is of great difficulty, since it would require an even more deep analysis of the simulator in order to know how the implementation could be done.

The MIIS is also an important element missing in this simulator.

4.3 NS2/NIST 802.21 Modifications

In this section we enumerate the additions and modifications made to the simulator in order to improve the current IEEE 802.21 implementation.

The current state of the simulator only allowed, as mentioned before, handovers between Wi-Fi-WiMAX. Even though the NIST add-on provides the UMTS technology, their definition of MIH with UMTS is very poor, probably because the UMTS code was not developed by NIST, but by another organization named EURANE[17]. So, the concept of handover between UMTS and other technologies is not well defined in the simulator, and in order to implement it, was necessary a very deep analysis of both the add-ons, as well as the NS-2 implementation.

There are several points extremely important to mention about the simulator's current UMTS implementation, which are:

- the implementation is based on the 3GPP Release 99, and so the model implemented is the UTRAN. When defining an UMTS scenario we define the RNC, BS and the UE.

- the concept of mobility using an UMTS interface is distorted. In fact, what happens is that the UE is a stationary point that has no capability to move and is always in the BS range. However what is done is that, the UE (interface) is defined and associated to a MN, so wherever the MN is, it is connected to the UMTS interface. The disadvantage is that the MN never leaves the UMTS BS range, and there is no possibility to simulate handovers between UMTS cells. The interpretation made regarding this situation was:
  - Nowadays, the 3GPP is available worldwide and the user has access to the 3GPP network almost everywhere.

    This thesis was done with this reality in mind.
- when defining any type of device in NS-2, whether it is a router, a Wi-Fi/WiMAX BS or a MN interface, the simulator creates the MAC layer, and with it, an unique MAC address associated to the device. However this doesn't happen with the UMTS devices, namely the BS and the UE. According to the channels that are configured, DCH or HS-DCH, the MAC adresses are change. The devices are created with a specific MAC address by the base MAC class, but are changed according to the configurations made in the UMTS specific MAC class. Regarding this issue, the simulator works in the following way:
  - Each technology has its specific MAC class. The NS-2 when creating any element, calls its MAC class which is common to all elements, and after that the specific one for each technology is called. In the UMTS case, when the specific one is called, it changes the unique MAC address given by the base class.

4.3.1 Modifications

It is important to mention that the modifications made to the simulator in order to allow the interaction between the IEEE 802.21 and the UMTS technology were done, taking in consideration that the data channel used for UMTS in the simulations was the DCH channel.

4.3.1.1 MAC Layer

Regarding the MAC address issue for UMTS elements, some changes in the simulator were done, namely in the MAC class.

To exchange the MIH messages between the diferent entities the current implementation works as follows: each MIH entity has associated to it a MAC address; in order to send messages we need to get the IP addresses; this is done through a function that receives as input the entity MAC address and returns the IP address of its node. In other words, we need the MAC address provided to each entity in the NS-2 MAC class, whether it is changed or not later (as happens with UMTS).

In order to provide unique MAC address values into UMTS elements, so that they could be distinguished it was necessary to made a small change in the MAC layer of the simulator. The NS-2 MAC layer is defined in the files located in the "mac" folder, namely in the mac.cc and mac.h files. An extra variable was created in order to store the original values of the MAC addresses. With this change, the variable of the MAC address of UMTS elements is still with the value zero, which is necessary for the UMTS structure to work, but at the same time it is possible to distinguish them from each other, and from other elements in the network by analyzing the new variable.

4.3.1.2 MIHF

The MIH code was also provided with several changes due to the UMTS technology:

- First of all, UMTS does not support broadcast, and so when a UE is sending a Capability Discover Request, it needs to send directly to the target MIH.

- As it is known, theoretically the UMTS network MIH is suppose to be in the BS in order to control each BS individually. However, due to the simulator limitations it was not possible to install it in the BS and as in the simulations there is only one BS for UMTS, the solution found was to install the MIH in the RNC node, and connect it to the MAC layer of the BS. This has no relevant implication because in this case the RNC only covers one BS. Although the network

  MIH for UMTS being in the RNC does not have major influence in a theoretically level, it has regarding the MIH implementation. Several functions already implemented were modified in order to support the UMTS network MIH. The main functions were:

  - MIH_Link_Up
  - MIH_N2N_HO_Query_Resources Request
  - MIH_MN_HO_Candidate_Query Response
  - MIH_N2N_HO_Commit Request
  - MIH_N2N_HO_Commit Response
  - MIH_MN_HO_Commit Response
  - MIH_N2N_HO_Complete Request
  - MIH_N2N_HO_Complete Response
  - MIH_MN_HO_Complete Response

- The current simulator implementation only performs IEEE 802.21 handovers when a Link Going Down is detected. In this new upgrade, it is possible to perform a handover not only in a Link Going Down case, but also when a Link_Detected is received. The IEEE 802.21 - draft 14 in its examples only shows handovers deployed by a MIH_Link_Going_Down message. However it is possible that we are for example connected to an UMTS network, that provides the user the required resources, but at some time we have availale another network that can have a better performance or even a better pricing and still provide the user its requirements. In this situation, the user could turn the interface up in order for it to detect the new network and see if it has better conditions than its serving network. If so, a handover process would occur.

The modifications mentioned above, are considered the most relevant ("high level") ones. Each of of these modifications led to more changes in the code, considered "low level" changes, and as so are not mentioned here.

4.3.2 New Functions

This section enumerates and describe the commands that were added/implemented in order to execute both handovers proposed in chapters 3 (with static and dynamic MIIS).

MIH Command
MIH_Get_Information
MIH_Update_Information (New message/Out of the IEEE 802.21 standard)

Table 4.8: MIH Commands added

Entity
Media Independent Information Service (MIIS)

Table 4.9: Entities added

The MIHF is implemented in the class MIHAgent located in the files mih.cc and mih.h (header file). The functions added in this class were mainly required for the sending and receiving of the following messages:

- MIH_Get_Information request
- MIH_Get_Information indication
- MIH_Get_Information response
- MIH_Update_Information

Each one of these new messages is responsible for transporting specific information. In order to clarify what each message contains, the information of each one of them is mentioned beneath:

MIH_Get_Information.request Parameters: dest_id, which has the MIHF_ID of the destination of the request (PoS); mn_position, which specifies the current position of the MN so that the IS provide the access networks in the MN's range.

MIH_Get_Information.indication Parameters: source_id, is the MIHF_ID of the source of the request (MN); mn_position, that forwards the information received in the MIH_Get_Information.request about the MN's position.

MIH_Get_Information.response Parameters: dest_id, is the MIHF_ID of the destination of the response (information provided by the source_id in the MIH_Get_Information.request); num_candidates, which has the number of possible PoA candidates in the response; miis_candidate_list, has the information about each one of the PoAs such as the network type, network ID and its resources.

MIH_Update_Information Parameters: source_id, indicates the source of the information so that the IS knows which PoA information to update; parameters, has the information about the current resources of the PoA.

The main functions added to the MIHF located in the files mih.cc and mih.h, in order to process the new messages were:

- send_get_info_req - prepares the message created by the MIH User and sends it.
- recv_get_info_req - receives the message and collects the information to pass to the MIH User.
- send_get_info_ind - with the information provided by the MIH User, this function is responsible for sending the MIH_Get_Info indication to the IS responsible for the network.
- recv_get_info_res - function responsible for receiving a MIH_Get_Information response. If the message is in the network MIHF, this function forwards the message to the MIHF user that requested the information (MN).
- process_get_info_res - function to forward the MIH_Get_Information response received from the IS to the MN if the MIH where it is, is from a PoA.
- send_get_info_res - sends the MIH_Get_Information response to the MN.

Also the MIH Users, located in the files Handover_PoA.cc, Handover_PoA.h, Handover_MN.cc and Handover_MN.h were changed. The Handover_PoA refers to the network MIH User while the Handover_MN refers to the terminal MIH User. The functions added were:

- In the terminal MIH User
  - process_get_info_req: after receiving the indication to start the handover process (MIH_Link_Going_Down or MIH_Link_Detected) informs the MIHF to send a MIH_Get_Information Request to the PoA MIH
  - process_get_info_conf: informs the MIHF to proceed with the handover, whether the following message is an MIH_MN_HO_Candidate_Query Request as in it is stated in the standard, or a MIH_MN_HO_Commit Request using a Dynamic MIIS.

- In the network MIH User
  - process_get_info_ind: informs the MIHF to send a MIH_Get_Information Indication to the IS.
  - process_update_information: informs the MIHF to send a MIH_Update_Information to the IS.

The Information Server was implemented in the folder hstng/miis. The files created were the miis.cc and the miis.h.

First of all it was necessary to create a new agent, to install the IS in a device (in the simulations it was installed in routers). This agent was named MIISAgent and the following variables were associated to it:

- miisId_ - unique MIIS identifier.
- num_PoA - number of PoAs registered in the IS.
- candidate_list - list of the PoAs information.

In order to create the IS as the 802.21 standard specifies, the following functions were implemented:

- recv_get_info_ind - processes the receipt of a MIH_Get_Information Indication
- process_get_info_res - gathers the information requested by the MIIS client and creates the MIH_Get_Information Response
- send_get_info_res - function responsible for sending the MIH_Get_Information Response message to the MIH of the MIIS client serving network.

The following functions were added, so that the IS is capable of receiving and processing the MIH_Update_Information message:

- recv_update_info: process the receipt of a MIH_Update_Information message.
- process_update_info: stores the information received from the PoA in the IS database.

4.3.2.1 MIH_Link_Going_Down

MIH_Link_Going_Down messages are sent when the conditions of a link to which the MN is connected are getting worst (e.g. losing coverage). The MN is receiving this message currently classified with a "degree" (%), until the link is down. The MIH User defines a limit value, and when this value is reached it starts to process an handover (see figure 4.4). The MN only starts the handover if the MIH User is using the link.

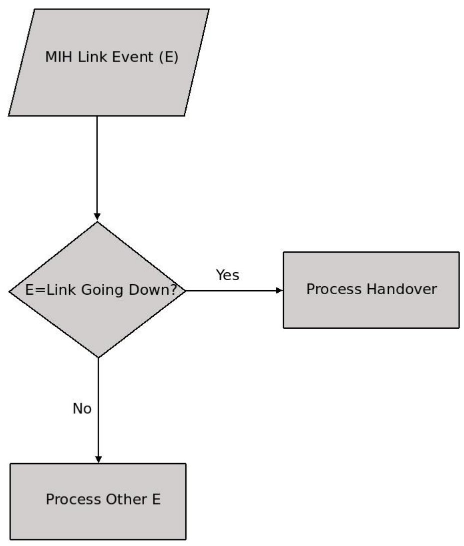

Figure 4.4: MIH_Link_Going_Down.indication

The MIH User, after knowing it has to initiate a handover, it can:

- Verify the status of other links to which the MN is connected (Link Up). If it has no Link Up, the MIH User requests the MIHF to perform a link scan on each interface including the one to which the MN is losing connection (see figure 4.5).

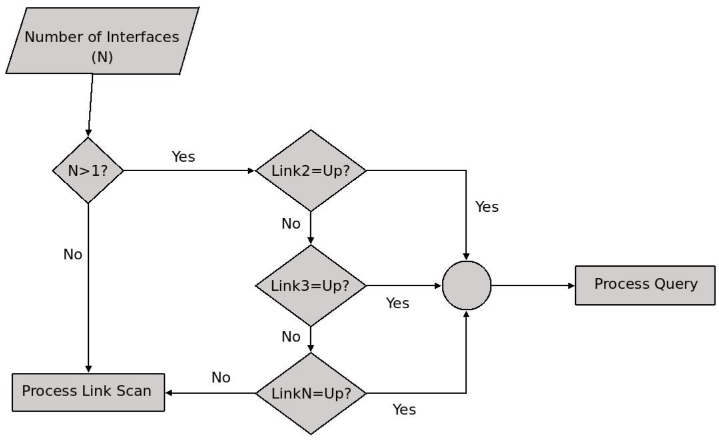

Figure 4.5: MIH_Link_Going_Down.indication (cont.)

Supposing that some Link was Up or that was found during the scan, it collects the information. In the meantime the MIH User verifies which resources are needed for each class of service (flow), according to the flows that are being used at the moment. After gathering this informations, it sends a MIH_MN_HO_Candidate_Query Request message to the serving network in order to know which of the candidate networks has the better resources to provide the MN.

- If the network is provided with an IS, it can process the handover by using the IS information. If so, the MN will send a MIH_Get_Information Request to the serving PoS with the purpose of knowing which networks are in the MN's range.

Figure 4.6: MIH_Get_Information.request

4.3.2.2 MIH_Link_Detected

As it was mentioned in section 4.3.1, the process of handover can be triggered by the reception of a MIH_Link_Detected when an interface of the MN detects a new network in range. In this situation it could be an advantage for the MN to perform an handover, and so, it sends a MIH_Candidate_Query Request message since it doesn't need the geographical network information provided by the MIIS.

4.3.2.3 MIH_Get_Information Request

When a PoA receives a MIH_Get_Information Request, it processes an indication message to the MIIS (MIH_Get_Information Indication) requesting information about the surrounding networks (see figure 4.7).

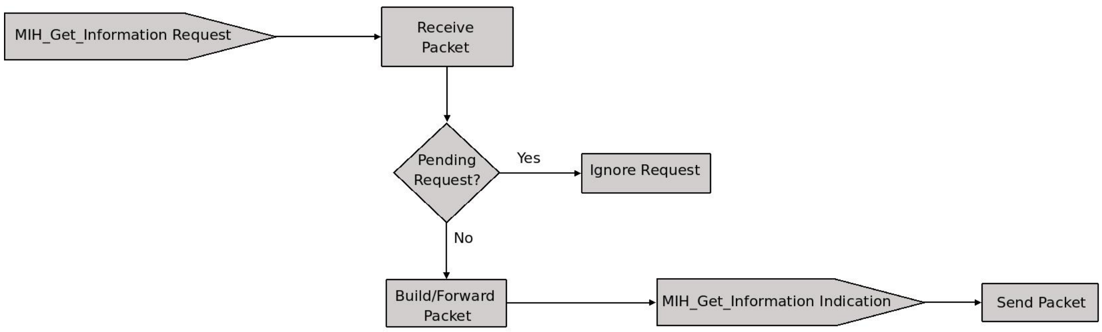

Figure 4.7: MIH_Get_Information.indication

A request for the IS can have queries for TVL, RDF, RDF Schema URL, and RDF schema. The priority of the queries is given by its order. The first query has the highest priority to be processed by the MIIS.

4.3.2.4 MIH_Get_Information Indication

When receiving a MIH_Get_Information Indication, the MIH User (MIIS Server) processes the query request and retrieves the specified information through a MIH_Get_Information Response (see figure 4.8).

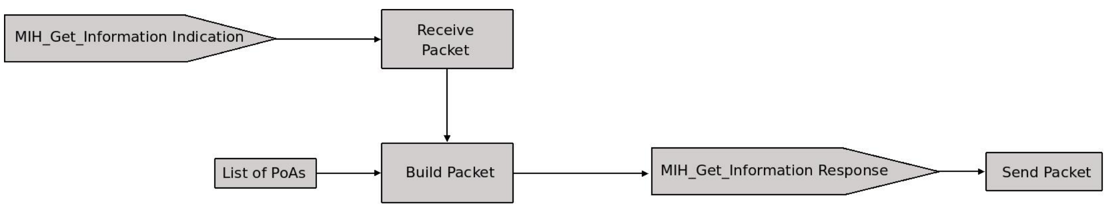

Figure 4.8: MIH_Get_Information Response

There is a field named MaxResponseSize, that specifies the maximum size of the Info Response parameters in the Response message. This parameter in the IS Server can be smaller than the one specified by the IS client. When this happens, one or more of the lower order list elements in the Info Response parameters are omitted.

4.3.2.5 MIH_Get_Information Response

The MIH_Get_Information Response is sent by the MIIS server; when getting to the serving PoA (where the network MIH is) another MIH_Get_Information Response will be sent to the designated MIIS client. Figure 4.9 ilustrates the process.

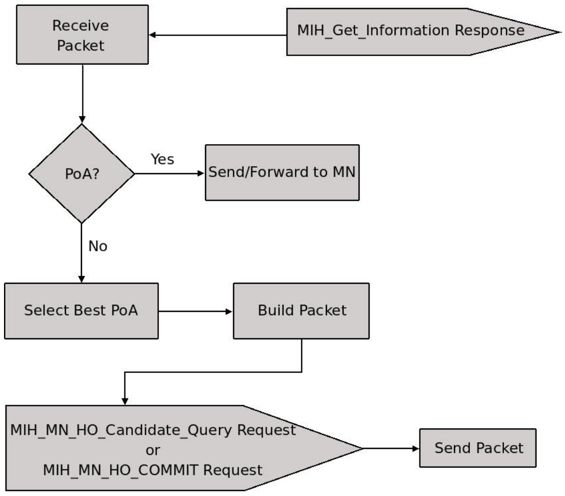

Figure 4.9: MIH_Get_Information.confirm

When the Information Response gets to the MIIS client, it takes suitable action according to the information provided by the IS.

At this point, according to the IEEE 802.21 standard the handover process should proceed with the schedule of a MIH_MN_HO_Candidate_Query Request message. However, in this study we will propose another approach, by sending a MIH_MN_HO_Commit Request on the reception of a MIH_Get_Information Response when using a dynamic IS. As explained in section 3.4, using a dynamic MIIS, the IS can provide updated information about the candidate networks to the MN in the Get Information process, being no longer necessary the Candidate Query process. In this case, the MN chooses the target network after receiving the MIH_Get_Information Response and sends a MIH_MN_HO_Commit Request to procede with the handover process.

4.3.2.6 MIH_Update_Information

In order to have a dynamic IS, it is necessary to provide it with the current status of the PoA's. In order to do so, this new message was implemented, carrying the information about the PoA resources. As explained before, the frequency of the messages should depend on the load of the PoA.

4.4 Summary

It was presented in this chapter the NS-2 simulator and the mobility add-ons functionalities already available to perform the integration of the 802.21 with the access technologies. We also presented and described the developed implementation in in order to enhance the 802.21 implementation in the NS-2 according to the IEEE 802.21 draft 14. Furthermore, we also described the implementation of the required functionalities for a dynamic MIIS.

Chapter 5

Results

In order to evaluate our implementation, we have created a scenario to simulate several inter-technology handovers. The development of the scenario tried to regard as much as possible a real practical situation (5.1). The wireless technologies available are UMTS, WiMAX and Wi-Fi. The three PoAs of the different technologies are connected to a common gateway, which makes the connection to the Core Network (that can be, for example, the Internet).

UMTS is deployed worldwide, being available almost everywhere. Of course there are exceptions, but we are considering mostly scenarios in urban areas, and there is rarely a place in a city where there is no UMTS access. Regarding this interpretation, we consider our scenario with full access to UMTS. WiMAX is a technology that will be experiencing widespread adoption in the next years, by commercial broadband operators. For now, we can only suppose possible scenarios for WiMAX. WiMAX (802.16e) can provide up to 70Mbps with a range of 20Km, however because of simulation limitations in this case we simulate with 500m of range. We can suppose for example that it is covering an University Campus. Regarding to Wi-Fi, as it is of everyone's concern, it is technology commonly used in particular houses, companies, schools, libraries, etc. The simulated Wi-Fi network provides an 11Mbps bandwitch a range of 50m. Through figure5.1 it is possible to see that Wi-Fi and WiMAX have an overlapped area. Of course UMTS overlaps both Wi-Fi and WiMAX ranges.

In this scenario we have a mobile user (MN) that has interfaces for the three technologies and is crossing through the different technologies.The study relies on the handovers between the different access networks.

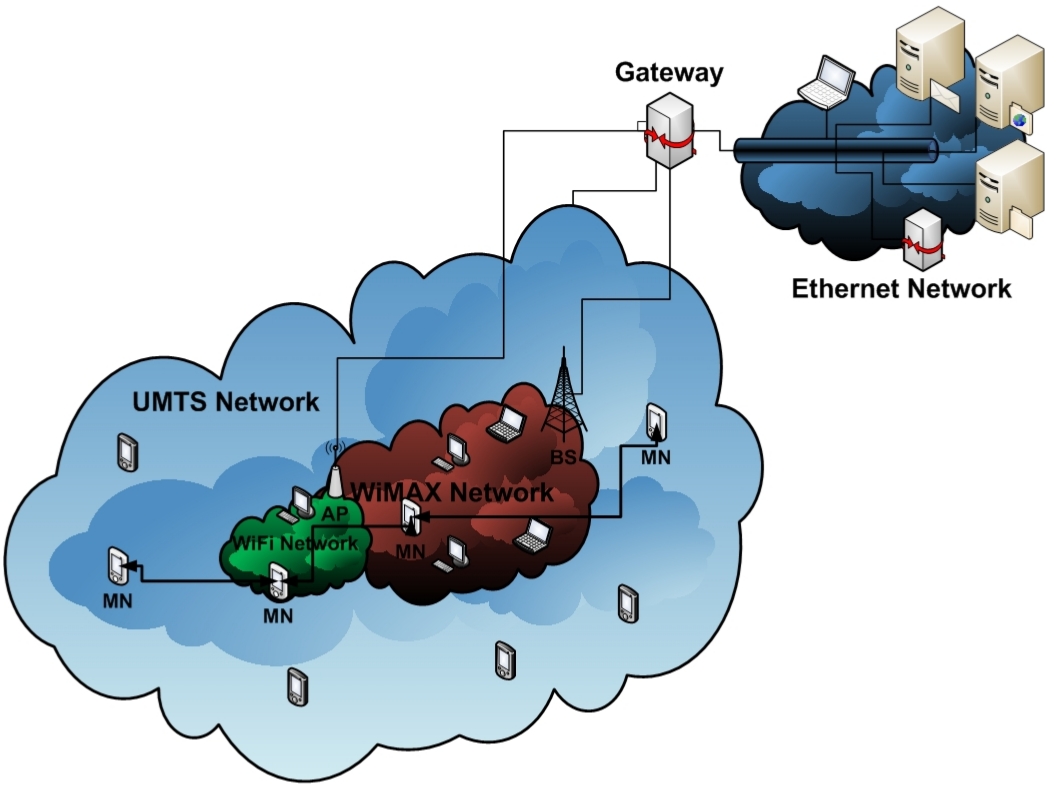

Figure 5.1: Scenario

This chapter presents three different handovers: 1) from Wi-Fi to WiMAX, 2) from WiMAX to UMTS and 3) from UMTS to Wi-Fi. For each one of these handover scenarios, we tested the handover performance using the procedure specified in the IEEE 802.21 standard, and the new concept, using a Dynamic MIIS. An important demonstration is provided in section5.3 where the network cable topology is changed, providing a better overview of the enhacement that the Dynamic MIIS can provide to the handover process.

The chapter is divided into 5 sections: the first lists the measured parameters in the several handovers; section 5.2 presents the handover from Wi-Fi to WiMAX and the results obtained; section 5.3 refers to the WiMAX to UMTS handover; section 5.4 presents the obtained results regarding the handover from a UMTS to a Wi-Fi network; and the last section is a brief summary of the chapter. Sections 5.2, 5.3 and 5.4 all present two types of handovers: with static MIIS and with dynamic MIIS. Section 5.4 also presents a handover situation without MIIS.

5.1 Measured Parameters

The measures taken in this chapter comprise the latency of the handovers, the delay of the packets, jitter and HO preparation time.

The time for preparing the handover is showed in detail, presenting each one of the steps of the process. For the MIIS as it is in the standard, we measured the times of the MIIS Query, Candidate Query and Commit. As to the Dynamic MIIS, we measured the MIIS Query and Commit, since we do not need the Candidate Query in this process.

The handover latency is the time interval since the redirect message sent by the MN to the CN node until the first packet is received on the target interface. This value shouldn't be higher than 150 ms because according to the International Telecommunication Union's, for VoIP calls, the delay between packets should not be higher then 150 ms in each direction.

The packet delay is the time interval since the CN sends the packet until the MN receive it. The jitter is the variance of the packet delay.

In the simulations done, the MN is receiving a Constant Bit Rate (CBR) flow from the core network with rates since 256Kbps to 2Mbps. The background users are also receiving CBR flows: Wi-Fi - 512Kbps; WiMAX - 512Kbps; UMTS - 256Kbps. The packet size is 1500 bytes.

It is also important to mention that the MIH of the networks are located in their PoA. As to the IS, it is located in the gateway shared by the three technologies.

Despite the three cases have been tested with the same degree of detail, it was considered unecessary to especify each case in this Thesis with the same detail. Since the behaviour is similar while changing the MN's flow rate, for all the three cases, it is only presented the Wi-Fi-WiMAX case with the different flow rates. For the other two cases, the behavour is similar, presenting only one MN rate example (256Kbps).

All the simulations were run between 10 to 20 times, and the values presented contain the mean of those runs.

5.2 Wi-Fi-WiMAX

In this section it is considered that the MN is connected to the Wi-Fi AP and moving towards the WiMAX BS range. At a certain point in time, the MN receives a Link_Going_Down indicating that it is about to leave the Wi-Fi AP range, and that it will need to performe an handover. Two possible situations are considered for this case: the first one, using the MIIS as it is in the IEEE 802.21 standard, and the second using the proposed Dynamic MIIS in 3.4.

For this handover the candidate networks will be WiMAX and UMTS, since they are the two networks in the MN's range.

5.2.1 Handover with MIIS (IEEE 802.21 standard)

To perform a handover, four diferent phases are performed: Handover Initiation, Handover Preparation, Handover Execution and Handover Completion. The Handover Initiation phase considers the network topology acquisiton (get information from the IS - MIIS query) and the resources availability check (check what are the resources available in the candidate networks - Candidate query). In this sub-section, were done tests for a MN flow rate of 256Kbps, 512Kbps and 2Mbps.

- MN - 256Kbps

  The two figures bellow show the Handover Initiation phase time behaviour, as background users are introduced in the network.

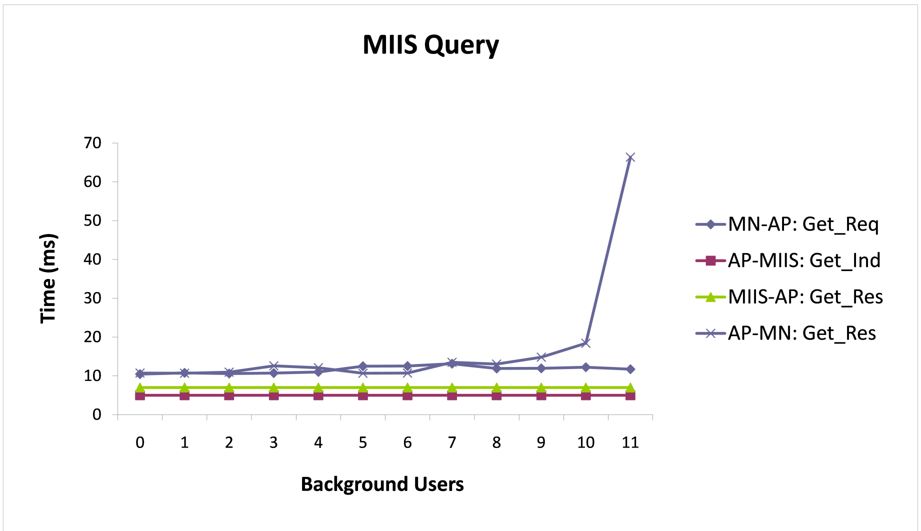

Figure 5.2: MIIS Query process time vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 256Kbps

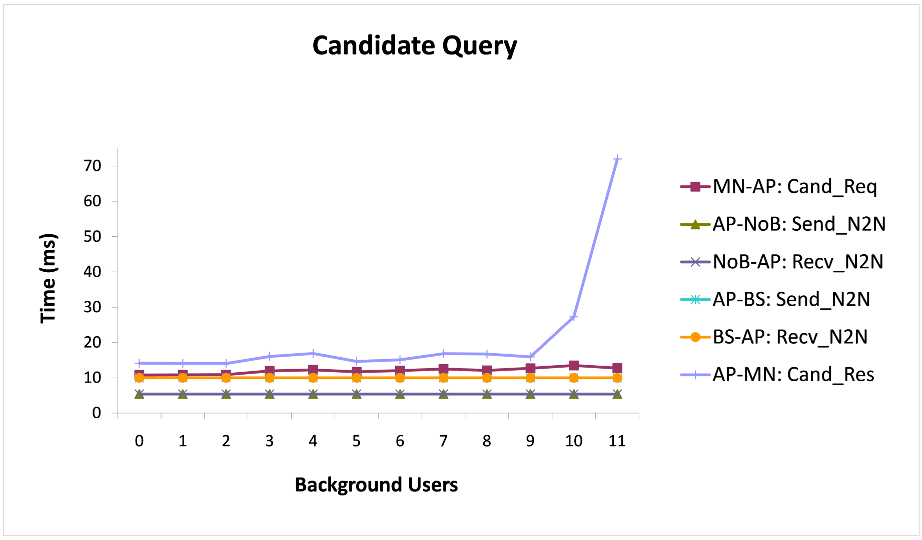

Figure 5.3: Candidate Query process time vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 256Kbps

As it is possible to see through the figures above, the variations are noticed in the Get_Res (Get_Information.response) Cand_Res (Candidate_Query.response). Since the background flows introduce in the MN and background users are DL, the most afected messages are the DL ones. The cable messages (N2N) do not notice any change, since the cables have a very high rate. Notice that the Candidate N2N messages are sent to both the WiMAX BS and the UMTS NodeB. The most delayed and afected messages are the MIH_Get_Information.response and the MIH_Candidate_Query.response, for the reason mentioned before (flows DL), noticing an increase when the 10th background user is introduced, as well as the 11th. When the 10th user is introduced, the AP has already about 50% of its bandwitdth capacity occupied, for which it is entering the saturation zone. The behaviour in this situation is not considered since it is not logical.

The same behavior is noticed when performing the Handover preparation phase (Commit process), as it is possible to see in the figure below.

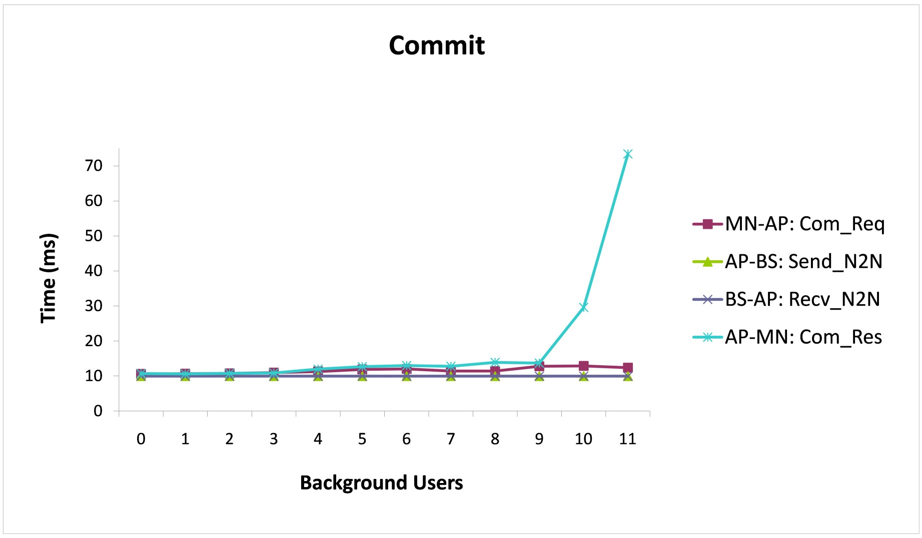

Figure 5.4: Commit time vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 256Kbps

The following figure considers the Handover Initiation Phase time and the Handover Preparation time. As it is expected, its evolution is similar to the wireless DL messages of the previous phases. The time is constant, around the 125ms until the 10th backgound user is introduced, when the time starts to increase.

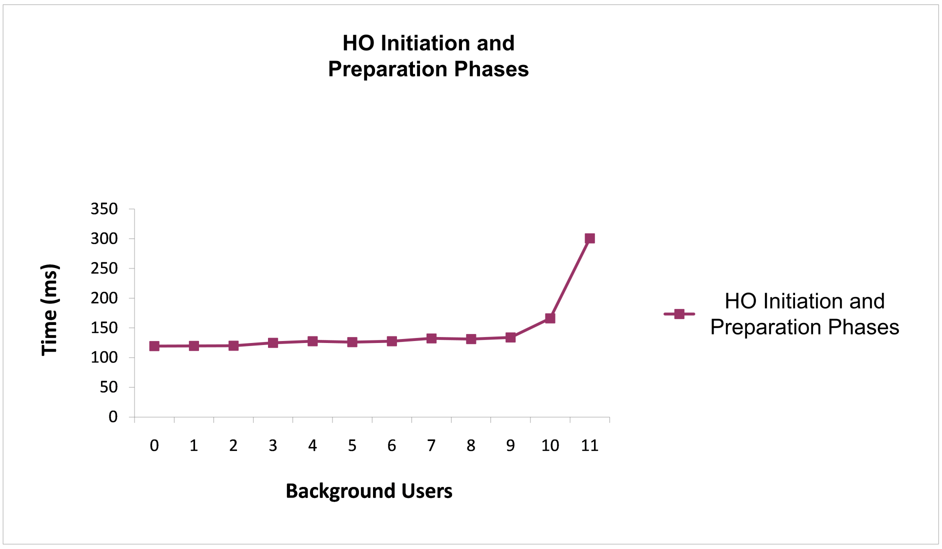

Figure 5.5: HO Initiation and Preparation time vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 256Kbps

As to the Handover delay it is defined as the time since the redirect message for the MN's flow is sent to its CN until the first packet is received at the MN's new interface (WiMAX in this case), is around 50 and 60 ms as it is possible to see through 5.6.

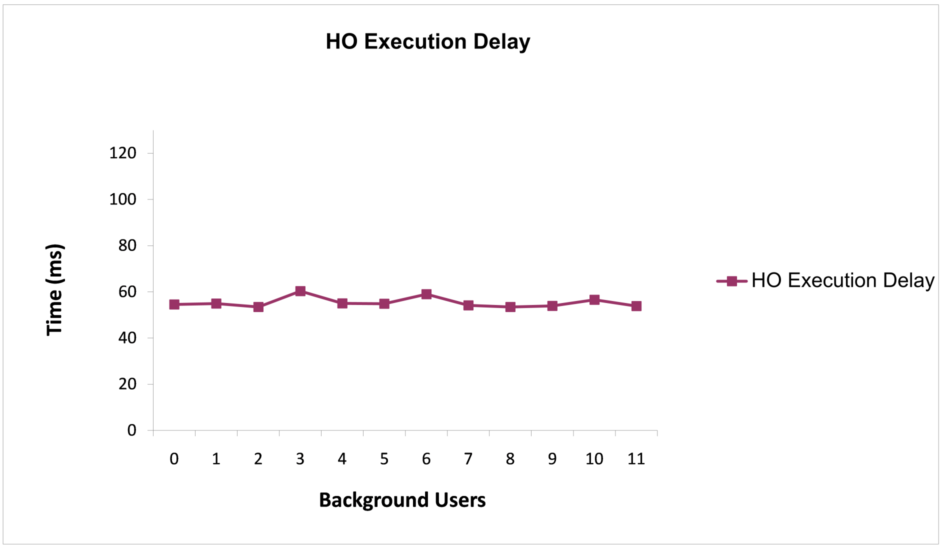

Figure 5.6: Handover Execution Delay vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 256Kbps

Regarding QoS metries, as packet delay and packet jitter before, during and after the handover, the time and behaviour is showed in the two following figures.

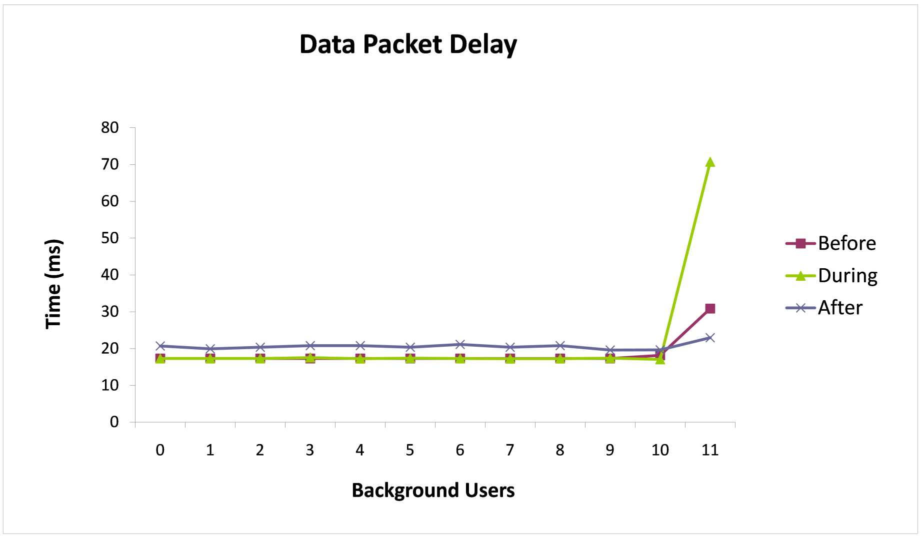

Figure 5.7: Data Packet Delay vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 256Kbps

The data packet delay before as well as during the during the handover, using the Wi-Fi interface, is lower than 20ms, until the 11th (saturation). After the handover execution, already using the MN's WiMAX interface the packet delay is as expected more than it was when connected to the WiMAX BS since the average wireless propagation time of WiMAX is bigger than the Wi-Fi.

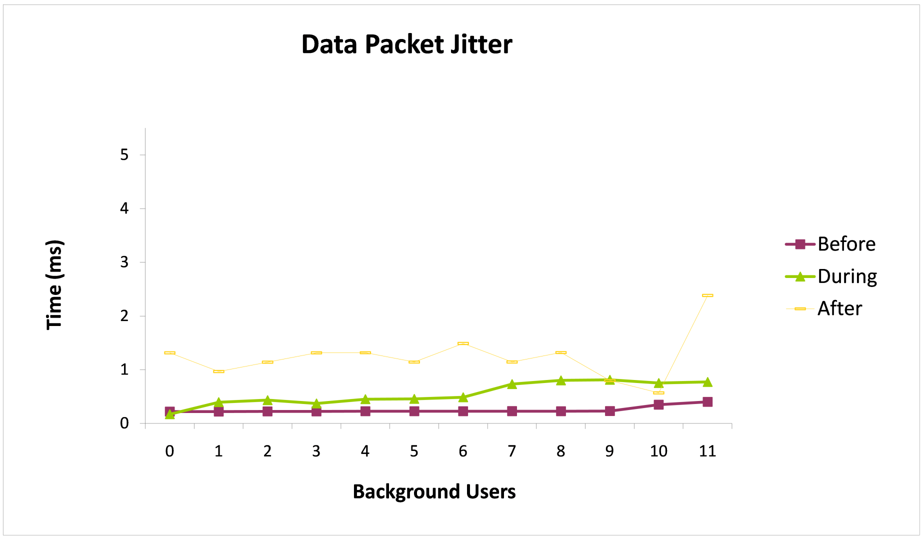

Figure 5.8: Data packet jitter vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 256Kbps

As to the data packet jitter, the values are very small and don't vary too much, which is normal.

- MN - 512Kbps

  Now, using a different MN flow rate, 512Kbps the same evaluation was performed as for the 256Kbps. As happend in the 256Kbps case, after the introduction of the 10th user, the behaviour is not taken into acount since the PoA is already in saturation.

  Figures 5.9, 5.10 and 5.11 show the Handover Initiation and Preparation phases behaviour as background useres are introduced. The behaviour is similar to the 256Kbps case.

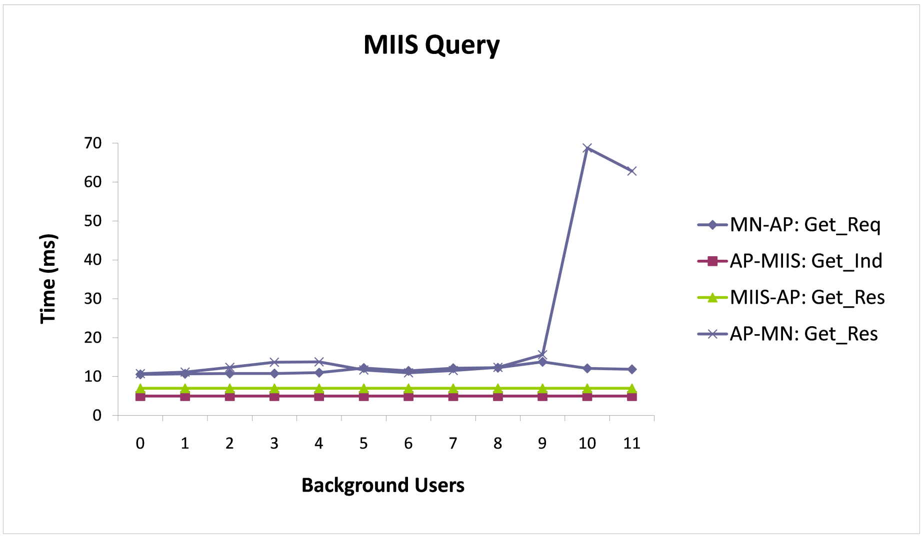

Figure 5.9: MIIS Query process time vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 512Kbps

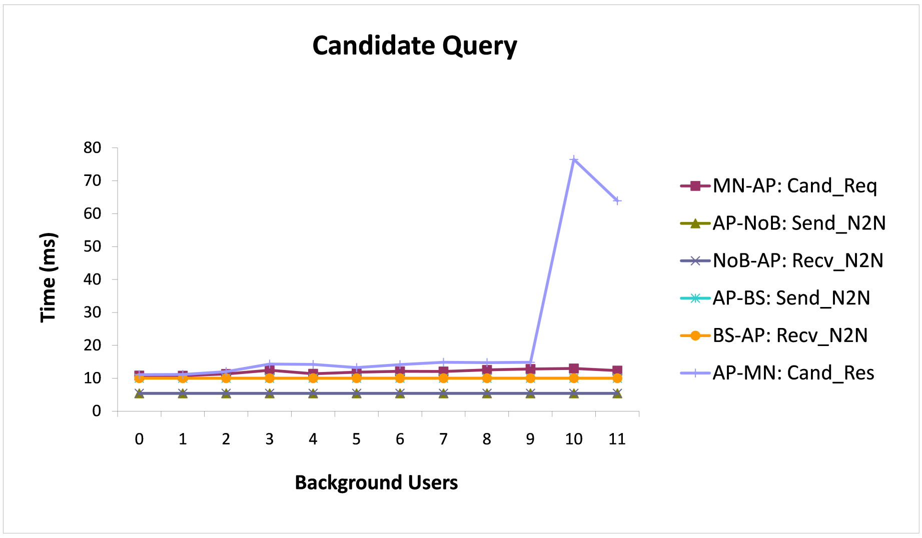

Figure 5.10: Candidate Query process time vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 512Kbps

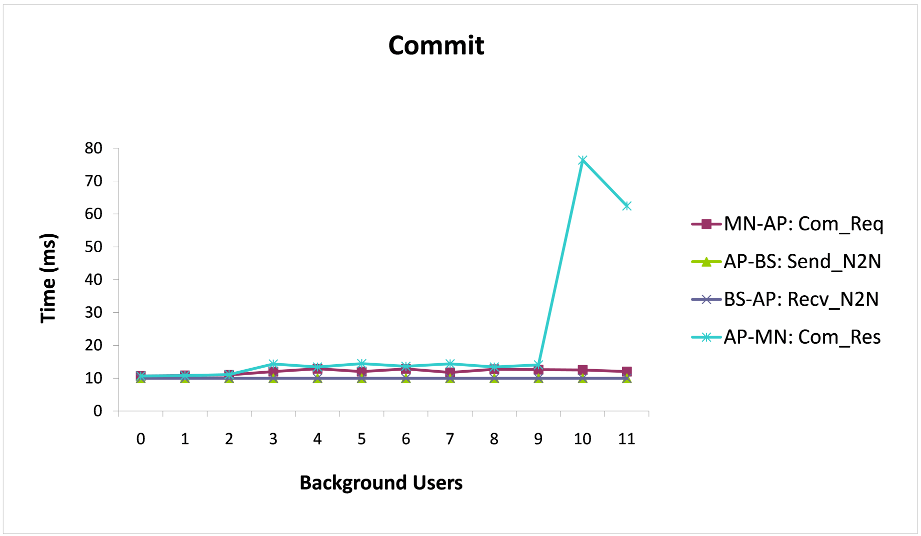

Figure 5.11: Commit time vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 512Kbps

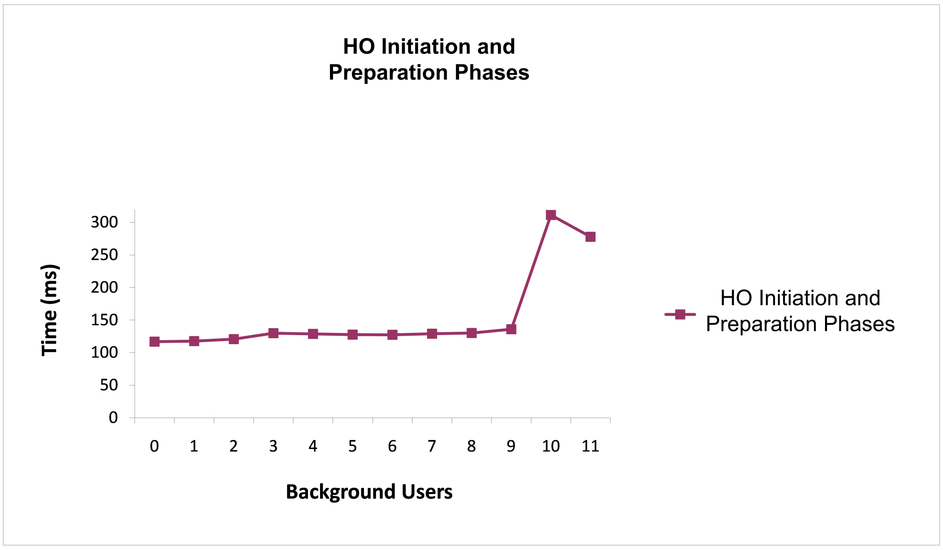

Figure 5.12: HO Initiation and Preparation time vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 512Kbps

The handover execution delay follows the same behaviour as the 256Kbps, but in this case, it is possible to notice that the average time is a bit lower than in the 256Kbps, since the rate is higher and so, the packets are sent with a less interval between them. When receiving the redirect message, the CN sends the first packet faster than in the 256Kbps.

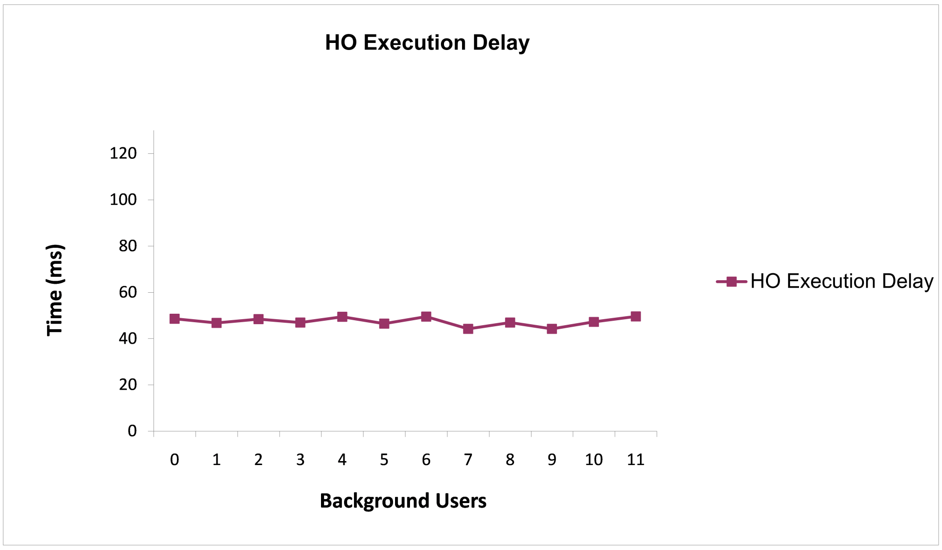

Figure 5.13: Handover Execution Delay vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 512Kbps

Data packet delay also has a similar behaviour as in the 256Kbps. Regarding the packet jitter, the difference is noticed in the values after the handover, when is already using the WiMAX interface, where the value is higher.

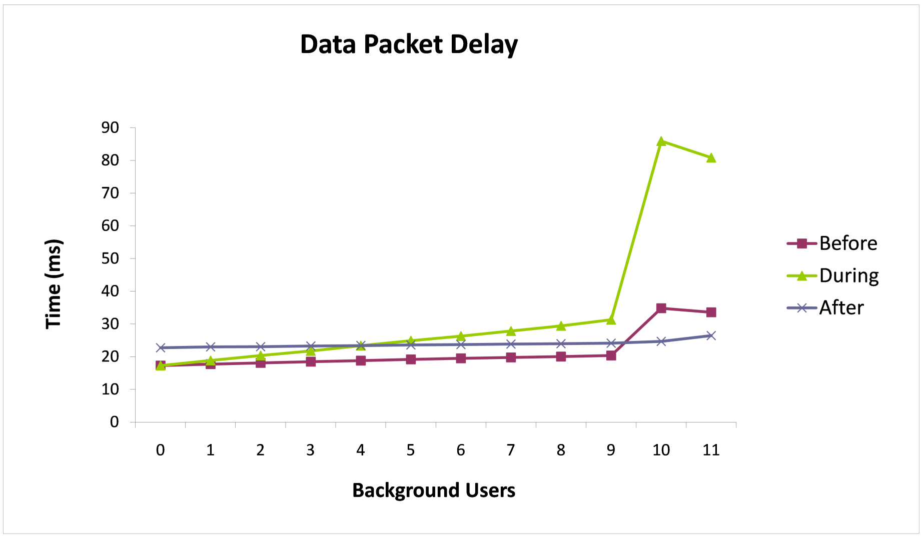

Figure 5.14: Data Packet Delay vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 512Kbps

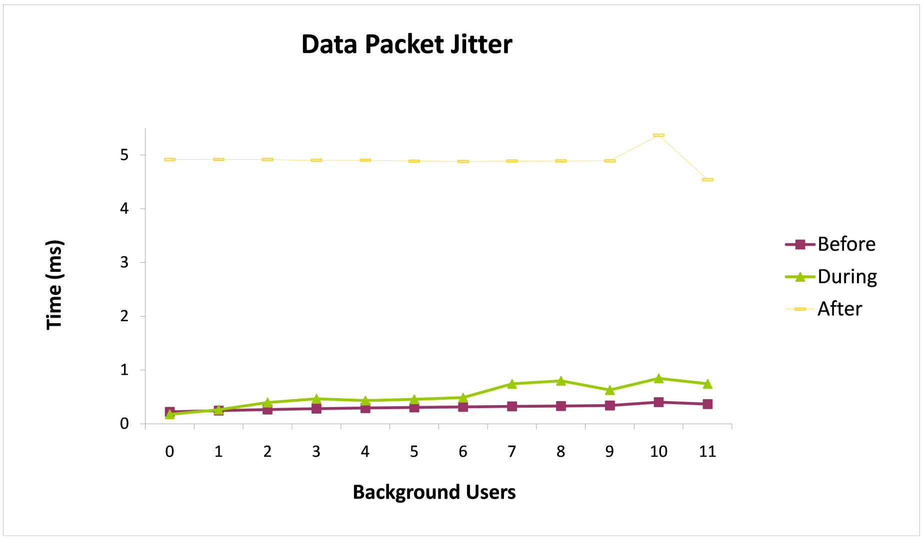

Figure 5.15: Data packet jitter vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 512Kbps

- MN - 2Mbps

  Using a MN flow of 2Mbps it is possible to notice through figure 5.16 that the Wi-Fi AP enters in saturation when the 7th background user is introduced, that is when it reaches nearly 50% of capacity. The values after introducing the 8th user are not shown here since they don't have any representation, because at that time we are already experiencing significantly high packet loss. The graphs representing the HO Initiation and the HO preparation phases (figures 5.16, 5.17, 5.18, 5.19) have an identical behaviour as the ones for the 256Kbps and 512Kbps.

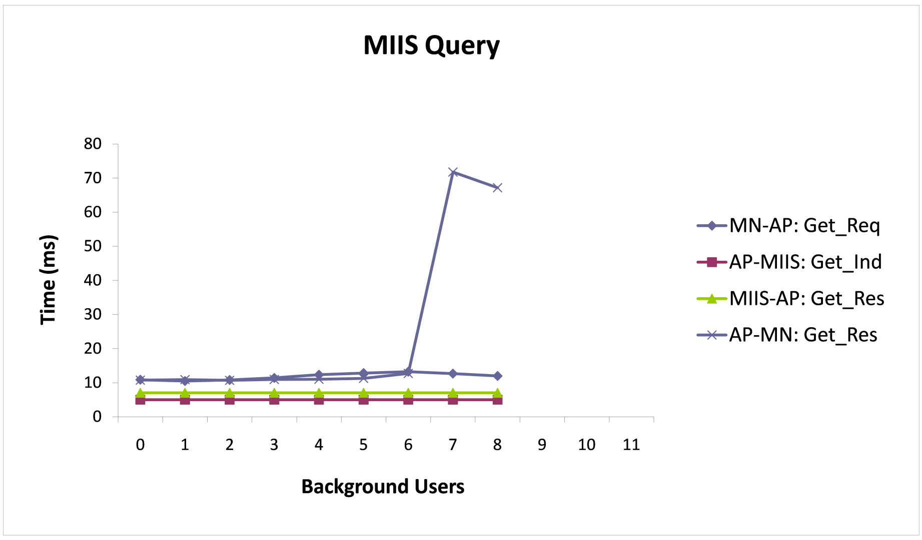

Figure 5.16: MIIS Query process time vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 2Mbps

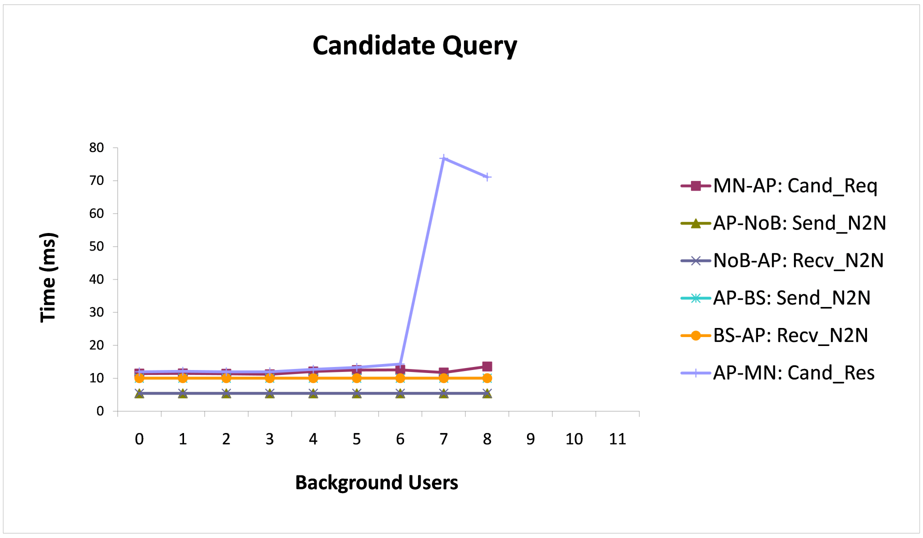

Figure 5.17: Candidate Query process time vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 2Mbps

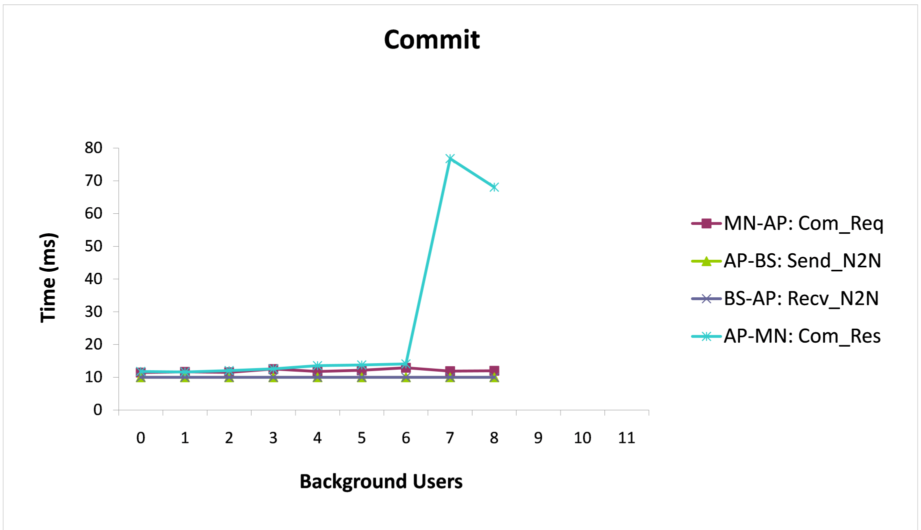

Figure 5.18: Commit time vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 2Mbps

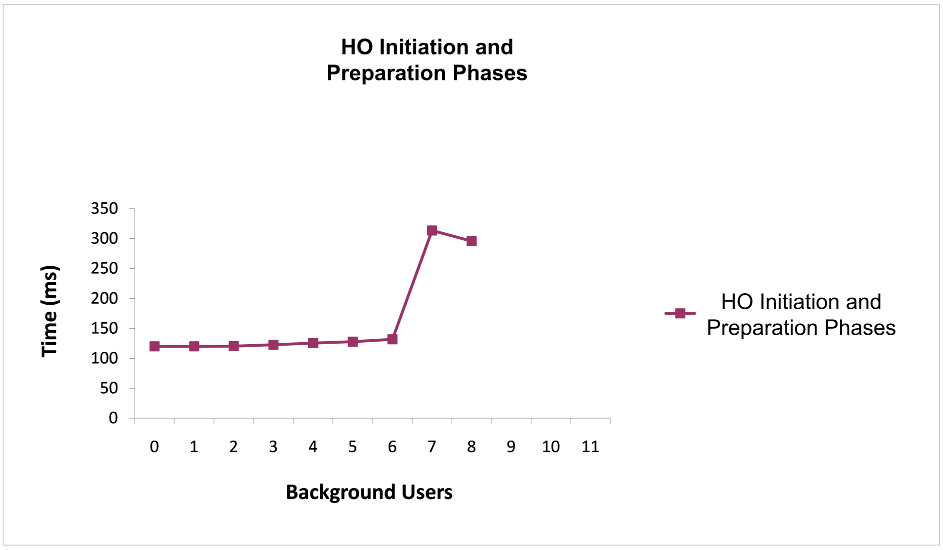

Figure 5.19: HO Initiation and Preparation process time vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 2Mbps

As in the previous tests for 256Kbps and 512Kbps, the handover execution delay for 2Mbps experiences a similar behaviour. It decreases as the flow rate increases, which is a very logical behaviour.

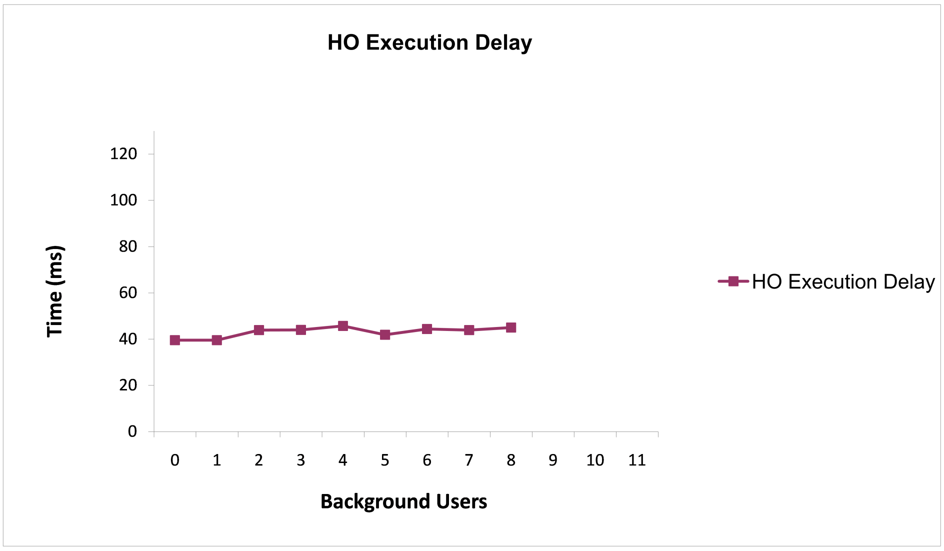

Figure 5.20: Handover Execution Delay vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 2Mbps

Regarding the data packet delay, its development is similar to the previous flow rates for the same reasons. Of course the high levels are achieved sooner, since the Wi-Fi AP saturates earlier. The jitter is small, increasing just a bit while users are introduced in the Wi-Fi network.

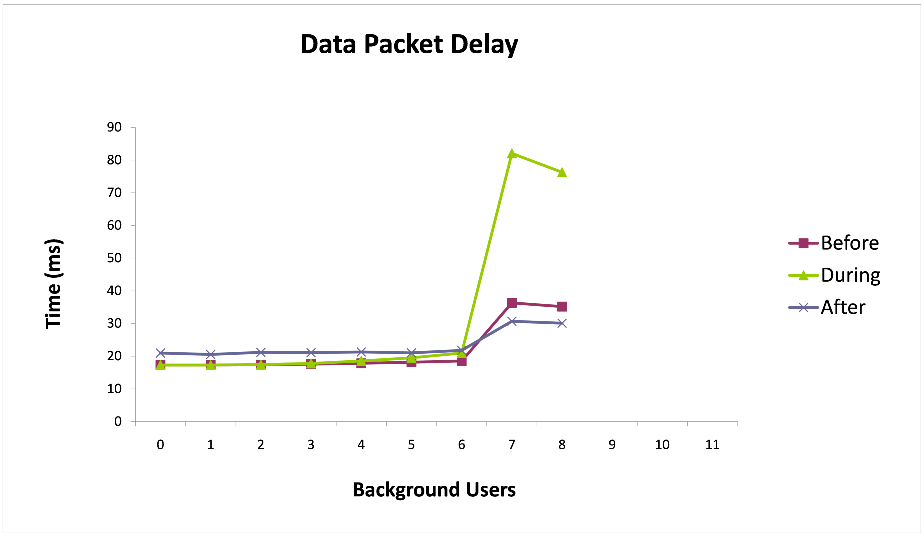

Figure 5.21: Data Packet Delay vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 2Mbps

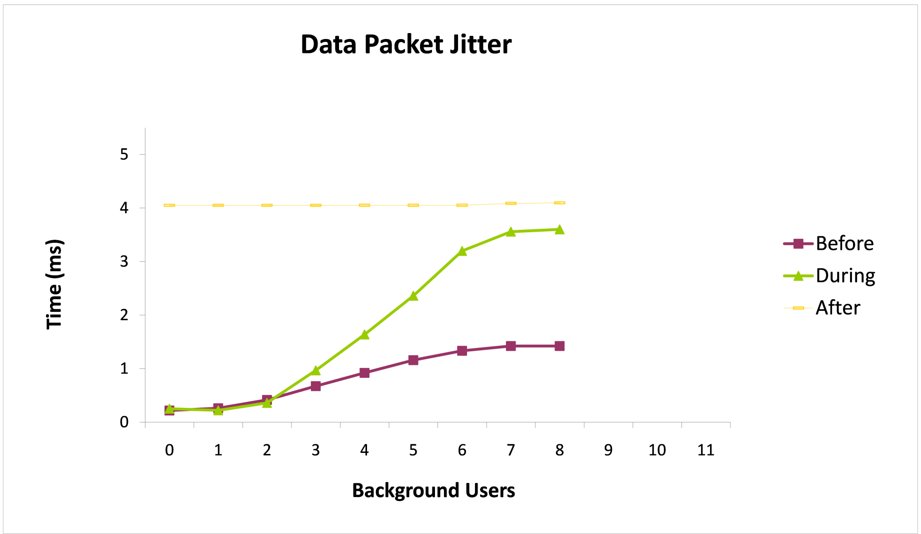

Figure 5.22: Data packet jitter vs Number of users (IEEE 802.21) - Wi-Fi-WiMAX 2Mbps

5.2.2 Handover with Dynamic MIIS

With this new approach to the media independent handover process, the main phases of the handover remain the same, however it is no longer necessary the Availability Resource Check phase of the Handover Initiaton phase, since it is done together with the Network Topology Acquisition in the MIIS Query. Therefore, the Handover Initiation phase which was done in two steps (MIIS Query and Candidate Query), is now done in one (MIIS Query).

- MN - 256Kbps

  As it was done in the previous subsection, the first graphs presented are those relative to the Handover Initiation and Preparation phases.

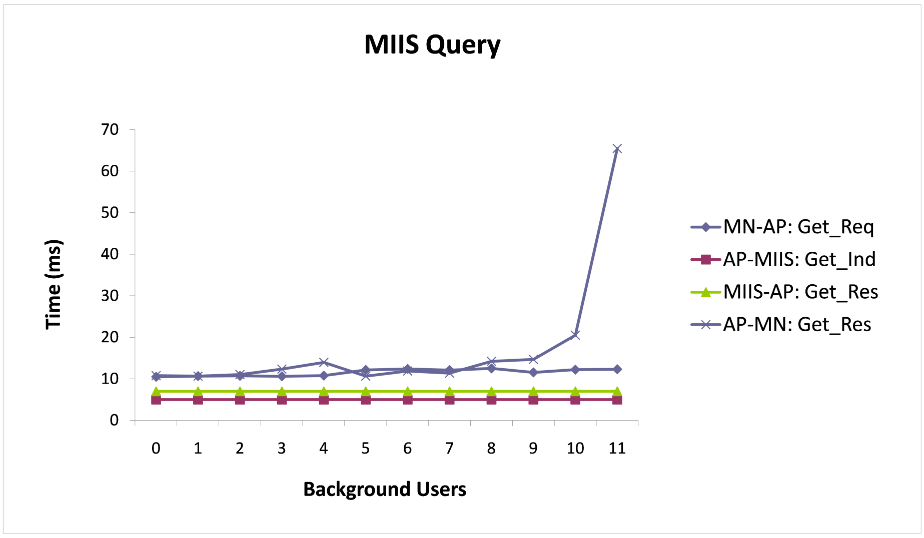

Figure 5.23: MIIS Query process time vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 256Kbps

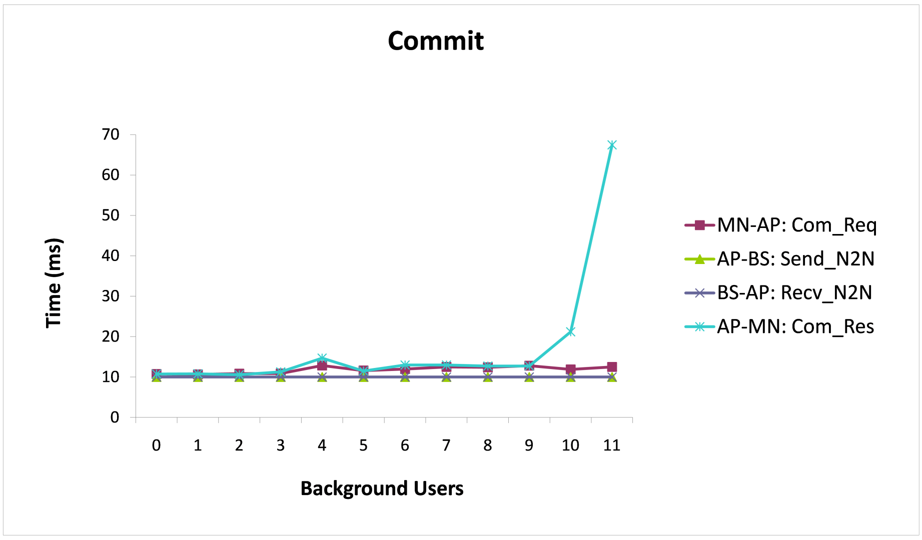

Figure 5.24: Commit time vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 256Kbps

Logically, the behaviour of both Initiation and Preparation phases is identical to those registered for the static MIIS case.

Since the Candidate Query is no longer necessary, a decrease in the handover preparation (including initiation and preparation), is of course, registered. This time is know around 30ms less than the previous case (static MIIS).

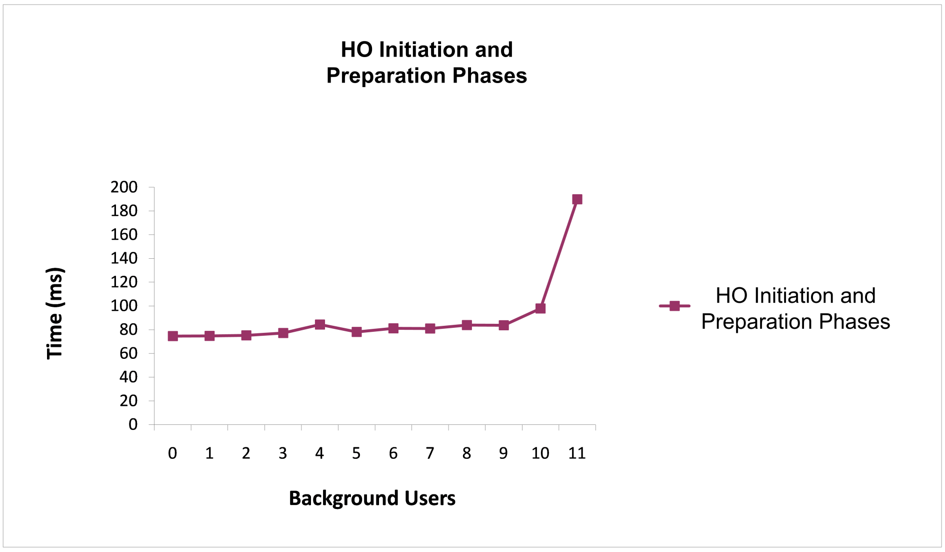

Figure 5.25: HO Initiation and Preparation time vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 256Kbps

The following graphs represent the Handover Execution Delay, Data Packet Delay and Jitter. All of this measures are identical to the ones presented in 5.2.1. There were no differences expected in this situation, since the Dynamic MIIS only affects the Handover Initiation, and therefore, all the handover preparation time remains the same.

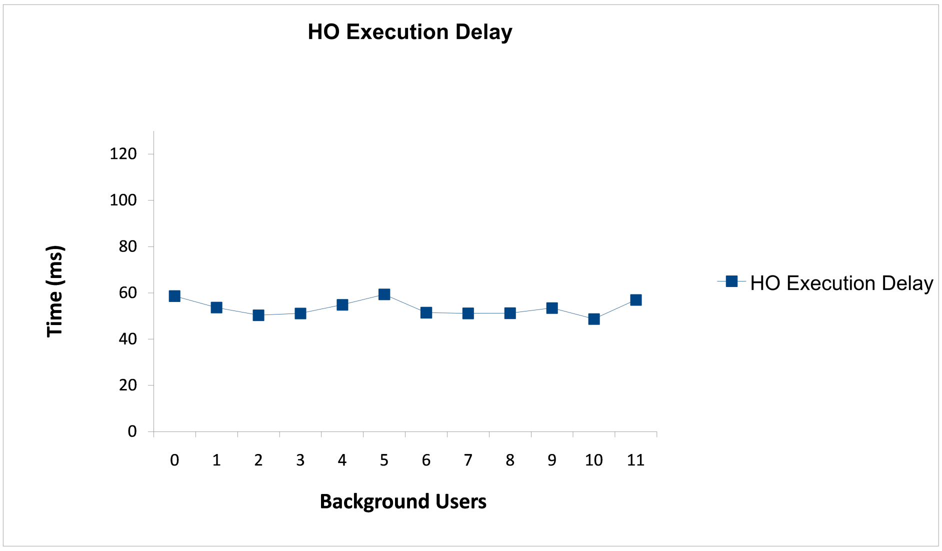

Figure 5.26: Handover Execution Delay vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 256Kbps

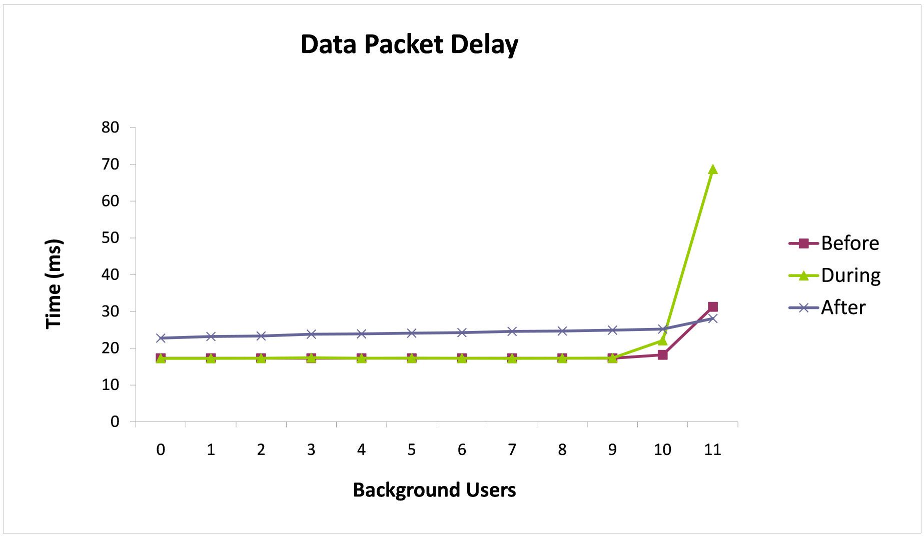

Figure 5.27: Data packet delay vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 256Kbps

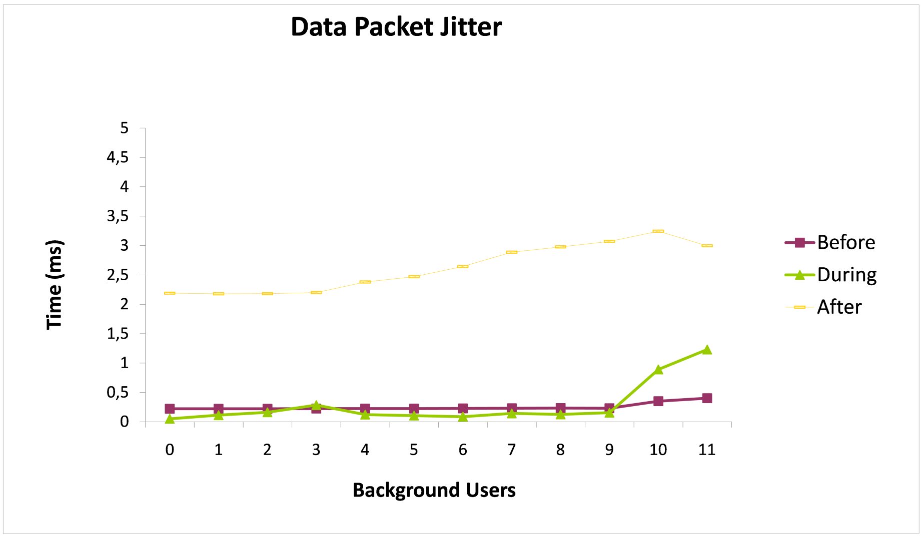

Figure 5.28: Data packet jitter vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 256Kbps

The measures taken for a MN flow rate of 512Kbps and 2Mbps are similar to those taken for the static MIIS case. The only difference noticed in the measures is in the handover preparation time, which is less.

- MN - 512Kbps

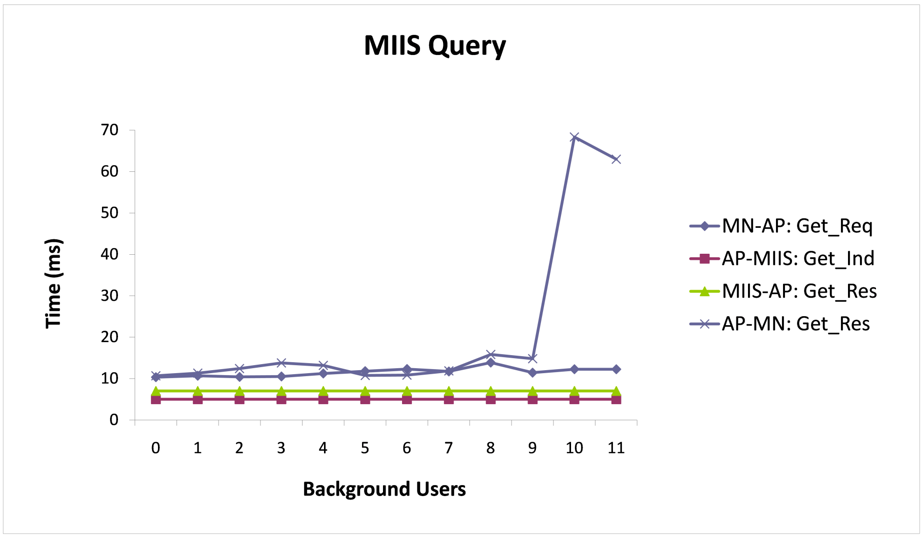

Figure 5.29: MIIS Query process time vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 512Kbps

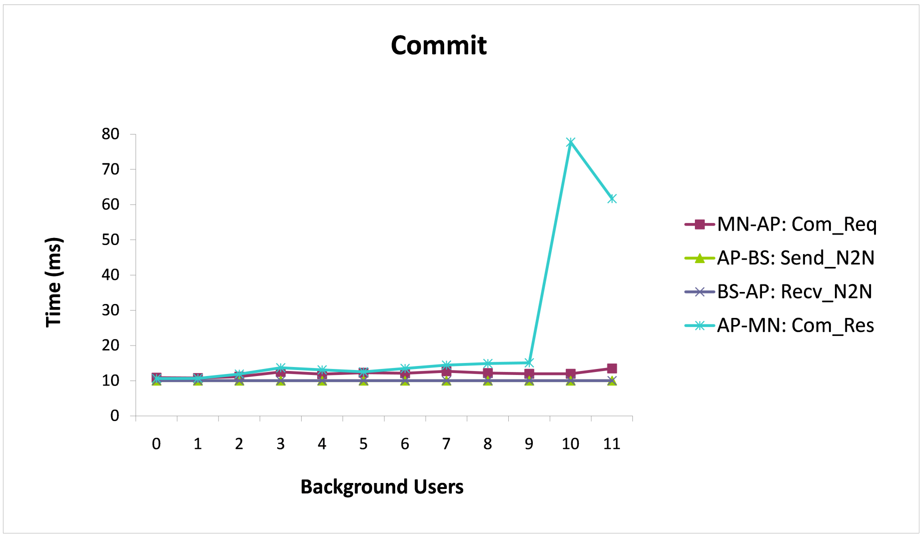

Figure 5.30: Commit time vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 512Kbps

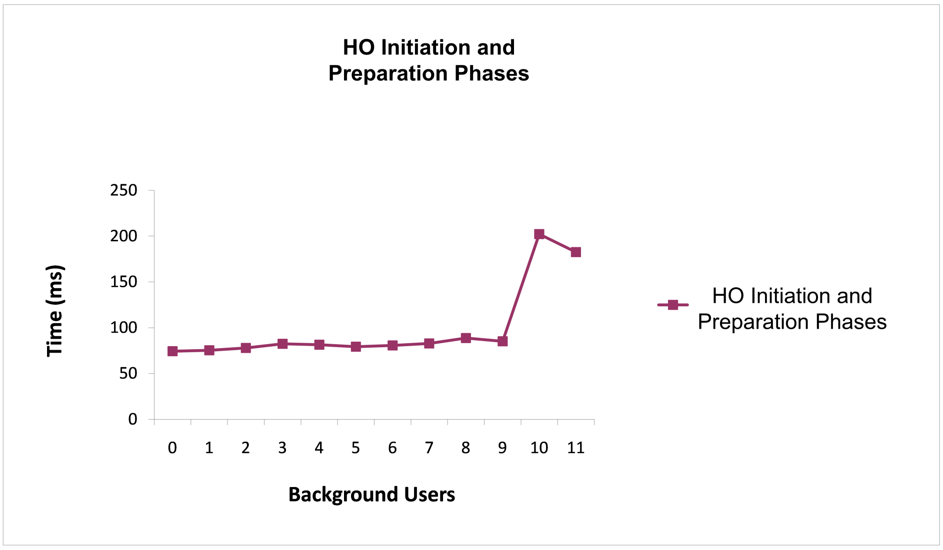

Figure 5.31: HO Initiation and Preparation time vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 512Kbps

The time since the handover is triggered until the MN sends the message to redirect the flow from the Wi-Fi interface to the WiMAX interface is less than in the static MIIS case. It also presents the same behavior compared to the 256Kbps as in the static MIIS.

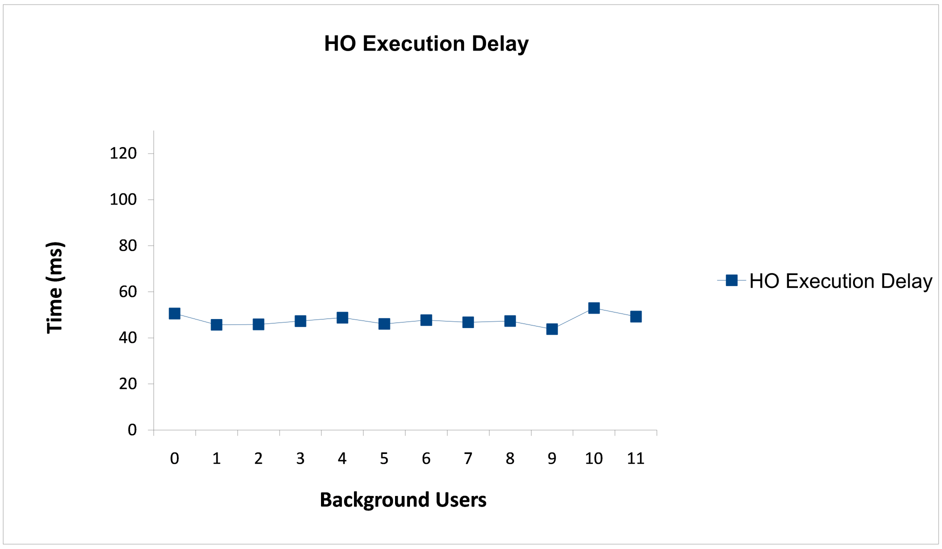

Figure 5.32: Handover Execution Delay vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 512Kbps

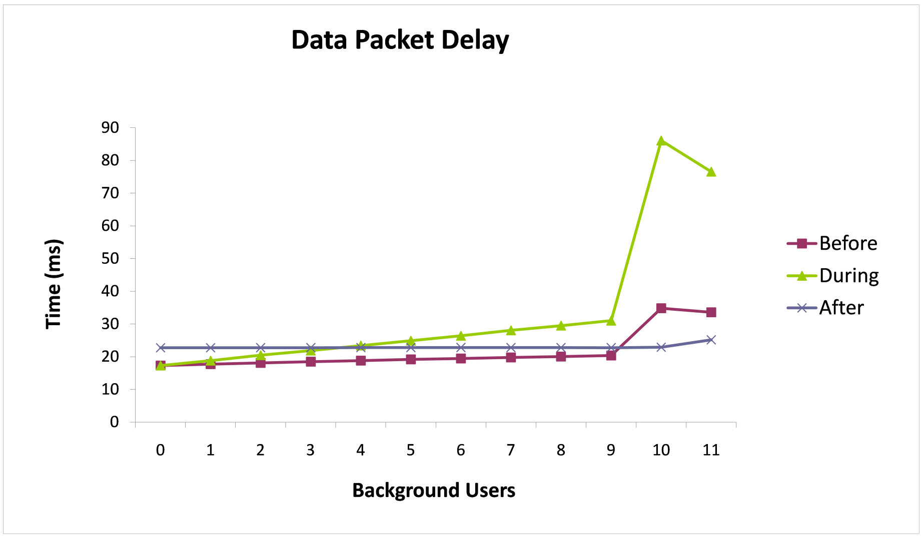

Figure 5.33: Data packet delay vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 512Kbps

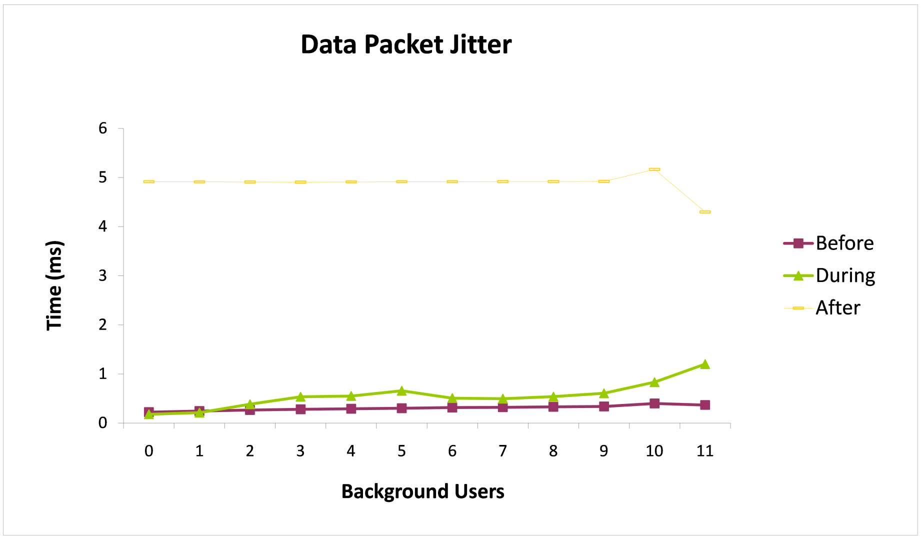

Figure 5.34: Data packet jitter vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 512Kbps

- MN - 2Mbps

  For the 2Mbps MN flow, the behaviour is similar to the static MIIS case, except of course in this case there is no Candidate query, and therefore, the initiation phase takes less time. As to the data packet delay and jitter, as well as to the handover execution delay, the behaviour is identical to the static MIIS case.

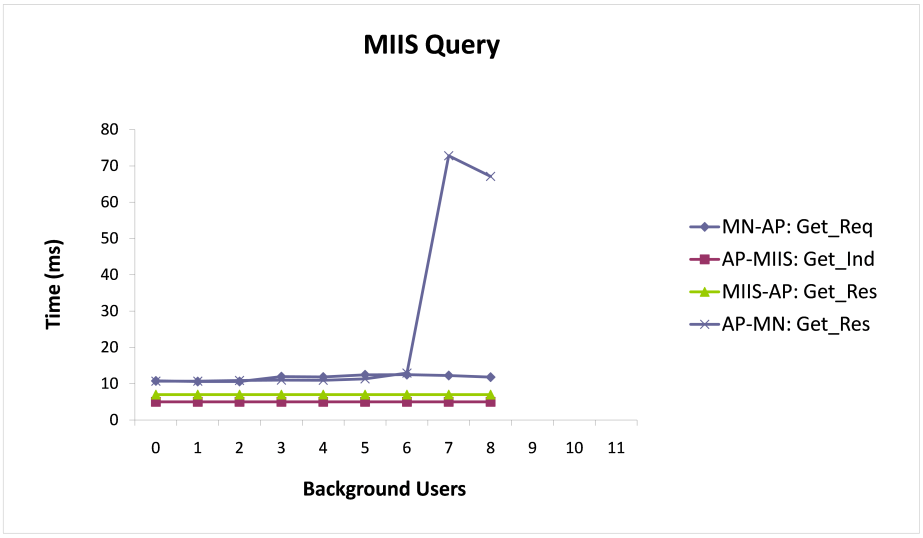

Figure 5.35: MIIS Query process time vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 2Mbps

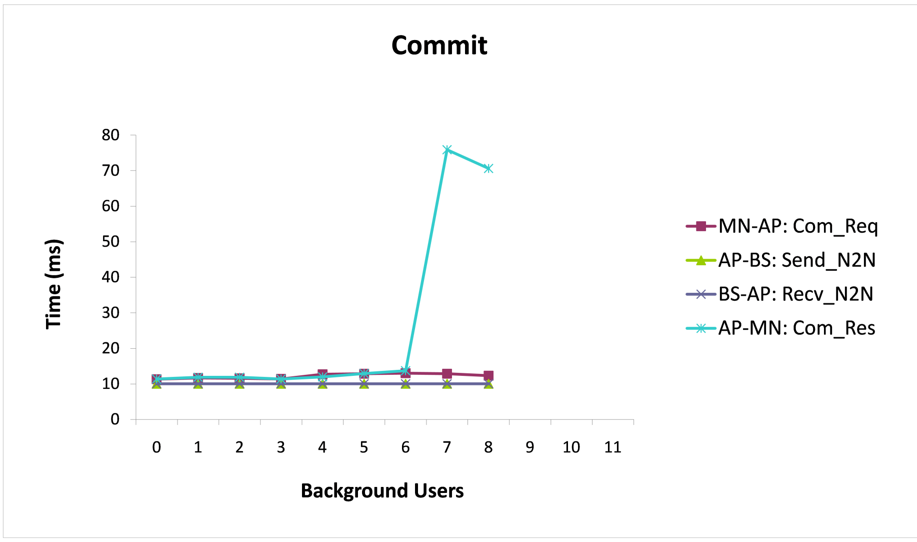

Figure 5.36: Commit time vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 2Mbps

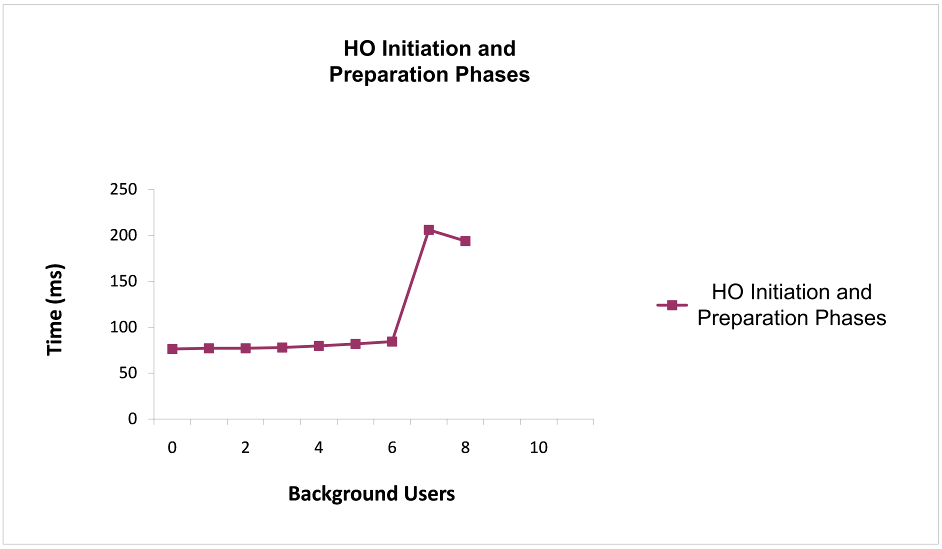

Figure 5.37: HO Initiation and Preparation time vs Number of users (Dynamic MIIS) - Wi-Fi-WiMAX 2Mbps

5.3 WiMAX-UMTS

Considering that the MN is connected to the WiMAX BS and is moving towards the outside of its range, an handover process will be triggered , as in the Wi-Fi-WiMAX case, through a Link_Going_Down message. The simulations were done using the static and dynamic versions of the IEEE 802.21 MIIS.

In this situation the MN is moving out of the WiMAX BS range, towards the UMTS cell. Therefore, the only candidate network is the UMTS network (see 5.1).

For the two following sub-sections, it is only presented the graphs regarding the 256Kbps MN flow rate. Using 512Kbps or 2Mbps will defer in the same way as it happend in the Wi-Fi-WiMAX handover (earlier saturation of the PoA and less Handover Delay Execution).

5.3.1 Handover with MIIS (IEEE 802.21 standard)

- MN - 256Kbps

  As it was done in the previous sections, it is first presented the graphs regarding the phases of initiation and preparation of the handover. As it is possible to observe through the three figures bellow (MIIS Query, Candidate Query and Commit), the time of the wireless uplink messages (requestes: MIH_Get_Information.request, MIH_Candidate_Query.request, MIH_Commit.request) is increasing while background users are introduced in the network. This happens, because the WiMAX uplink channel is shared (Best Efford) and therefore the users must compete to access it. On the downlink direction the channel control is centralized by the WiMAX BS.

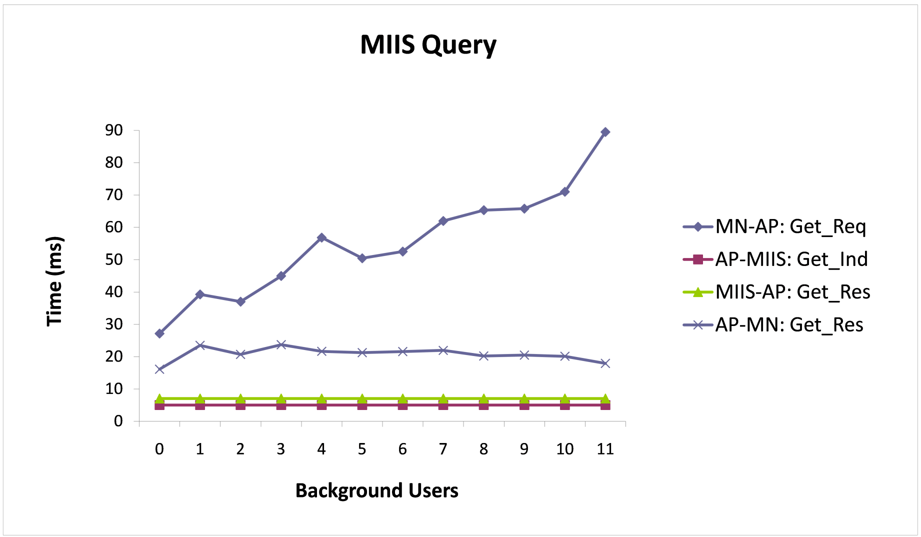

Figure 5.38: MIIS Query process time vs Number of users (Dynamic MIIS) - WiMAX-UMTS 256Kbps

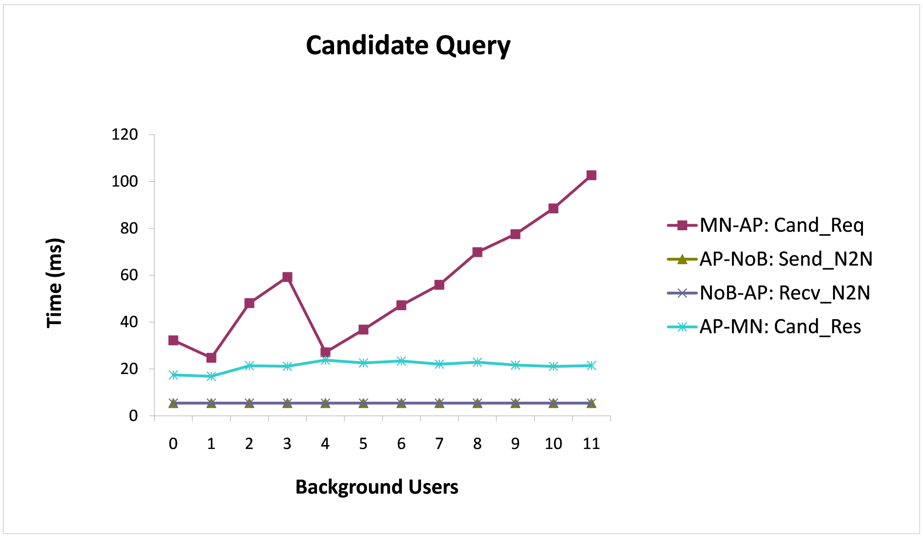

Figure 5.39: Candidate Query process time vs Number of users (IEEE 802.21) - WiMAX-UMTS 256Kbps

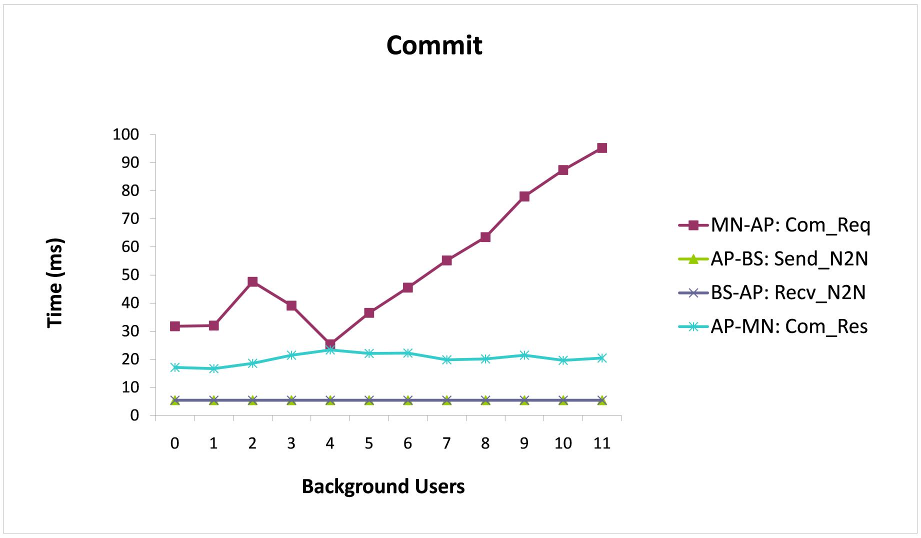

Figure 5.40: Commit time vs Number of users (IEEE 802.21) - WiMAX-UMTS 256Kbps

According to the previous graphs, it is expected a progressive increase of the overall handover preparation time. It is possible to confirm it through the following graph. The time varies from about 175ms with no background user, to nearly 400ms with eleven users.

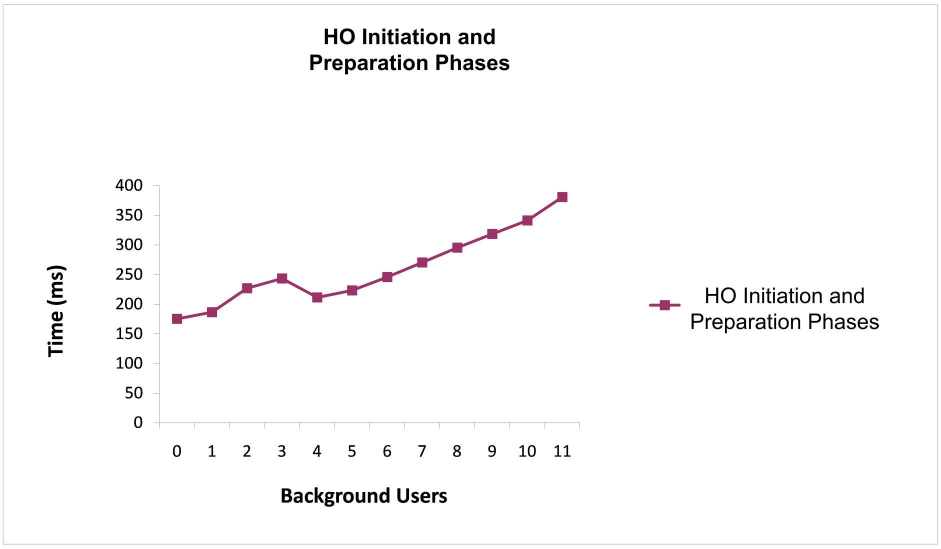

Figure 5.41: Handover Initiation and Preparation time vs Number of users (IEEE 802.21) - WiMAX-UMTS 256Kbps

The handover execution delay is similar while users are introduced, varying between 100 and 120ms. This time will decrease if the flow data rate is increased.

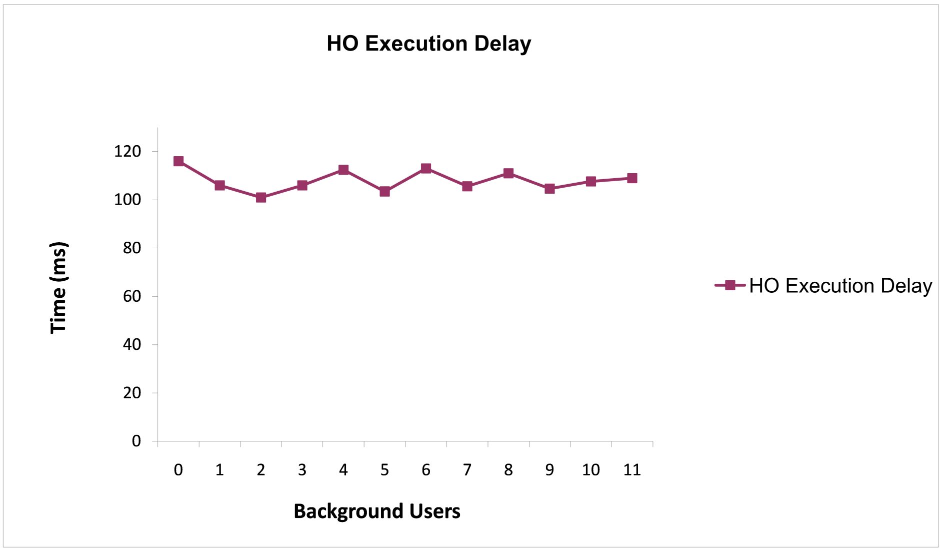

Figure 5.42: Handover Execution Delay vs Number of users (IEEE 802.21) - WiMAX-UMTS 256Kbps

Regarding the data packet delay, before and during the handover, the time is between the values 20 and 25 (ms). As the average time of propagation in WiMAX is around 15ms, plus the time it takes from the CN to the WiMAX BS, the packet delay is aceptable. After the handover, when the MN is receiving the data packets through the UMTS interface, the delay increases to around 70ms (2.1.4.3). As to the jitter, its values are very low compared to the delay itself, not affecting the integrity of the delay values.

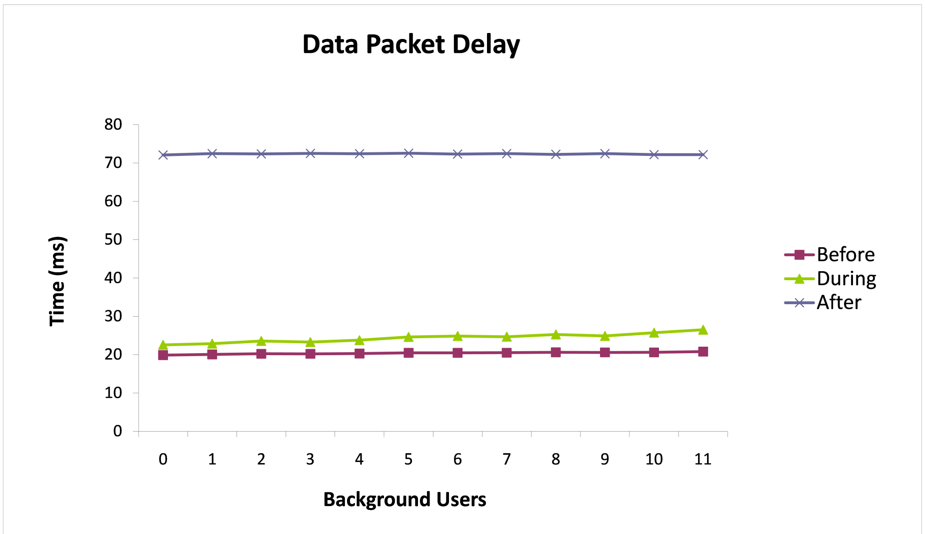

Figure 5.43: Dtata packet delay vs Number of users (IEEE 802.21) - WiMAX-UMTS 256Kbps

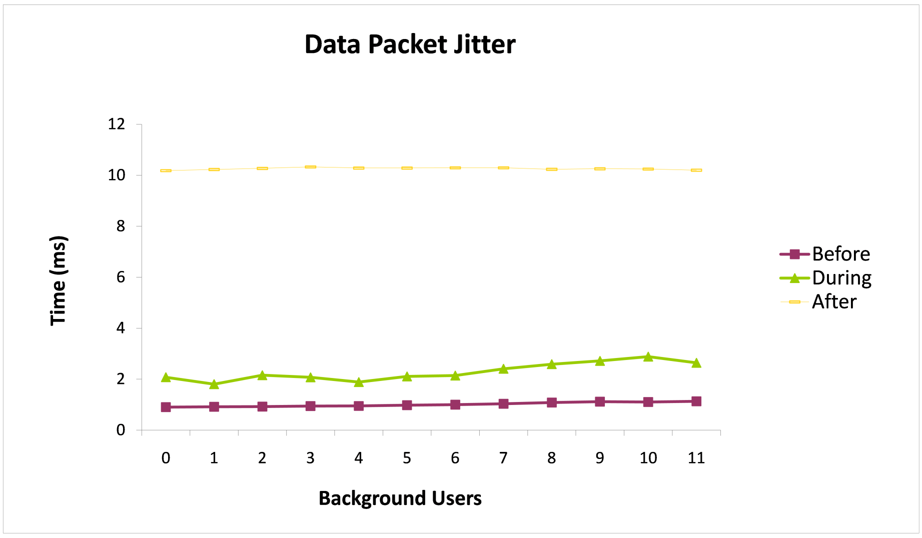

Figure 5.44: Data packet jitter vs Number of users (IEEE 802.21) - WiMAX-UMTS 256Kbps

5.3.1.1 Changing the cable network topology

In this sub-section, the distance from the GW and the UMTS NodeB is increased, having the connection a delay of 30ms (while in the previous cases the delay is 5ms). All the messages exchanged in the handover process evolving the UMTS NodeB will have a bigger delay. The handover preparation time using the static MIIS is between 280ms and 400ms (please see Figure 5.48). The aim of this experience is to show the enhancement that the dynamic MIIS brings (section 5.3.2.1) to the handover process. Increasing the delay/distance of the connection between a candidate network and the GW will icrease the handover process time, as we can see through the figures bellow. Using the dynamic MIIS, the candidate query is excluded and the handover time reduced over 60ms (time of the candidate N2N messages).

- MN - 256Kbps

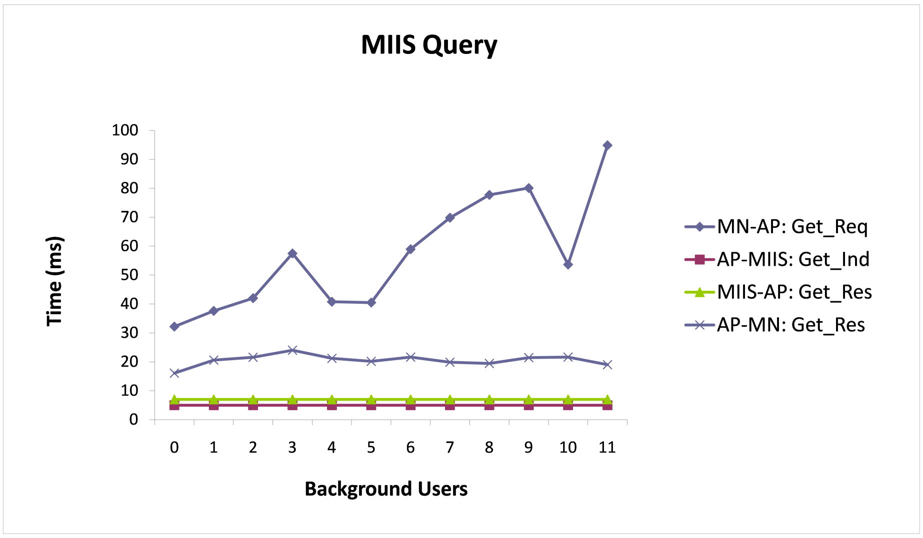

Figure 5.45: MIIS Query time vs Number of users (IEEE 802.21) - WiMAX-UMTS change

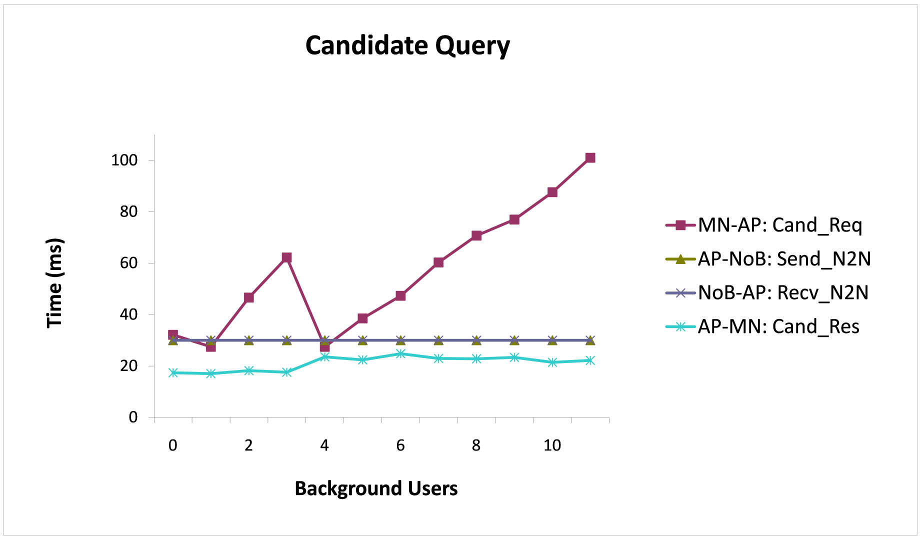

Figure 5.46: Candidate Query time vs Number of users (IEEE 802.21) - WiMAX-UMTS 256Kbps

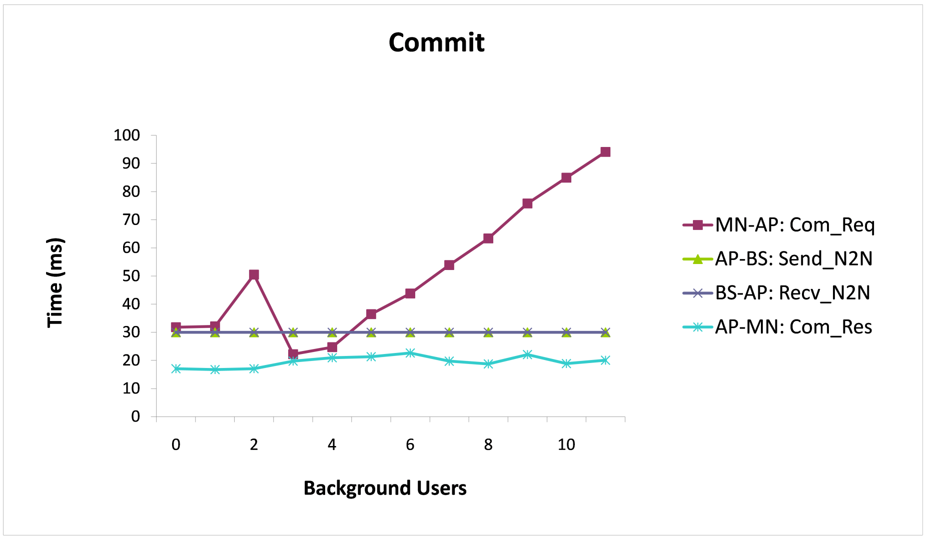

Figure 5.47: Commit process time vs Number of users (IEEE 802.21) - WiMAX-UMTS 256Kbps

The graph below is the most relevant one. As it is possible to notice, the time for the process is higher than the cases presented before (see figure 5.41). This is because now we have a delay of 30ms instead of 5ms in the link connection between the GW and the NodeB. The increase of distance (link delay) has an important influence in the handover process.

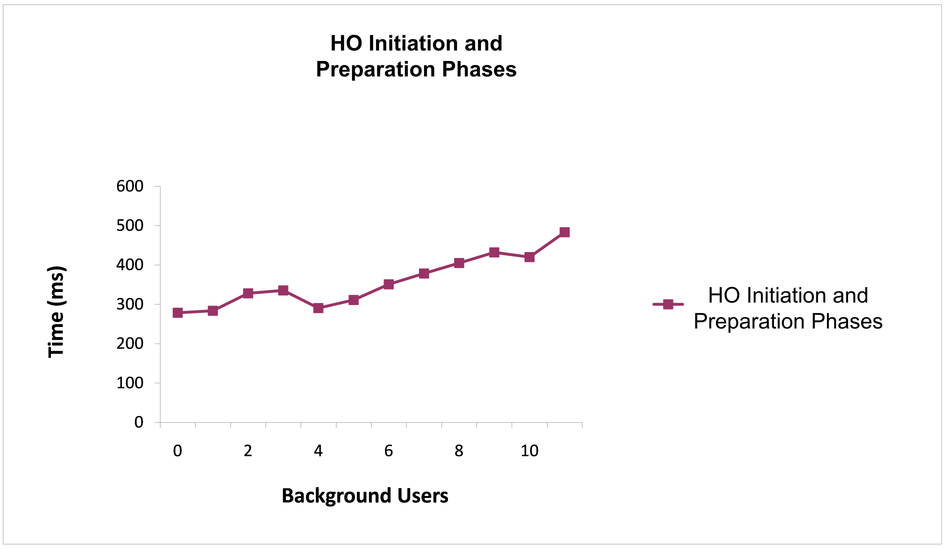

Figure 5.48: HO Initiation and Preparation time vs Number of users (IEEE 802.21) - WiMAX-UMTS 256Kbps

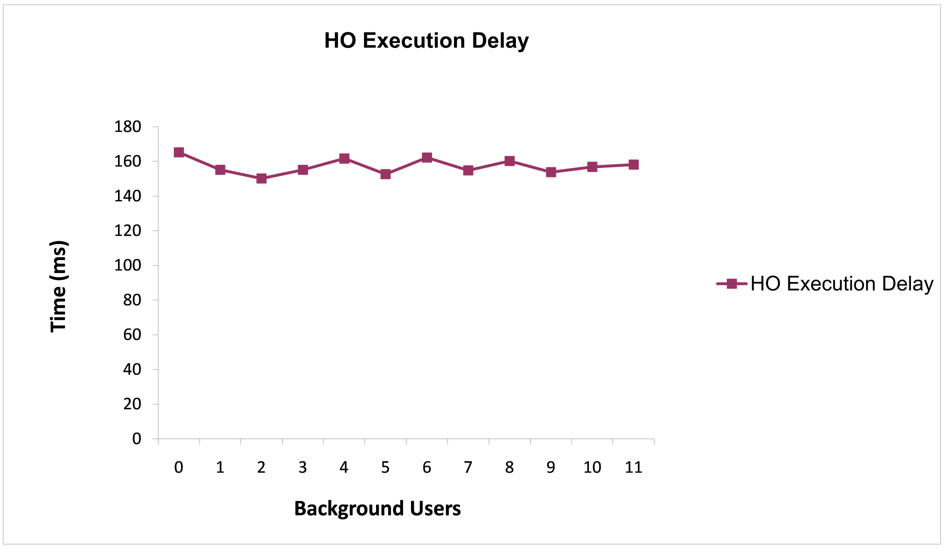

Figure 5.49: Handover Execution Delay vs Number of users (IEEE 802.21) - WiMAX-UMTS 256Kbps

5.3.2 Handover with Dynamic MIIS

- MN - 256Kbps

With a Dynamic MIIS, since the Candidate_Query message is no longer necessary, the main difference is registered in the overall time of the handover preparation time (5.52), where the time varies between 110 and 150ms according to the background users in the network.

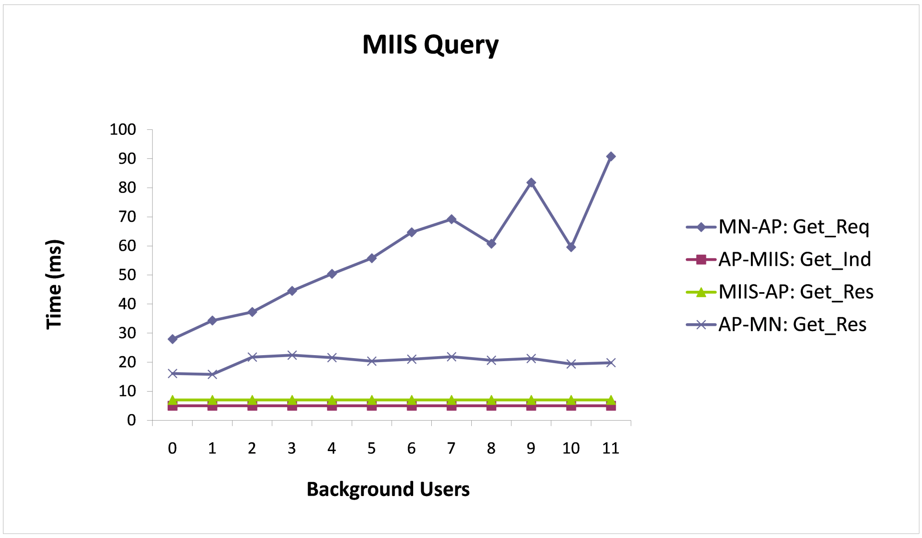

Figure 5.50: MIIS query vs Number of users (Dynamic MIIS) - WiMAX-UMTS 256Kbps

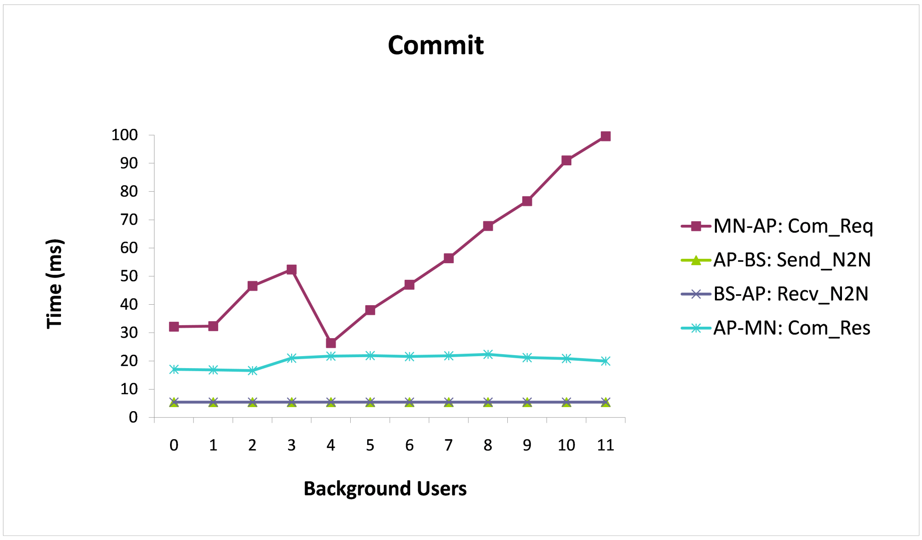

Figure 5.51: Commit vs Number of users (Dynamic MIIS) - WiMAX-UMTS 256Kbps

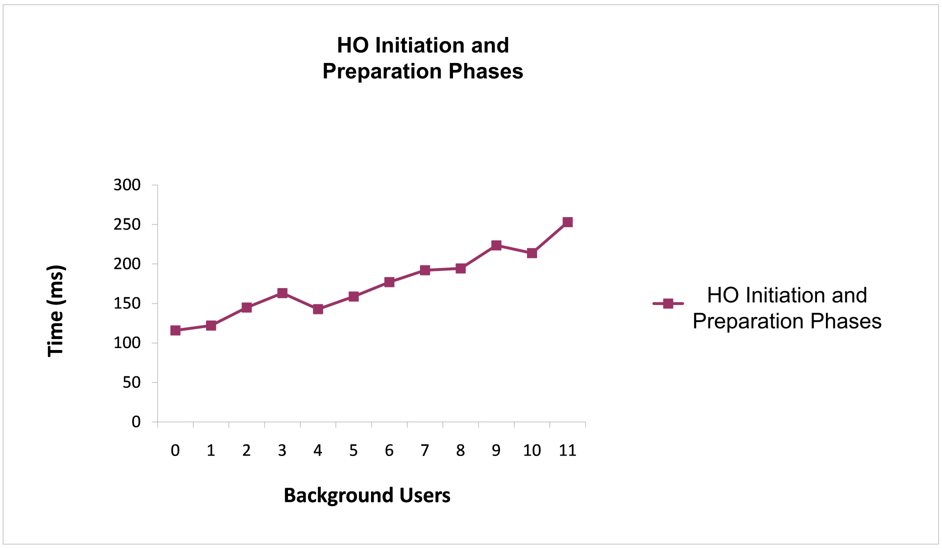

Figure 5.52: HO Initiation and Preparation time vs Number of users (Dynamic MIIS) - WiMAX-UMTS 256Kbps

There is also no difference in the graphs of the Handover Execution Delay, data packet delay and jitter, from those presented with a static MIIS.

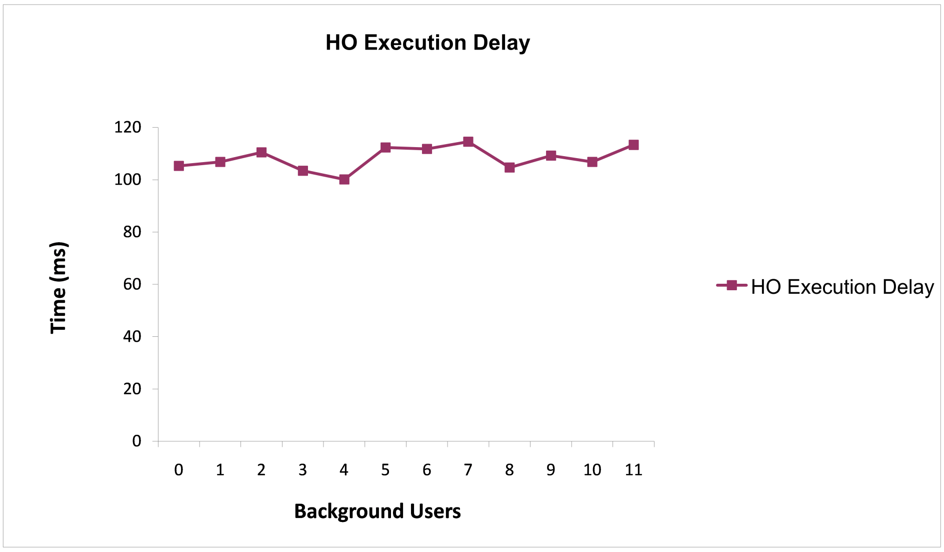

Figure 5.53: Handover Execution Delay vs Number of users (Dynamic MIIS) - WiMAX-UMTS 256Kbps

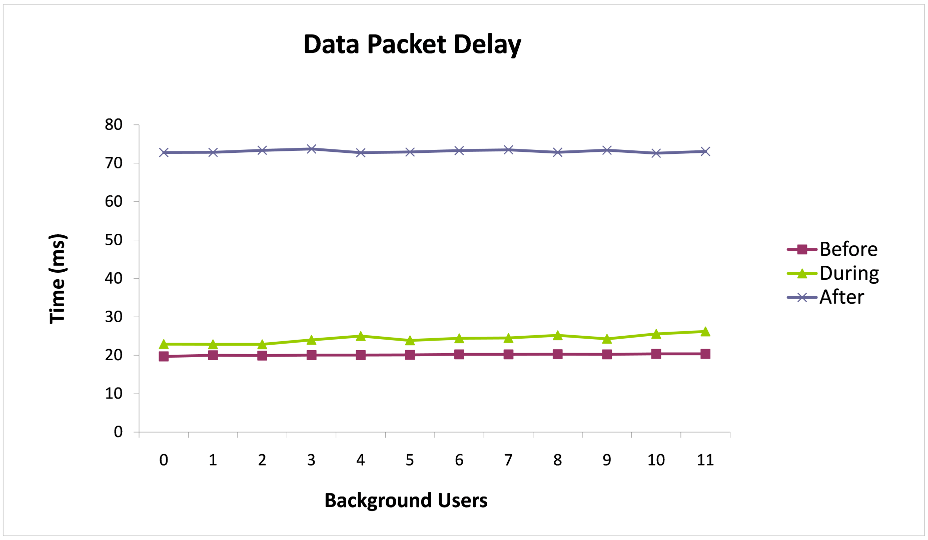

Figure 5.54: Data packet delay vs Number of users (Dynamic MIIS) - WiMAX-UMTS 256Kbps

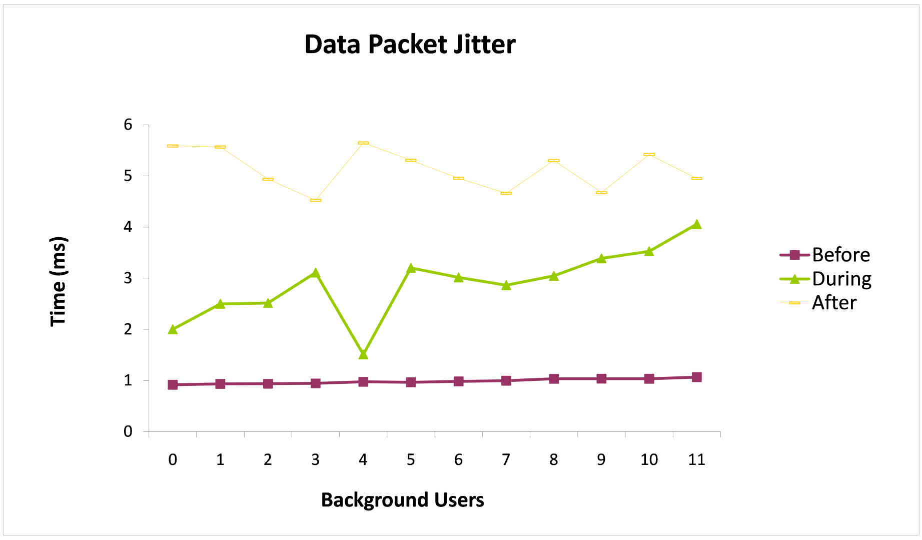

Figure 5.55: Data packet jitter vs Number of users (Dynamic MIIS) - WiMAX-UMTS 256Kbps

5.3.2.1 Changing the cable network topology

In this case, it is enhanced the improvement that the Dynamic MIIS brings to the process of handover, where the time of the handover preparation phase is between 170 and 325ms. Through figure5.56 it is possible to see the improvement brought by the dynamic MIIS (please see figure 5.48 regarding the static MIIS to clearly understand).

- MN - 256Kbps

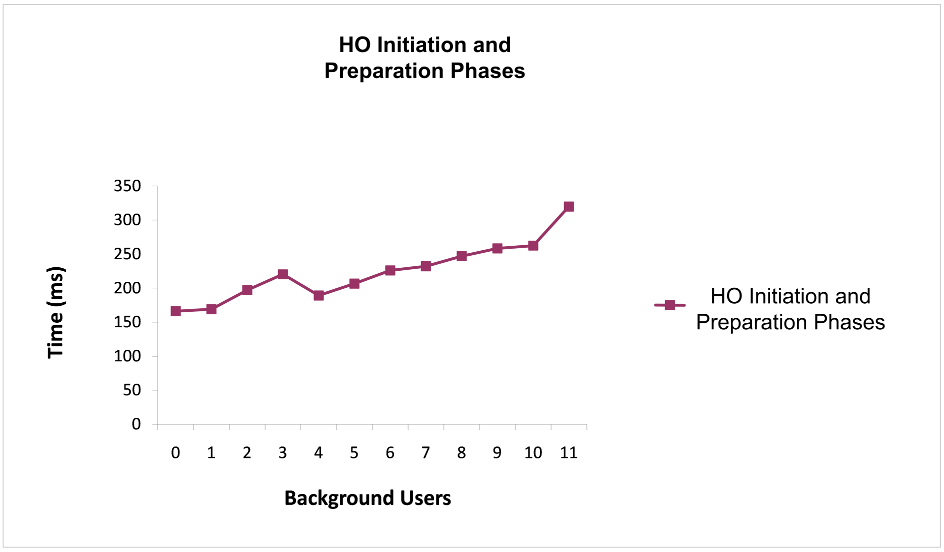

Figure 5.56: Handover Initiation and Preparation time vs Number of users (Dynamic MIIS) - WiMAX-UMTS - change

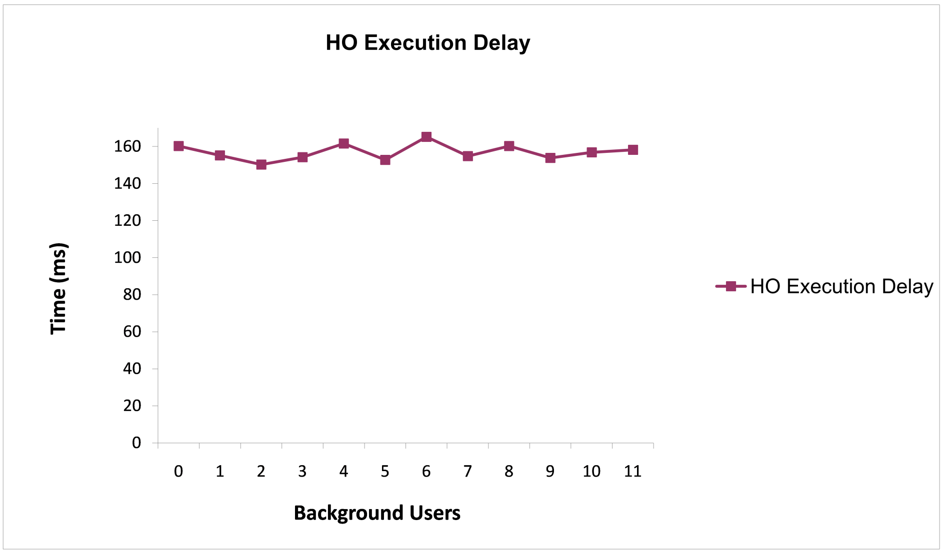

Figure 5.57: Handover Execution Delay vs Number of users (Dynamic MIIS) - WiMAX-UMTS - change

5.4 UMTS-Wi-Fi

This section presents the measurements made in the UMTS-Wi-Fi Handover. Different from the other handovers presented, which were triggered by a link going down message, in this case it is triggered through a link detect message. As it was mentioned before, the UMTS network covers all the scenario, and so a link going down message is never received. However we might need to change to a different network for several reasons. First, the MN is connected to the UMTS NodeB and enters the Wi-Fi AP range. At this point, the MN receives a Link_Detected and will start an handover process. Off course that at this point the MN is not sure that the best choice is to change to the link which was detected, however, that is why there is a handover initiation, so that in its end, decisions are taken.

In this specific situation, as the purpose is to perform the handover and register its performance, the decision was always to perform the handover to the Wi-Fi network.

It is important to remind, that UMTS works in a different way from Wi-Fi and WiMAX. The packets sent between the UMTS NodeB and the MN through the DCH channel are sent with an interval of 20ms, which is its TTI, and in blocks of 40 bytes (2.1.4.3). Since the bandwith of the UMTS DCH channel is 384Kbps, doing the maths, the transport block set will be 24.

5.4.1 Handover without MIIS

When a handover is triggered through a link detect message, as in this situation, it is not strictly necessary to consult the IS since it is not needed the network topology, because the possible target network for handover is already known (Wi-Fi in this case).

- MN - 256Kbps

Presented in 5.58 and 5.59, the Candidate Query and Commit messages have diferent behaviors. The Candidate Query request time varies, because it is the first message of the handover process, and it is only triggered when the Link Detect message is received. So, depending on the instants that the Link Detected is received, it influences the Candidate Query request time. As it was explained in section 2.1.4.3, the packets are transmited over the DCH channel with a certain TTI, which in the simulations is 20ms. Summarizing, if a packet is placed in the buffer, in a time near the next TTI, it takes less time, if not it may need to wait until 20ms. This happens for the first message of the process of handover using the UMTS interface.

The cable messages (N2N), take always the same time, since the cables have high rate capacity, as it happen and was exlpained in the other cases.

Regarding the Candidate Query Response, its time varies because the data flow comming from the CN is downlink, and so, the message is sent faster or slower deppeding on the buffer's overload. (If there was no data flow, the time would be always the same. This situation was tested but considered unnecessary to present).

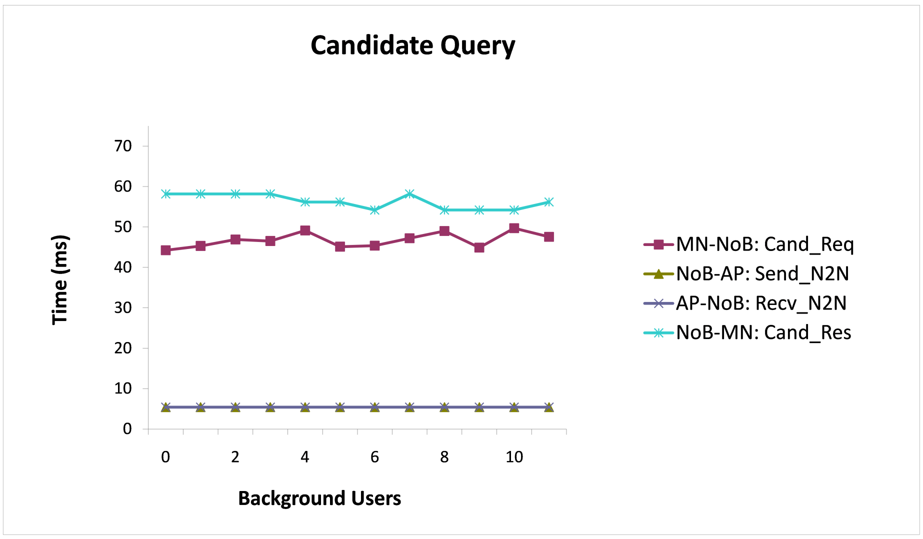

Figure 5.58: Candidate Query process time vs Number of users (without MIIS) - UMTS-Wi-Fi

As to the Commit process, the request message (Commit Request) sent takes always the same time since it is sent immediately after receiving the Candidate Query Response and, the buffer is always free because there is no data uplink flow. The Commit Reponse message varies for the same reason explained for the Candidate Query reponse message.

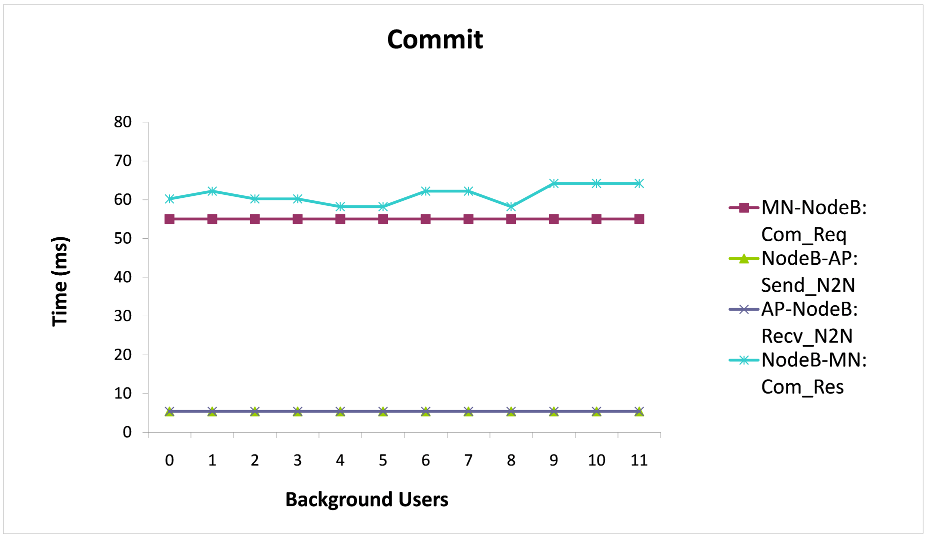

Figure 5.59: Commit time vs Number of users (without MIIS)

Regarding the overall time of the handover preparation time is almost constant because the time for processing the candidate and commit messages has low variations as background users are introduced.

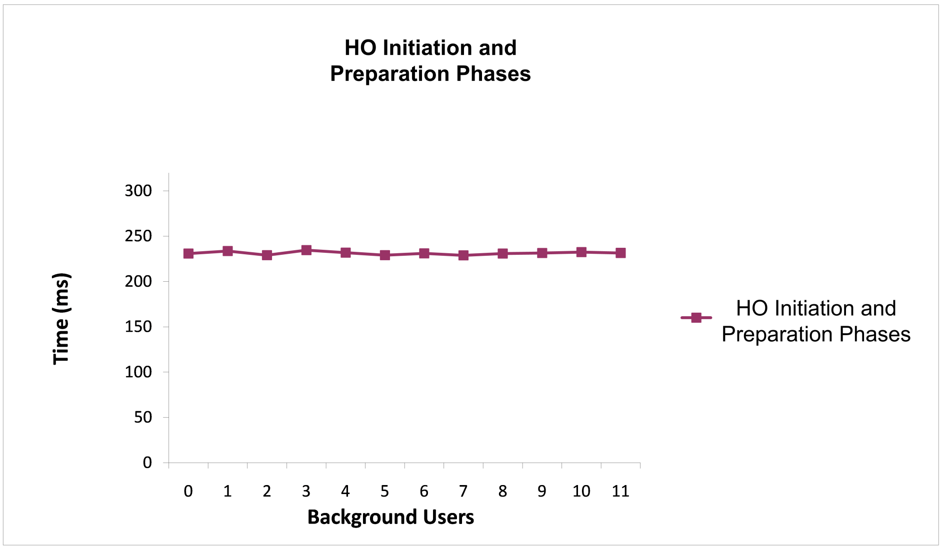

Figure 5.60: Handover Initiation and Preparation phase time vs Number of users (without MIIS)

The handover execution delay, as well as the data packet delay and jitter have a normal behavior. As explained before, when the 11th user is introduced, the AP is entering saturation and so the times increase a lot. Despite that, the packet delay, before the handover is high compared to after, because the UMTS has a high delay. As to the jitter, its values are also acceptable, being low and regular until entering in saturation.

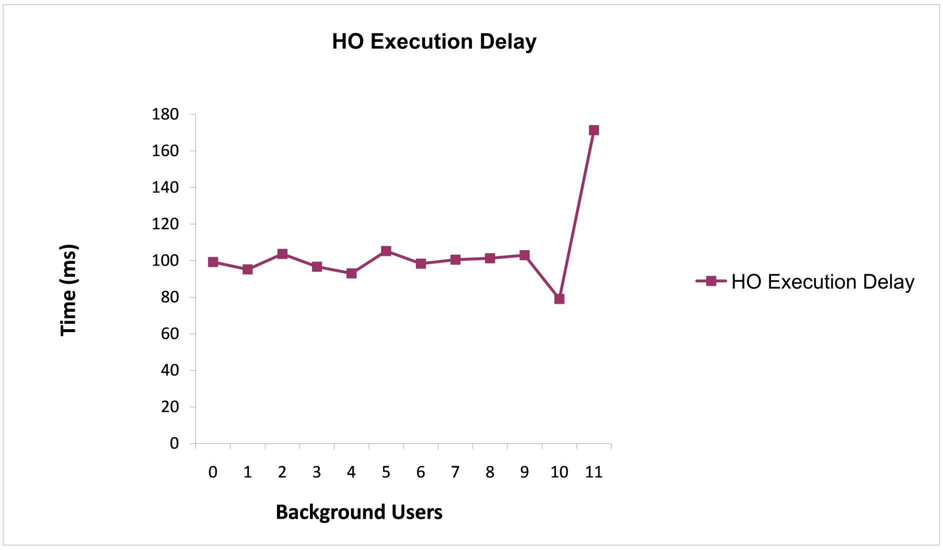

Figure 5.61: HO Execution Delay vs Number of users (without MIIS)

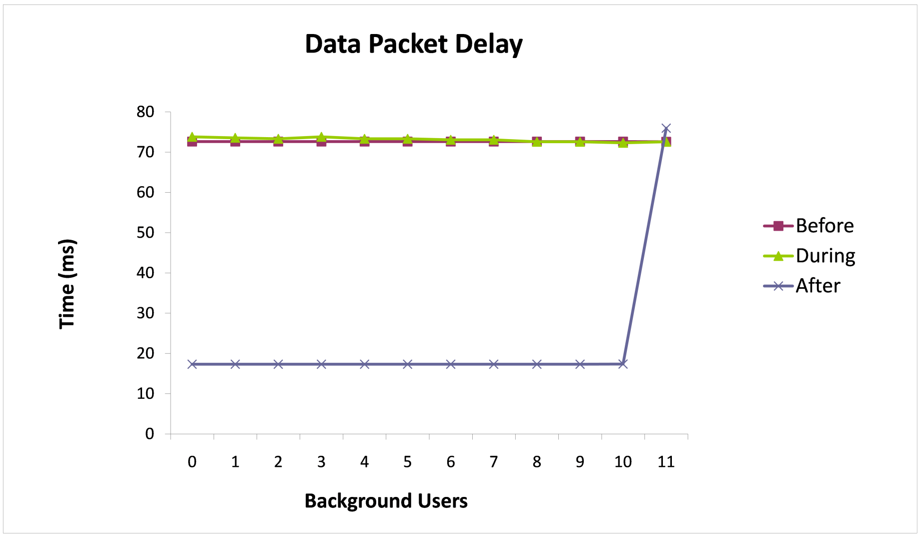

Figure 5.62: Data packet delay vs Number of users (without MIIS) - UMTS-Wi-Fi

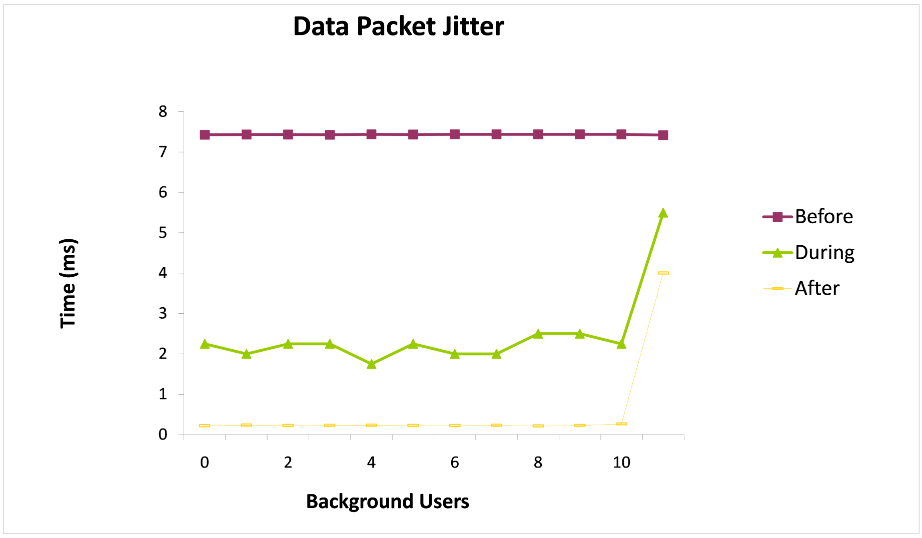

Figure 5.63: Data packet jitter vs Number of users (without MIIS) - UMTS-Wi-Fi

5.4.2 Handover with MIIS (IEEE 802.21 standard)

- MN - 256Kbps

As explained for the previous handover scenarios, in this situation, the handover preparation phase includes the IS query, the candidate query and the commit phase.

The variations of the MIIS Query graph is similar to the presented in the Candidate Query of the handover process without MIIS for the same reasons. The Candidate Query and Commit process are identical to the Commit process presented in the previous subsection (without MIIS).

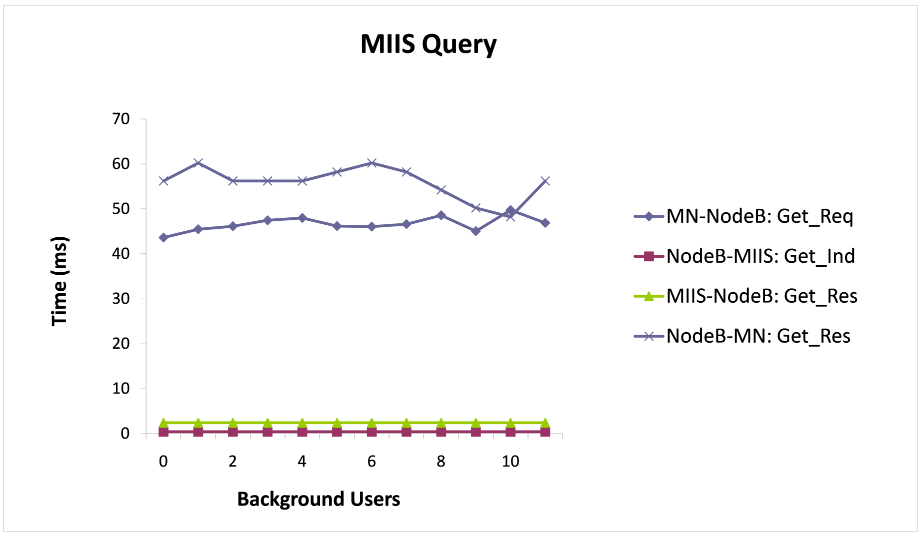

Figure 5.64: MIIS Query time vs Number of users (IEEE 802.21) - UMTS-Wi-Fi

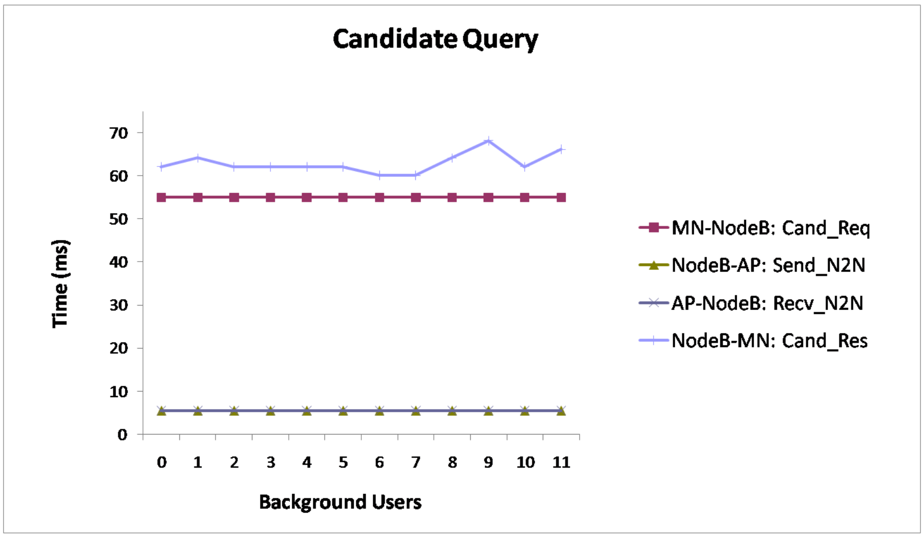

Figure 5.65: Candidate Query time vs Number of users (IEEE 802.21) - UMTS-Wi-Fi

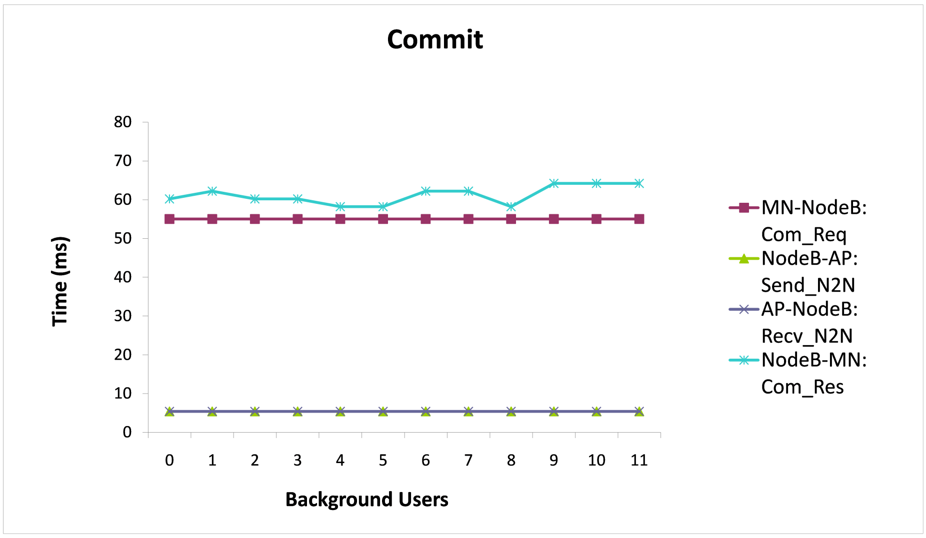

Figure 5.66: Commit time vs Number of users (IEEE 802.21) - UMTS-Wi-Fi

Regarding the Handover Preparation time, it is of course higher than the present earlier, because it is necessary to also query the IS about the network.

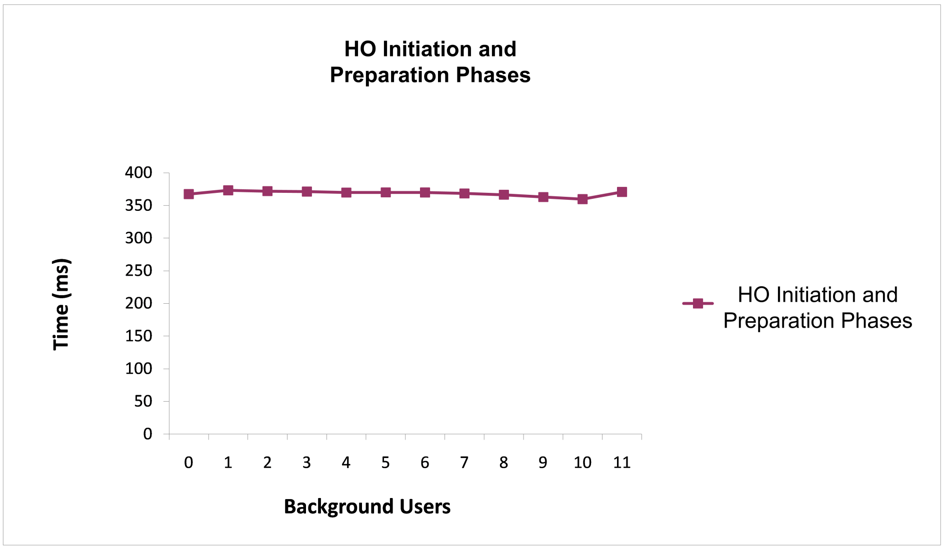

Figure 5.67: HO Initiation and Preparation phase time vs Number of users (IEEE 802.21) - UMTS-Wi-Fi

The Handover Execution Delay is identical to the previous, since the use or not use of the MIIS doesn't interfere with this process., only the change of the flow rate could change low or high these values.

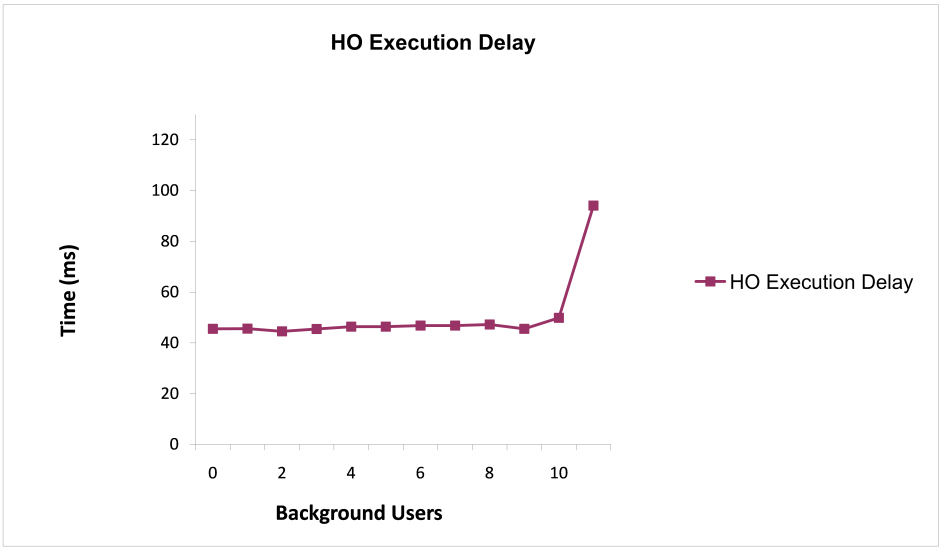

Figure 5.68: Handover Delay vs Number of users (IEEE 802.21) - UMTS-Wi-Fi

Packet delay and jitter and handover delay follow the same patern as the case with no MIIS (please see figures 5.62 and 5.63).

5.4.3 Handover with Dynamic MIIS

Not diferent from the Wi-Fi-WiMAX and WiMAX-UMTS handovers, also for the UMTS-Wi-Fi, better handover preparation times are acomplished, which enhance the handover process, compared to standard solution presented in the IEEE 802.21. The graphs behaviour is explained in the two previous sub-sections.

- MN - 256Kbps

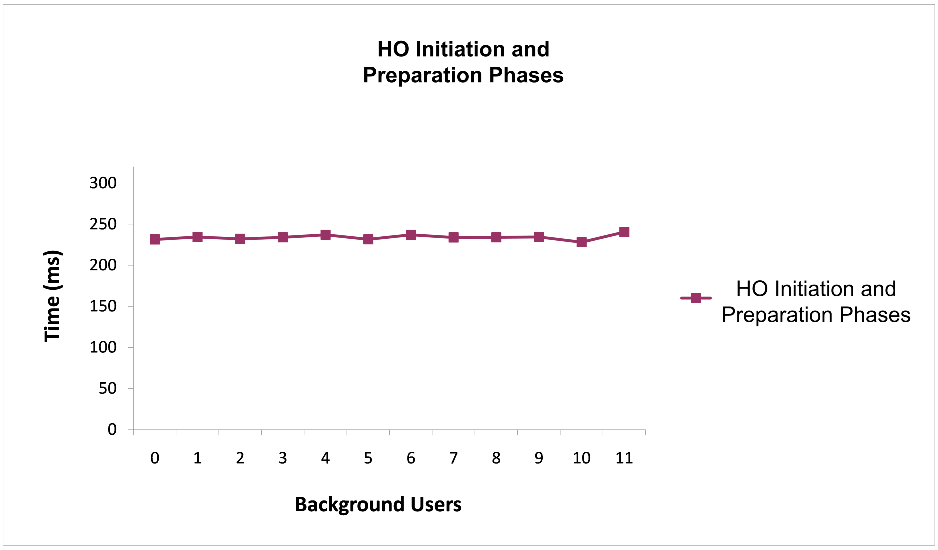

Figure 5.69: HO Initiation and Preparation phase time vs Number of users (Dynamic MIIS) - UMTS-Wi-Fi

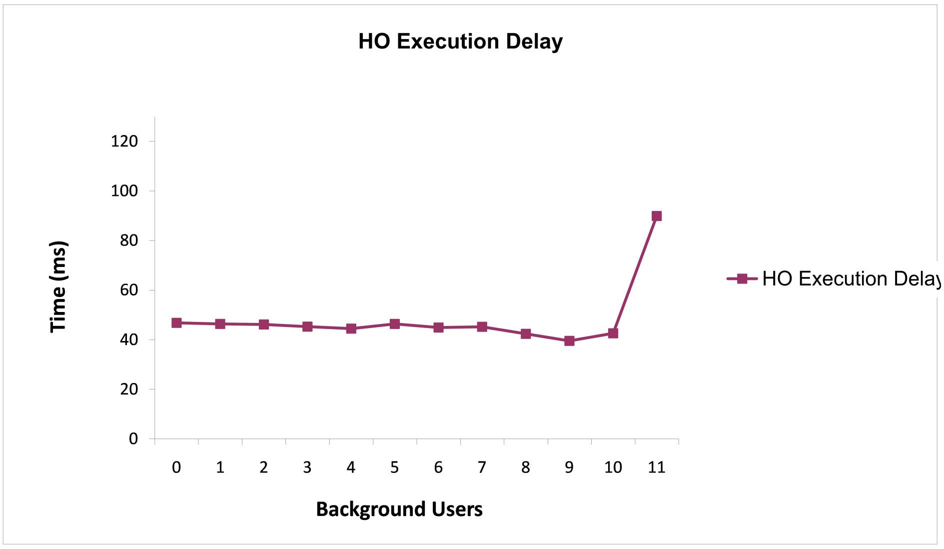

Figure 5.70: Handover Delay vs Number of users (Dynamic MIIS) - UMTS-Wi-Fi

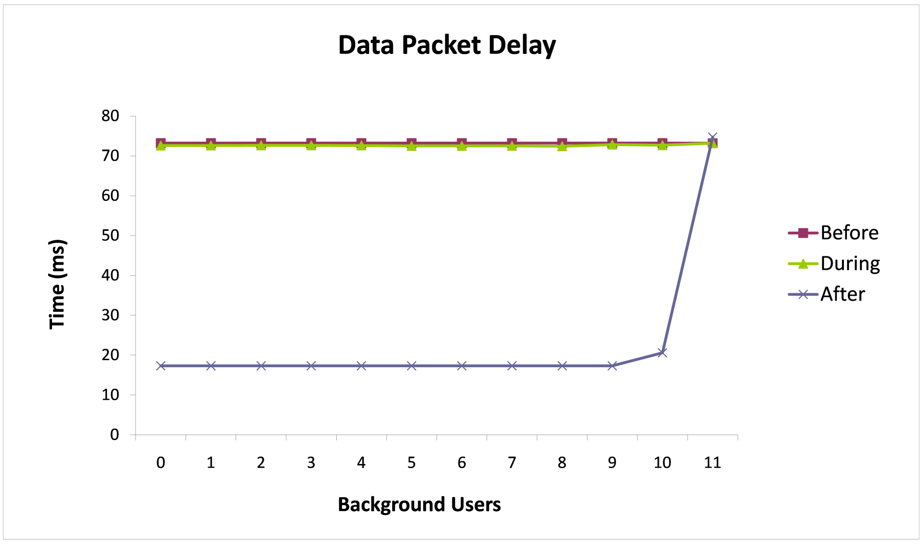

Figure 5.71: Data packet delay vs Number of users (Dynamic MIIS) - UMTS-Wi-Fi

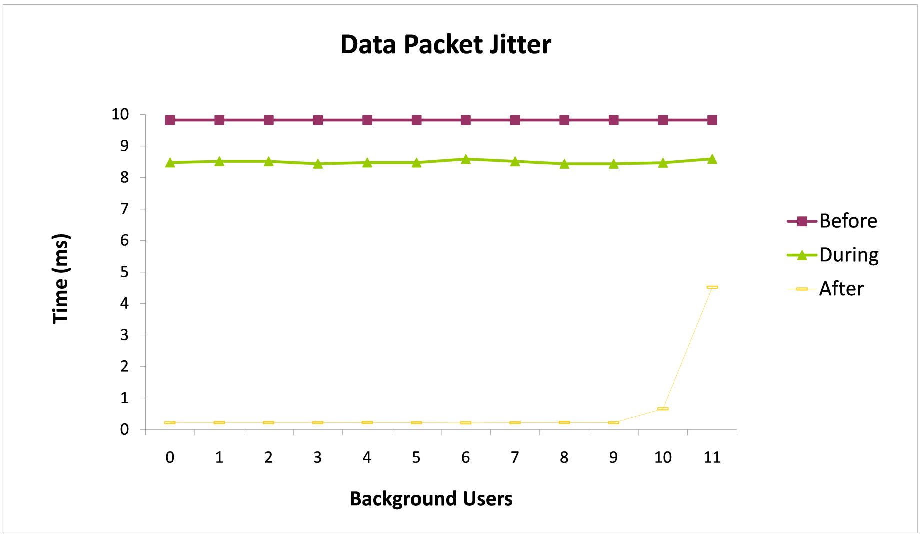

Figure 5.72: Data packet jitter vs Number of users (Dynamic MIIS) - UMTS-Wi-Fi

5.5 Summary

It has been presented in this chapter the obtained results for each type of handover process, with the MIIS as it is defined in the IEEE 802.21, without the MIIS for a specific case, and with a new concept, the dynamic MIIS, as well as several different inter-technology handover scenarios (between Wi-Fi, WiMAX and UMTS).

In the Wi-Fi-WiMAX handover analysis, it is easy to conclude that using a Dynamic MIIS, the time taking to prepare the handover is considerably much better, reducing nearly 40ms compared to the Static IS. The same happens to the WiMAX-UMTS and UMTS-Wi-Fi handovers. Regarding the data packet delay, jitter and handover delays, using the two different methods do not provide any changes. Also a interesting fact, and a logical one too, is that the handover delay decreases as the MN flow rate increases, since the interval between packets is less.

Through the results presented, it is showed that it is possible to achieve better results with the use of a dynamic MIIS in all the three handovers studied.

Chapter 6

Conclusions

6.1 Final Conclusions

This thesis presented an integration of the IEEE 802.21 framework with three broadband wireless technologies, namely UMTS, Wi-Fi, WiMAX. Besides the heterogeneous handovers procedures based on the IEEE 802.21 defined in this proposal, we also proposed a new upgrade to the IEEE 802.21. Also a deep analysis of the network simulator was performed, and several modifications were performed to support the envisioned mechanisms and scenarios. At first, the simulator supported 4 of the 5 phases of the proposed handover procedure (resource check, handover preparation, handover execution, handover completion) for handovers from WiMAX to WiMAX and from Wi-Fi to WiMAX. Now, after the work of this Thesis, the simulator supports all the 5 phases, including the network topology acquisition, and supports the several handovers possible in a scenario with Wi-Fi, WiMAX and UMTS. The UMTS integration with IEEE 802.21 was a major part of the work done in this Thesis, since the previous implementation just supported the UMTS technology. Also, the IEEE 802.21 protocol implemented was very incomplete, for integration with all technologies.

Finally, a new concept regarding the IEEE 802.21 MIIS service was presented. IEEE 802.21 defines that a IS has static information about its networks, allowing it only to provide the MIHF few information. The improvement introduced, allows the IS to have dynamic information (Dynamic MIIS), which gives it the capability to provide more information regarding its networks, improving handover process.

Several types of handovers were simulated, with the different technologies available and the different procedures presented. Through the obtained results, it was possible to evaluate the performance of the technologies during the handovers, in terms of handover delays and packet losses during handover. An overall and important conclusion taken from the three different types of handovers (Wi-Fi-WiMAX, WiMAX-UMTS, UMTS-WiFi), is that the use of a Dynamic MIIS instead of a static one reduces the initiation and preparation handover process time. The increase of the flow rate in the Wi-Fi-WiMAX handover reflects in an earlier saturation of the WiFi AP, while the Handover Execution delay reduces. The same happened for the WiMAX-UMTS and Wi-Fi-UMTS handovers, however the values were not presented. In the UMTS-Wi-Fi handover was also presented a situation with no MIIS, which proved to have good results, with low handover initiation and preparation time. However, this last situation depends on the network topology (if the distance between the NodeB and AP is less than the one from the NodeB and the IS). All times measured are associated to the access networks (Wi-Fi, WiMAX and UMTS have different propagation times), and the network topology (cable delay/length).

Through the work done in this thesis, we can conclude that the IEEE 802.21 is a big advantage regarding the mobility issue, if properly improved and applied to the specific technologies.

6.2 Future Work

Regarding a future work, there are several things still to be done. One example is the creation of more complex scenarios, evolving more access networks and more Information Serves. For example, we can suppose that in a country each operator would have one IS (at least), but the communication between IS of the same operator or even from different ones is necessary. Also, it is required to perform a deep study of the implementation, in order to support better QoS decision parameters than the ones already implemented. Finally, implementation for real scenarios could be done (for example, with the topology of the networks available in a certain geographical area), as well as for scenarios with other types of networks (mesh networks, etc).

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