IP Converged Heterogeneous Mobility in 4G networks -Network-side Handover Management Strategies-

Dissertation
zur Erlangung des Doktorgrades
der Mathematisch-Naturwissenschaftlichen Fakultäten
der Georg-August-Universität zu Göttingen

vorgelet von
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aus Aosta

Goettingen, 2007

D7

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Tag der mündlichen Prüfung: 12 April 2007

Summary

Eine Zukunft, in der mobile Terminals mit einem oder mehreren Netzwerkanschlüssen im Stande sind über drahtlose und drahtgebundene Netze und unterschiedlichen Makro- und Mikroradiozellumgebung zu roamen, verlangt die Entwicklung von erweiterten Methoden zur Kontrolle von IP basierter Mobility. Diese Methoden sollten traditionellen Terminal Mobilität (hauptsächlich wegen der Bewegungsfreiheit der Nutzer) und die Beweglichkeit über heterogene Netze hinweg in Gegenwart von Benutzern, die sowohl mobil als auch stationär arbeiten, beachten. Um dies zu ermöglichen, wird eine verknüpfte Interaktion, angefangen bei einer großen Anzahl an Layern-2 Zugriffstechnologien bis hin zu den allgemeinen IP Layern benötigt, um den Austausch von Nachrichten zwischen den Terminals und den Netzwerk-Komponenten zu erlauben. Deshalb ist es nötig, dass die althergebrachten Host Mobility gesteuerten Konzepte sich hin entwickeln zu den Bedürfnissen mobiler Operatoren im Kontext zu vollständig entwickelten Netzwerk kontrollierter Mobility. Das Konzept der Netzwerk-Kontrollierten Handovers ist weithin üblich im Umfeld der cellular Netzwerk-Technologien. Mit Hilfe von Multimode Terminals, die Layer-2 Techniken nutzen, kann dieses Konzept nur innerhalb der jeweiligen Technologie angewandt werden, was die volle Ausnutzung des multi-access, des Mehrfach-Zugriffs, erfordert. Wir diskutieren im Folgenden eine Netz-übergreifende Layer-3 Technik und stellen eine Analyse der Effizienzvorteile dieser Technik vor. Generell wurde dabei ein Performance Gewinn der Systemnutzung von 25% erreicht. Diese Doktorarbeit stellt und bewertet einen neuen Rahmenentwurf vor, basierend auf den künftigen Standard IEEE 802.21. Dabei wurden sowohl Netzwerk als auch Host basierende Mobility berücksichtigt.

Acknowledgements

I would like to extend my heartfelt thanks to the following people for their help in making this thesis possible.
I would like to thank my supervisor Prof. Dieter Hogrefe for his kind support at University of Goettingen and Amardeo Sarma for his fruitful feedback during my research work at NEC Network Laboratories in Heidelberg.
I am grateful to prof. Ignacio Soto, Albert Banchs, Rui Aguiar and Albert Vidal for their helpful discussions which significantly contributed to the results presented in this thesis. I also would like to give a big hug to Antonio and Daniel with whom I enjoyed a great team work implementing and debugging the simulator code.
Thanks also to all my colleagues at NEC who directly or indirectly contributed to the development of this thesis.
Finally, I would not be here without the constant support of my parents, who stimulated the interest in committing to new challenges, and Ara who **patiently** waited a large number of evenings and week-ends for my work to be delivered.

Contents

List of Tables

List of Figures

Glossary

2G Second Generation wireless telephony technology

3G Third Generation wireless telephone technology

3GPP Third Generation Partnership Project

4G Fourth Generation Communication Systems

AAA Authentication Authorisation Accounting

ADSL Asymmetric Digital Subscriber Line

AN Access Network

AP Access Point

AR Access Router

ASN Access Service Networks

BSS Base Station system

CN Core Network

CoA Care of Address

CS Circuit Switch

CSN Core Service Network

eNodeB evolved Node B

FDD Frequency Division Duplex

GGSN Gateway GPRS Supporting Node

GMD Global Mobility Domain

GMLC Gateway Mobile Location Center

GMP Global Mobility Protocol

GPRS General Packet Radio Service

GSM Global System for Mobile Communications

HA Home Agent

HLR Home Location Register

HSS Home Subscriber Server

IMS IP Multimedia Subsystem

IP Internet Protocol

IPv4 Internet Protocol version 4

IPv6 Internet Protocol version 6

ISDN Integrated Services Digital Networks

LCS LoCation Services

LMA Local Mobility Anchor

LMD Local Mobility Domain

LMP Local Mobility Protocol

LMU Location Measurement Unit

LTE Long Term Evolution

MAG Mobility Access Gateway

MAP Mobility Anchor Point

ME Mobile Equipment

MGW Media Gateway Function

MIHO Mobile initiated Handovers

MIP Mobile IP

MME Mobility Management Entity

MN Mobile Node

MS Mobile Station

MSC Mobile Switching Centers

NAP Network Access Provider

NIHO Network Initiated Handovers

PDN Packet Data Network

PLMN Public Land Mobile Network

PoA Point of Attachement

PoS Point of Service

PS Packet Switch

PSTN Public Switched Telephone Network

RNC Radio Network Controller

RNS Radio Network System

RRC Radio Resource Control

SAE System Architecture Evolution

SGSN Serving GRPRS Supporting Node

SIM Subscriber Identity Module

SRNS Serving Radio Network Subsystem

TDD Time Division Duplex

UE User Equipment

UMTS Universal Mobile Telecommunications System

UPE User Plane Entity

UTRAN UMTS Terrestrial Radio Access Network

WLAN Wireless Local Area Network

Chapter 1

Introduction

With the early development of mobile cellular networks a new paradigm in communication became available for users mostly concerned with the public standard telephony network. Users started to be mobile and since then wireless communications gained more and more importance resulting in new fora standardizing the upcoming networks architectures and related protocol functionalities. The traditional offered services over these networks (GSM) were mostly concerned with voice communications. In parallel to this, the Internet world started to rapidly evolve and to become necessary part of our everyday life. Nowadays a large set of services is offered through the World Wide Web (WWW) helped, also, from the availability of broadband access technologies such as ADSL.

In the recent past years, wireless Internet access via e.g. Wireless LAN has become widely spread both in private/corporate or public environments, making Internet access at the same time mobile and ubiquitous. The merging of the Internet world together with the wireless communication world, combined with the availability of mobile devices supporting multiple wireless technologies such as Wireless LAN and 2G/3G, created new business opportunities for mobile operators. In this new world users can access services anywhere and anytime, being always best connected while enjoying a great variety of applications.

Lately, in the evolution of the mobile communication systems, one element is playing a fundamental and key role: the Internet Protocol. In the emerging landscape of the wireless heterogeneous world the IP (IPv4 and IPv6) stack acts as a common convergence between the 802 family of networks and 3GPP,3GPP2, SAE Long Term Evolution networks. Supporting IP in the wireless access network as well as in the core network has become a task or of primary importance both in the research community as well as in the manufacturers world to produce revenue from the delivery of multimedia services. However, the creation of a common platform IP-based to optimally control mobile subscribers across wireless heterogeneous access is not a trivial task. The first effort, produced from the 3GPP standardization

body, addresses the design of a 3G/WLAN inter-working function for the delivery of IMS based services. The renewed architecture, therefore, compounds standard CS services with advanced PS services supporting IP datagrams exchange both over the radio channel and in the core part of the network.
It is intuitive that, in such environments, subscribers are mobile and they expect the quality of the service delivered on the PS network to be equally comparable to the one experienced on the CS network. That is, quality and continuity of the offered services are not a nice add on rather primary requirements to be fulfilled, else compromising network deployments and revenues of mobile operators. It has been already identified [1] that the support of policy control (e.g. mobility) designed for 3G networks presents shortcomings when applied to heterogeneous wireless access. One of the most controversial aspects is the way control of mobile subscribers is performed.
In a wireless system mobility is the action of changing point of access to the wireless access network while keeping ongoing connections, a procedure also known as handover. Traditional mobility support in CS based networks is network controlled. The network requires pilot measurements to the mobile station and the corresponding network element is the decision maker. On the other hand, the IETF standardization body, which is standardizing all the mobility extensions to the IP protocol, considers the mobility procedure mostly host centric. Although recent efforts show concrete changes in the development of new protocols [2] many issues are not yet solved. As already mentioned, the mobility problem and its solution are not yet clearly identified. That is, the control should reside in the network but IETF protocols are not yet ready to efficiently support IP-based network controlled mobility across wireless heterogeneous access.
The IEEE 802.21 WG [3] is undergoing a new standardization effort aiming at developing a new standard for media independent handover control across the 802 family of network and the 3GPP and 3GPP family of networks. The standard includes the design of components residing in the mobile node and in network and it specifies the required protocol operations for information exchange. Starting from the IEEE 802.21[1], the work presented in this document focuses on the evaluation of a framework for network initiated and controlled handovers in an IP-based heterogeneous wireless access scenario. The extensive simulation study aims at identifying possibilities and challenges of network controlled an initiated handovers highlighting the requirements for future 4G networks design. To the best of author's knowledge this is one of the first studies on such topic closely following standardization bodies and related research activities. That is, starting from the analysis of mobility procedures in 2G and 3G networks we present solutions on how to support comparable

[1] This protocol has been selected to provide early feedback in the development phase of procedures for network controlled handovers as shown in this thesis.

procedures in a multi wireless heterogeneous environment for end to end IP-based seamless services delivery.
The results obtained have been published in several international conferences [4], [5], [6], [7], [8], [9], [1], [10], [11] and have been input to both IEEE and IETF standardization bodies. The appendix A summarizes the technical content of the contributions not explicitly described in the main body of the thesis being format and syntax too specific to the related standardization body. Nevertheless, it is worth to mention that the active work in the IEEE 802.21 WG resulted in the acceptance of the contribution on centralized network initiated handovers [12]. In parallel several contributions presented in the ITEF Mipshop WG (who is standardizing part of the layer three transport support for IEEE 802.21) have been accepted for publication as part of the working group document problem statement on Mobility Independent Services [13].
The structure of the work presented in the next chapters is as follow.
Chapter 2 reviews mobility in GSM and 3G networks covering current standard activities in 3GPP SA2 (LTE) and WiMax forum architecture. The input is taken from standards technical document and summarized having as goal to show the development of the mobility management. The reader should find this useful for the following chapter and 4G network considerations. Chapter 3 introduces as an example of 4G networks the Daidalos [14] architecture for mobility support as explained in [7]. In the second part of the chapter considerations [9] on mobile terminal initiated versus network initiated handovers, in the context of 4G networks, are given. The purpose is to show the benefit of network initiated handovers (via a simulative study) in an heterogeneous IP based multi wireless technology environment. This study is protocol agnostic giving general guidelines. To present the framework for performance assessment the IEEE 802.21 has been selected aiming at identifying weaknesses of the upcoming standard for centralized network controlled handovers[2]. Chapter 4 allows the reader to get acquainted with the IEEE 802.21 standard [3], highlighting the most interesting aspects for the development of this work. Chapter 5 introduces the terminal architecture [6], [5] developed to support speedy handovers based on 802.21 design. We show the benefit of the cross layer design and how terminals should implement multi wireless access support. Chapter 6 is the core of the thesis where the network controlled and initiated handover support [11] based on the 802.21 protocol is described and evaluated via extensive simulative performance study. The reader should find in the explanation of this section useful insights for IP based network controlled handovers in future 4G networks. Chapter 7 concludes our work presenting considerations available in [1].

[2]It would have been possible to develop a new protocol, loosing, however, the possibility to contribute to the advance of an upcoming standard.

As a final remark, appendix A provides an overview of the work supporting standardization effort covering both IEEE 802.21 WG and IETF Mipshop WG. Appendix B provides a review of the implementation effort published in [4] and in [10].

Chapter 2

Mobile Networks: a walk through

With the early development of the 2G (GSM) network mobile users started to enjoy a new dimension in communications being connected while on the move. Departing from the traditional PSTN communication model, reachability started to be of no concern to mobile subscribers able to place and receive voice calls anywhere within the coverage of the wireless cellular access. 2G networks define new architecture elements and associated functionalities introducing the concept of handover, namely the capability for mobile stations to switch point of attachment to the wireless access network. Such procedure usually involves radio operations. In the early releases of GSM networks mobility management was rather a simple operation. With the specification and deployment of the 3G standard mobility procedures are enhanced increasing both flexibility and complexity covering a large variety of scenarios. Traditional CS services are compounded with PS services introducing for the first time the Internet Protocol (IP) in mobile devices so far a wide spread technology mostly in the well known Internet word. Since then, providing IP connectivity to users on the move has become one of greatest challenges both from a business and research point of view. The 3GPP standardization body specifies protocols to support IP based services in the radio access network and interfaces enabling inter-working with emerging technologies natively supporting IP such as Wireless LANs . These inter-working functionalities allow users to enjoy a large variety of multimedia applications while keeping ongoing connections. In such environments mobility management constantly increases in complexity due also to the stringent requirements of real time communications (Voice over IP is just an example).
Considering the trend analyzed so far it is reasonable to envision a future where the Internet Protocol is the convergence layer between existing and upcoming technologies. The support for mobility in such potentially complex scenarios is not yet solved, especially when addressing paradigms such as *always best connected* or *seamless services across heterogeneous networks*. The availability of new wireless/wired access technologies, while enriches scenarios and optimizes choices for mobile users,

it also increases the complexity of mobility procedures affected not only by user preferences, context aware applications or the like but also from network operators's requirements. That is, network operators require the development of new tools for mobility management traditionally belonging to the CS problem space and here migrated to the new IP based networking world.
The research community has widely explored the IP mobility field [15], [16], [17], [18], [2], [19] and standards are currently undergoing first deployment experiences. However when envisioning future mobile networks following the ALL-IP paradigm heterogeneous access is not anymore and optional add-on rather a requirement that needs to be addressed and solved across the IP convergence layer. Along these lines, standardization bodies are currently studying the impact of such requirements on existing networks and how networks should evolve to efficiently support this new set of IP based services. For instance 3GPP System Architecture Evolution is defining how future mobile operators networks, in ten or more years time frame, should evolve to natively support 3GPP and non 3GPP networks based on the common IP protocol. The WiMax-forum[1] architecture is specifying the architecture for mobile support for IEEE 802.16 based networks. The wide landscape of wireless technologies suggest the development of common layers to manage mobility across technologies as seamlessly as possible leaving the intra technology case to technology-specific solutions. That is, the development of solutions is not anymore low layers agnostic rather it requires a tight integration to optimize procedures and performance.
Some of these concepts have been already demonstrated in the framework of several European founded projects. As an example the MobyDick project[2] proposed a platform where mobility security and quality of service where tightly integrated. The project successfully demonstrated the feasibility of the IP based approach. Evolving from traditional view of mobility managed at layer three with few interaction at layer two, the Daidalos[3] and Ambient Networks[4] projects are currently investigating advanced mobility management procedures looking more at technology specific requirements as well as at new mobile operators requirements.
The remainder of this chapter, while not aiming at an exhaustive review, intends to provide a mobility development walk through showing how mobility concepts evolved and how the upcoming requirements motivated the research experiments conducted in this work. For completeness, details of the introduced concepts can be found in the referenced technical specifications.

[1] http://www.wimaxforum.org
[2] http://www.ist-mobydick.org
[3] http://www.ist-daidalos.org
[4] http://www.ambient-networks.org/

2.1 2G Mobile Networks

With the early development of the GSM network [20], a new dimension in wireless communication became available for users mostly concerned with standard PSTN networks. With the availability of portable handsets reachability became of no concern to mobile subscribers able therefore to travel anywhere while still being able to receive or make voice calls. Although the mobility support is herein implemented on top of the circuit switch network, principles and procedures (eventually more complex) are present in nowadays systems. The goal of this section is to highlight such features drawing principles to be taken in consideration in the writing of this document.
[21] describes the functional components and network architecture of a PLMN. PLMN provides land wide mobile communication capabilities to users on the move as well as communication capabilities with external existing networks such as PSTN or ISDN networks. A PLMN is a set of interconnected Mobile Switching Centers (MSC) handling terminal connectivity toward the network and call routing to/from the terminal. In [21] the functionalities and associated procedures are listed. Here for brevity we report the ones closely related to mobility management.

2.1.1 Functional Components and Network Architecture

In a mobile system global reachability is typically maintained by a set of databases recording terminal's position and being updated each time the terminal changes its own location. How often the terminal changes its current point of attachment to the network (operation commonly denoted as handover) depends on the size of the radio cell where the terminal is currently connected to and on the granularity of the terminal mobility.
The *Home Location Register* (HLR) is a data base in charge of the management of mobile subscribers. A PLMN may contain one or several HLRs which depends on the number of mobile subscribers, on the capacity of the equipment and on the organization of the network. The HLR stores the subscription information and some location information enabling the charging and routing of calls toward the MSC where the mobile station (MS) is registered. In case the PLMN supports location services (LCS) the HLR stores a LCS privacy exception list (which indicates the privacy class of the MS subscriber) and a GMLC list.
Different types of identity are attached to each mobile subscription and are stored in the HLR:

- the International Mobile Station Identity (IMSI)
- one or more Mobile Station International ISDN number(s) (MSISDN)

If LCS is supported the LMU indicator is stored. There is always at least one identity, apart from the IMSI, attached to each mobile subscription and stored in the HLR. The IMSI or, the MSISDN may be used as a key to access the information in the database for a mobile subscription. The data base contains other information such as teleservices and bearer services subscription information, service restrictions (e.g. roaming limitation), supplementary services.
The *Mobile-services Switching Center* is an exchange which performs all the switching and signaling functions for mobile stations located in a geographical area designated as the MSC area. The main difference between a MSC and an exchange in a fixed network is that the MSC has to take into account the impact of the allocation of radio resources and the mobile nature of the subscribers and has to perform in addition, at least the following procedures:

- procedures required for the location registration (see [22])
- procedures required for handover (see [23])

The *Mobile Station (MS)* consists of the physical equipment used by a PLMN subscriber. It comprises the Mobile Equipment(ME) and the Subscriber Identity Module (SIM). The ME comprises the Mobile Termination (MT) which, depending on the application and services, may support various combinations of Terminal Adapter (TA) and Terminal Equipment(TE) functional groups. These functional groups are described in [24].

Figure 2.1 depicts the organization of PLMN functional components and related interfaces. MS, MSC and HLR retain most of the operations related to mobility and therefore relevant for the work presented in this document. Additionally figure 2.2 shows the network support and associated interfaces for Location Services specified in [25]. Location services features allow new and innovative location based services making current location of user's terminal available to the user, network operator, service provider or value added services providers. For the development of the thesis it is worth to note how the support of location information enables internal network operations such as asset management or traffic congestion reporting. Directed retry handover procedures (2.1.4) are an example.

2.1.2 Interfaces and Signaling Protocols

Interfaces in the PLMN network

The main interfaces handling mobility are with the A and Abis interface within the same MSC and the E interface handling mobility of MS between different MSCs. The A Interface between the MSC and the BSS is implemented at layer three on top of the Signaling System 7 and is specified in [26]. An overview of the SS7 signaling

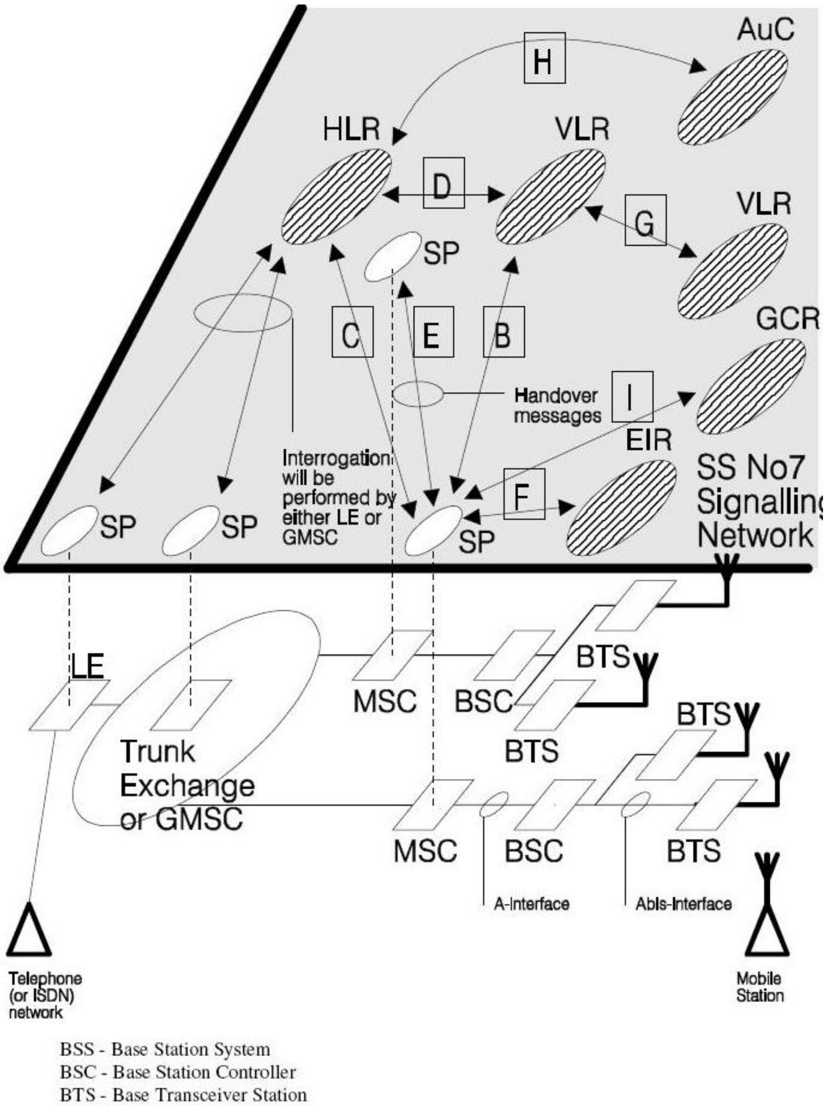


Figure 2.1. GSM Network

framework is provided in appendix C. The E interface for inter MSC mobility is presented as part of the [27] document. Here are some of the GSM CS interfaces in the MSC transported over SS7:

B VLR (uses MAP/B) Most MSCs are associated with a VLR, making the B interface internal

D HLR (uses MAP/D) Used for attaching to the CS network and location update

E MSC (uses MAP/E) Used for inter-MSC handover

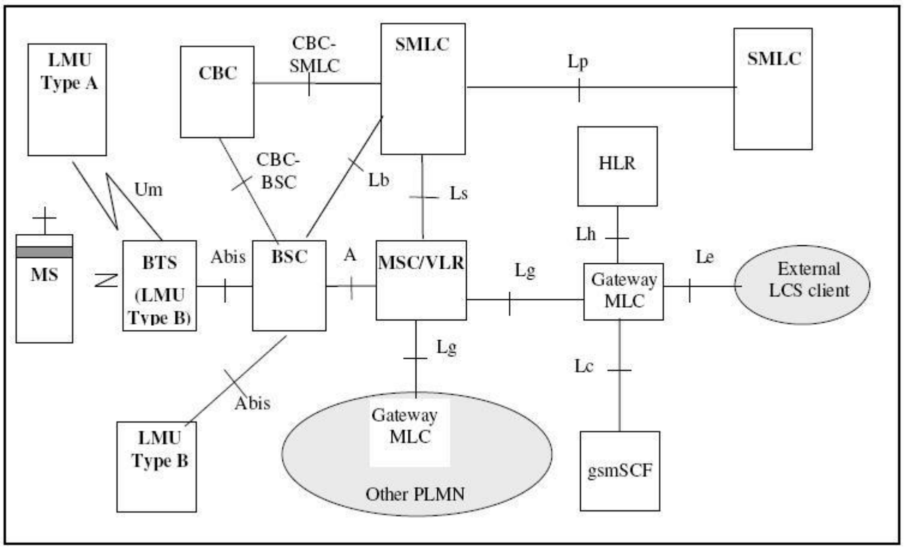


Figure 2.2. LCS Support Configuration

F EIR (uses MAP/F) Used for equipment identity check

H SMS-G (uses MAP/H) Used for SMS over CS

2.1.3 Handover initiation conditions

The procedures for handover initiation are described in Technical Specification [23] and are summarized in the following. The purpose of the handover procedures are to ensure that the connection to the Mobile Station (MS) is maintained as it moves from one Base Station System (BSS) area to another.
Handover is initiated by the network based on radio subsystem criteria (RF level, quality, distance) as well as network directed criteria (e.g. current traffic loading per cell, maintenance requests, etc.). In order to determine if a handover is required, due to RF criteria, the MS shall take radio measurements from neighboring cells. These measurements are reported to the serving cell on a regular basis. When a network determines a need for a handover the procedures given in [26] are followed. Additionally, the handover decision by the network may take into account both the measurement results from the MS and network directed criteria. The same decision process is used to determine when to perform both the Intra-MSC and Inter-MSC handover in all the procedures described in the present document.
The following case are possible:

1 handover between physical channels of the same Base Station System (BSS). This capability could be used in the following situations:

  - when the physical channel carrying the call is subject to interference or other disturbances
  - when a physical channel or channel equipment carrying a call has be to be taken out of service for maintenance or other reasons

2 handover between Base Station Systems (BSSs) of the same MSC

3 handover between BSSs of different MSCs of the same PLMN

Cases 2) and 3) are used in order to ensure continuity of the connection when an MS moves from one BSS area to another. For case 3) two procedures are defined:

- basic handover procedure where the call is handed over from the controlling MSC (MSC-A) to another MSC(MSC-B)
- subsequent handover procedure where the call is handed over from MSC-B to MSC-A or to a third MSC (MSC-B')

In both cases 2) and 3) the same procedures as defined in [26] and [28] apply on the A-interface and on the Radio Interface, respectively. In case 2) the handover procedures transport the A-interface messages between MSC-A and MSC-B described in the Mobile Application Part (MAP) [27]. The split in functionality between the BSS and MSC is described in the GSM 08 series of Technical Specifications. The interworking between [27] protocol and [26] protocol is described in the [29] Technical Specification. Handovers which take place on the same MSC are termed Intra-MSC handovers. This includes both Inter-BSS and Intra-BSS handovers. Handovers which take place between different MSCs are termed inter-MSC handover. Inter-MSC handover imposes a few limitations on the system. After inter-MSC handover call re-establishment is not supported. The list of features supported during and after Inter-MSC handover is given in GSM [30]

2.1.4 Procedures

Hereinafter examples of handover procedure are presented. It is not intended to present a complete and exhaustive report on GSM handover procedures, rather to summarize principles useful for the development of this work.

Intra MSC Handover case

The detailed explanation for Intra MSC handover procedures can be found in [26] and [28]. There are two types of handover that can be considered which involve a BSS and single MSC. These are Internal Handover and External Handover. An

Internal Handover is a handover which takes place between channels on a cell or cells controlled by a single BSS, without reference to the MSC, although the MSC maybe informed of its occurrence. Handovers between channels on the same cell or between cells on the same BSS which are controlled by the MSC are termed External Handovers and use identical procedures to those for Intra-MSC handovers.
Figure 2.3 depicts a basic operation for external Intra-MSC handover. It is impor-

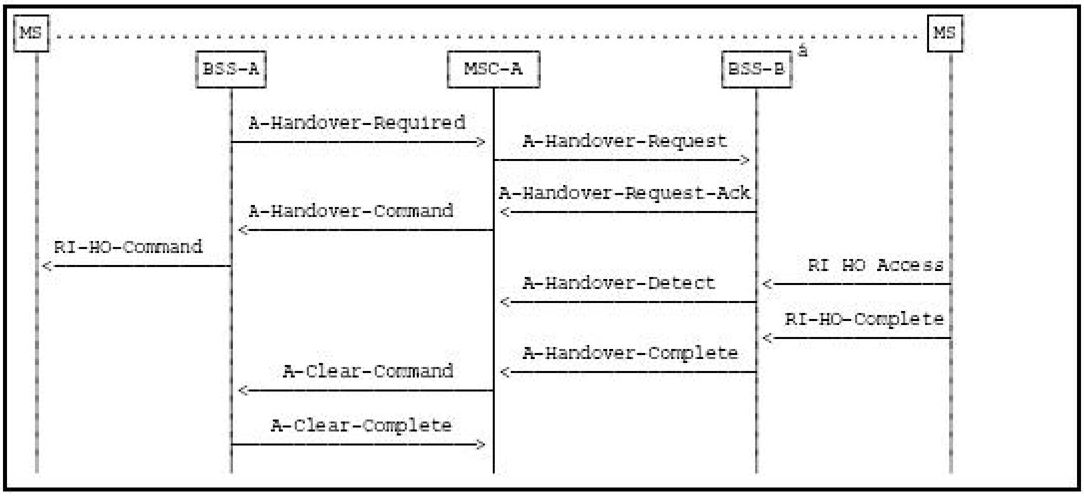


Figure 2.3. Basic External Intra-MSC Handover Procedure

tant to stress that the serving BSS-A determines when handover for a target MS should occur.

Inter MSC Handover Case

The Inter MSC handover case involves two MSCs, namely MSC-A and MSC-B hereinafter briefly described.

MSC-A In order to simplify the description of the handover procedures the controlling MSC (MSC-A) can be considered to be composed of five functional units:

1. BSC/MSC (MS/BSC) Procedures MSC-A. This unit is used to control the signalling between the MSC, BSC and MS.
2. Call Control Procedures MSC-A. This unit is used to control the call.
3. Handover Control Procedures MSC-A. This unit provides both the overall control of the handover procedure and interworking between the internal interfaces.

4. MAP Procedures MSC-A. This unit is responsible for controlling the exchange of MAP messages between MSCs during an Inter-MSC handover.
5. Switch and Handover Device MSC-A. For all ongoing calls this unit is responsible for connecting the new path into the network.

MSC-B In the Inter-MSC handover case, the role of MSC-B is only to provide radio resources control within its area. This means that MSC-B keeps control of the radio resources connection and release toward BSS-B. MSC-A initiates and drives a subset of BSSMAP procedures toward MSC-B, while MSC-B controls them toward its BSSs to the extent that MSC-B is responsible for the connections of its BSSs. The release of the dedicated resources between MSC-B and BSS-B is under the responsibility of MSC-B and BSS-B, and is not directly controlled by MSC-A. In the same way, the release of the connection to its BSS-B, is initiated by MSC-B, when the dialogue with MSC-A ends normally and a release is received from the circuit connection with MSC-A, if any, or when the dialogue with the MSC-A ends abnormally.

The functional composition of an MSC acting as MSC-B is essentially the same as that of MSC-A. However, there are some differences. The functional units are as follows:

1. Call Control Procedures MSC-B. This unit is used for normal call control and signaling to MSC-A.
2. MAP Procedures MSC-B. This unit is responsible for controlling the exchange of MAP messages between MSCA and MSC-B and for signaling to the VLR in MSC-B.

Figure 2.4 depicts steps to be executed in case of an inter MSC handover requiring a circuit switch connection. For brevity the case not requiring a CS is not reported (please refer to [23]).

Directed retry handover

The directed retry procedure allows the network to select the optimum cell for the Mobile Station. The process of directed retry involves the assignment of a Mobile Station to a radio channel on a cell other than the serving cell. This process is triggered by the assignment procedures, as described in [26], and employs internal or external handover procedures as described in 2.1.4. The successful procedure for a directed retry is as shown in figure 2.5 and is described below.

If during the assignment phase, as represented by the A-ASSIGNMENT-REQUEST message, a handover becomes necessary, due to either radio conditions or congestion,

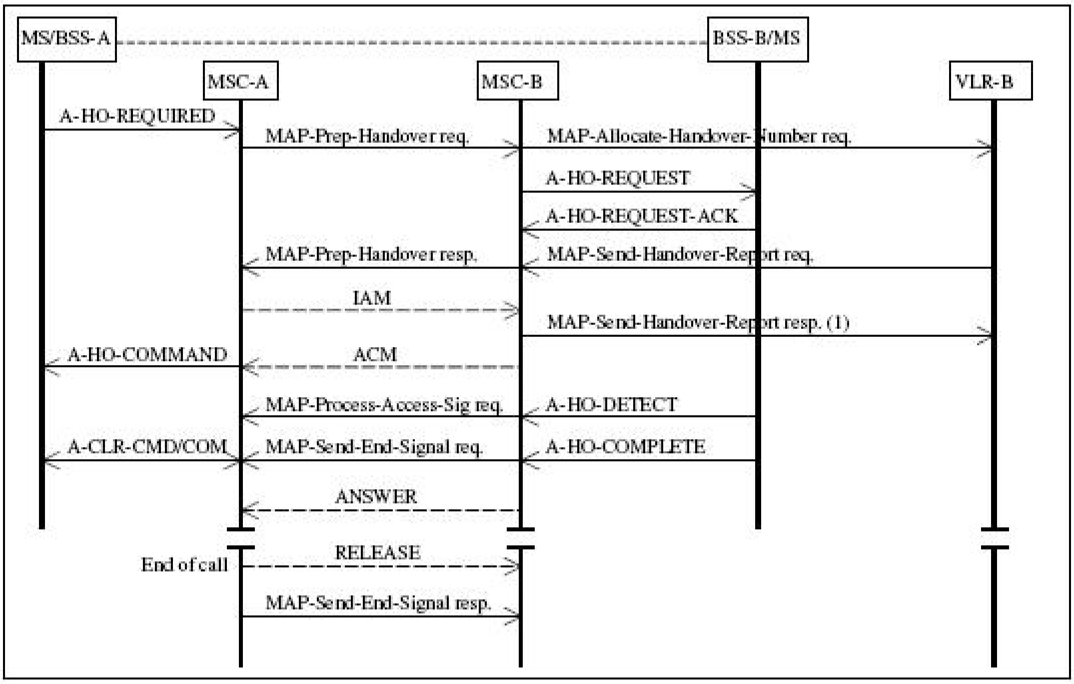


Figure 2.4. Basic Handover Procedure requiring a circuit connection

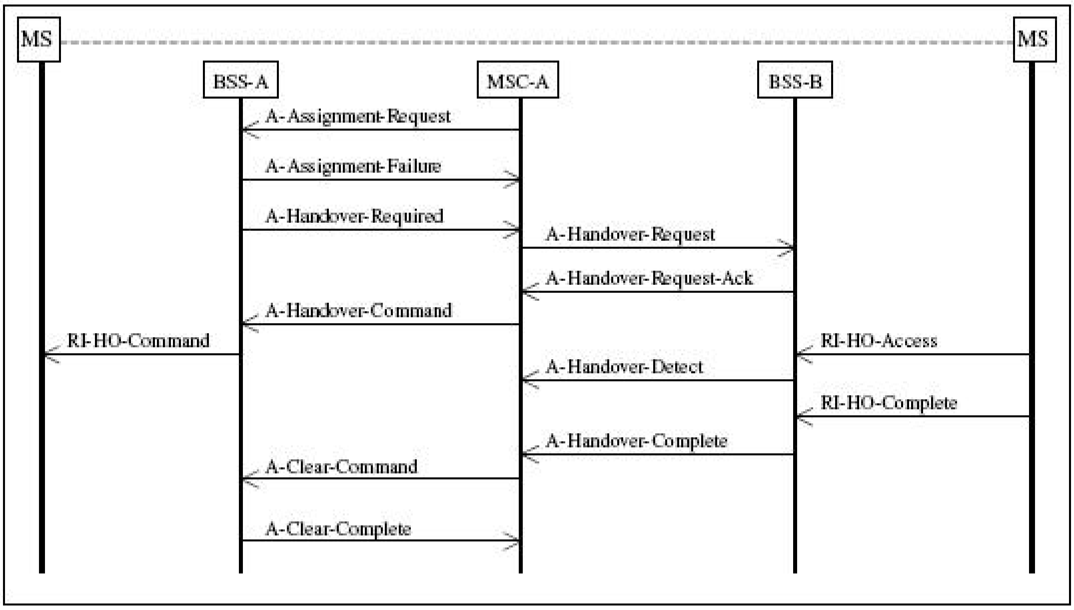


Figure 2.5. Example of a Directed Retry Intra-MSC Handover Procedure

then the Mobile Station may be handed over to a different cell. If a failure occurs during the handover attempt, for example A-HANDOVER-FAILURE returned from BSS-A or BSSB, then MSC-A will terminate the handover to BSS-B. Under these conditions MSC-A may optionally take one of a number of actions:

1. retry the handover to the same cell
2. select the next cell from the list contained in the A-HANDOVER-REQUIRED message and attempt a handover to the new cell
3. send an A HANDOVER REQUIRED REJECT to BSS-A, if an A HANDOVER COMMAND has not already been sent
4. retry the assignment procedure to BSS-A, if the failure message was returned from BSS-A. This option is additional to those for normal handover
5. Clear the complete call

The procedures for Inter-MSC handover are also applicable to the directed retry process. Please refer to [23].

2.2 3G Mobile Networks

The concept of Public Land Mobile Network (PLMN) has been introduced in section 2.1 providing CS connectivity to mobile subscribers and external networks (PSTN or ISDN). With the development of 3G networks PLMN is now regarded as an extension of networks (e.g. ISDN, corporate and public PDNs , etc) implementing a collection of MSCs areas in the CS domain and SGSN areas in the PS domain within a common numbering plan (e.g. same national destination code) and a common routing plan. The MSCs are the functional interfaces between the fixed networks and a PLMN for call set-up in CS domain. The GGSN and the SGSN are the functional interfaces between the fixed networks and a PLMN for packet transmission in PS domain. Functionally the PLMNs may be regarded as independent telecommunications entities even though different PLMNs may be interconnected through the ISDN/PSTN and PDNs for forwarding of calls or network information. A similar type of interconnection may exist for the interaction between the MSCs/SGSNs of one PLMN.
The PLMN infrastructure is now logically divided into a Core Network (CN) and an Access Network (AN) infrastructures, as defined in [31]. The CN is logically divided into a CS domain, a PS domain and an IM Subsystem. The AN is called BSS for GSM and RNS for UMTS. The CN is constituted of a Circuit Switched (CS) domain and a Packet Switched (PS) domain. These two domains differ by the

way they support user traffic.
These two domains are overlapping, i.e. they contain some common entities. A PLMN can implement only one domain or both domains. The CS domain refers to the set of all the CN entities offering "CS type of connection" for user traffic as well as all the entities supporting the related signalling. A "CS type of connection" is a connection for which dedicated network resources are allocated at the connection establishment and released at the connection release. The entities specific to the CS domain are: MSC, GMSC, VLR as described in section 2.1. The PS domain refers to the set of all the CN entities offering "PS type of connection" for user traffic as well as all the entities supporting the related signalling. A "PS type of connection" transports the user information using data packets. The entities specific to the PS domain are the GPRS specific entities, i.e. SGSN and GGSN.

2.2.1 Functional Components and Network Architecture

As described above the network architecture relies on CN and AN components briefly introduced in the following.

Core Network components

The *Home Subscriber Server (HSS)* is the master database for a given user as the HLR was in the 2G system. It is the entity shared between the CS and PS domain containing the subscription-related information to support the network entities actually handling calls/sessions. A Home Network may contain one or several HSSs: it depends on the number of mobile subscribers, on the capacity of the equipment and on the organisation of the network. As an example, the HSS provides support to the call control servers in order to complete the routing/roaming procedures by solving authentication, authorisation, naming/addressing resolution, location dependencies, etc. The HSS is responsible for holding the following user related information:

1. User Identification, Numbering and addressing information
2. User Security information: Network access control information for authentication and authorization
3. User Location information at inter-system level: the HSS supports the user registration, and stores inter-system location information, etc.
4. User profile information.

The HSS implement a large set of functionalities. It handles user identification providing the appropriate relation among all the identifiers in the system including CS, PS and IM domain. It provides access authorization enabling mobile subscribers

to connect/roam to the access network and service authorization allowing mobile subscribers for call/session setup. Being the HSS the central database retaining all the user related information on location and authorized services, the HSS is the key element for mobility management through the CS and PS domain.
The HSS is the only entity common to the CS and PS domain. There are components (some inherited from the 2G system) dealing with the CS domain such as the MSC 2.1 and the Media Gateway Function (MGW) . This component is PSTN/PLMN transport termination point for a defined network and interfaces UTRAN with the core network over Iu. A CS-MGW terminates bearer channels from a switched circuit network and media streams from a packet network (e.g. RTP streams in an IP network). Over Iu, the CS-MGW supports media conversion, bearer control and payload processing.
The new 3G standard network introduces entities for PS domain handling, namely the SGSN and GGSN. The SGSN stores data needed to handle originating and terminating packet data transfer including IMSI, one or more temporary identities, zero or more PDP addresses, location information and the GGSN address of each GGSN for which an active PDP context exists. The GGSN stores subscriber data received from the HLR and the SGSN. The GGSN also stores subscription information, the IMSI, zero or more PDP addresses, location information and the SGSN address for the SGSN where the MS is registered.

Access Network components

The access network components account for both the BSS and the Radio Network System (RNS) . The BSS organization has been described in 2.1. The (RNS) is the system of base station equipments (transceivers, controllers, etc...) which is viewed by the MSC through a single Iu-interface as being the entity responsible for communicating with Mobile Stations in a certain area. The RNS is viewed by the SGSN through a single Iu-PS interface. When Intra Domain Connection of RAN Nodes to Multiple CN Nodes is applied, an RNS may connect to several MSCs by several Iu-CS interfaces, and an RNS may connect to several SGSNs by several Iu-PS interfaces. The radio equipment of a RNS may support one or more cells. A RNS may consist of one or more base stations. The RNS consists of one Radio Network Controller (RNC) and one or more Node B (see later figure 2.7).

Basic configuration

The basic configuration of a PLMN supporting GPRS and the interconnection to the PSTN/ISDN and PDN is presented in figure 2.6 and in figure 2.7. This configuration presents signalling and user traffic interfaces which can be found in a PLMN. Implementations may be different since some particular functions may be gathered

in the same equipment and then some interfaces may become internal interfaces.
In the basic configuration presented in figure 2.6, all the functions are considered implemented in different equipments. Therefore, all the interfaces within PLMN are external. From this configuration, all the possible PLMN organisations can be deduced. In the case when some functions are contained in the same equipment, the relevant interfaces become internal to that equipment. For a brief summary of most relevan interfaces please refer to appendix

Configuration of 3GPP/WLAN Interworking

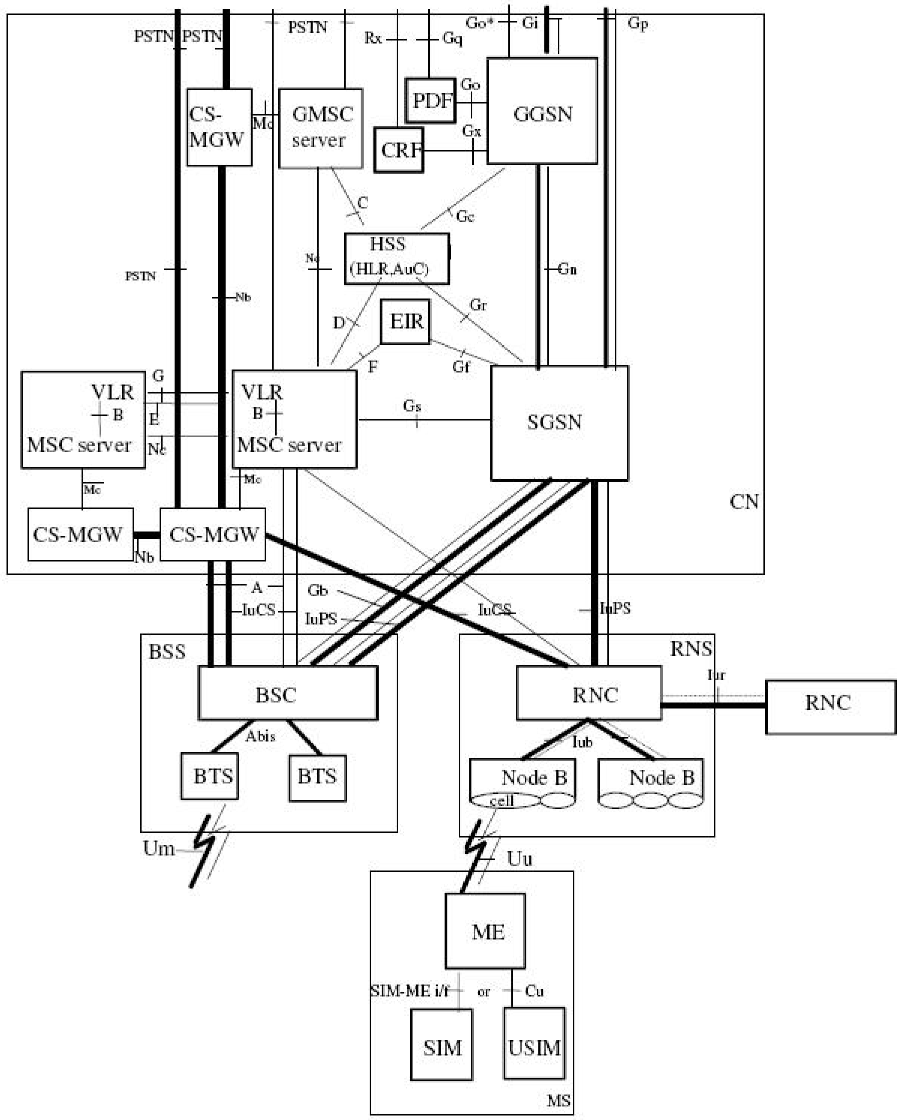
The 3G standard specifies also the interconnection of external packet data network such as WLAN to access packet based services. The configuration of the 3GPP/WLAN interworking function is presented in figure 2.8. The figure shows all network entities and reference point for the roaming scenario when a WLAN UE accesses PS based services in the home network. PS based services in the visited network are accessed via a Packet Data Gateway in the visited 3GPP network.

2.2.2 Interfaces and Signalling Protocols

The set of reference points and interfaces specified for the 3G architecture is quite large and a brief overview is reported in the appendix D. In the following we report the description of a specific interface related to service based local policy control enabling the control of subscribers with respect to services and provided quality of service and mobility. There are two reference points namely GGSNPDF (Go Reference Point) and PDF-Application Function (Gq Reference Point). The former allows the Policy Decision Function (PDF) to apply policy to the bearer usage in the GGSN. The latter allows for dynamic QoS-related service information to be exchanged between the Policy Decision Function (PDF) and the Application Function (AF). This information is used by the PDF for service based local policy decisions.
As will be illustrated in the development of this work, optimal decision on the usage of the IP bearer is not a trivial task especially when IP heterogeneous wireless access is considered. Considerations on extensions required will be given in the final chapter 7.

2.2.3 Handover Procedures

Section 2.1 introduces the concept of handover, namely the transfer of user connection from one radio channel to other. However when UMTS (3G) came this definition was no longer valid. In order not to confuse the jargon, the definition was



Legend:
Bold lines: interfaces supporting user traffic;
Dashed lines: interfaces supporting signalling.
NOTE 1: The figure shows direct interconnections between the entities. The actual links may be provided by an underlying network (e.g. SS7 or IP): this needs further studies.
NOTE 2: When the MSC and the SGSN are integrated in a single physical entity, this entity is called UMTS MSC (UMSC).
NOTE 3: A (G)MSC server and associated CS-MGW can be implemented as a single node: the (G)MSC.
NOTE 4: The Gn interface (between two SGSNs) is also part of the reference architecture, but is not shown for layout purposes only.
NOTE 5: The Go interface marked with a "*" has been included to this figure for backwards compatibility only, in order to support connecting to Release-5 IM CN Subsystem configurations

Figure 2.6. 3G Network

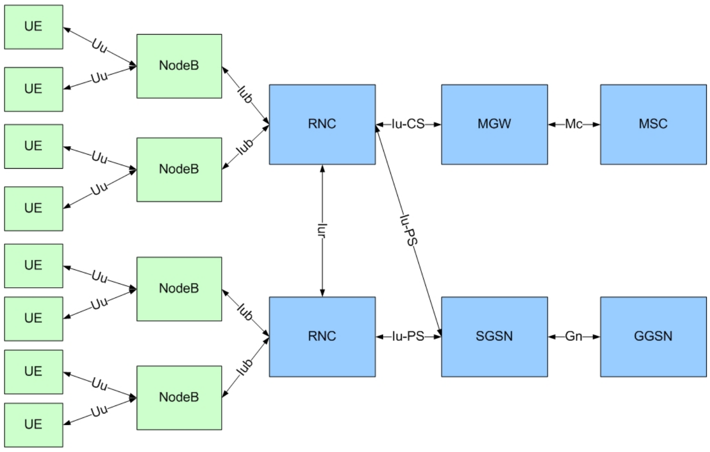


Figure 2.7. 3G Access Network Structure

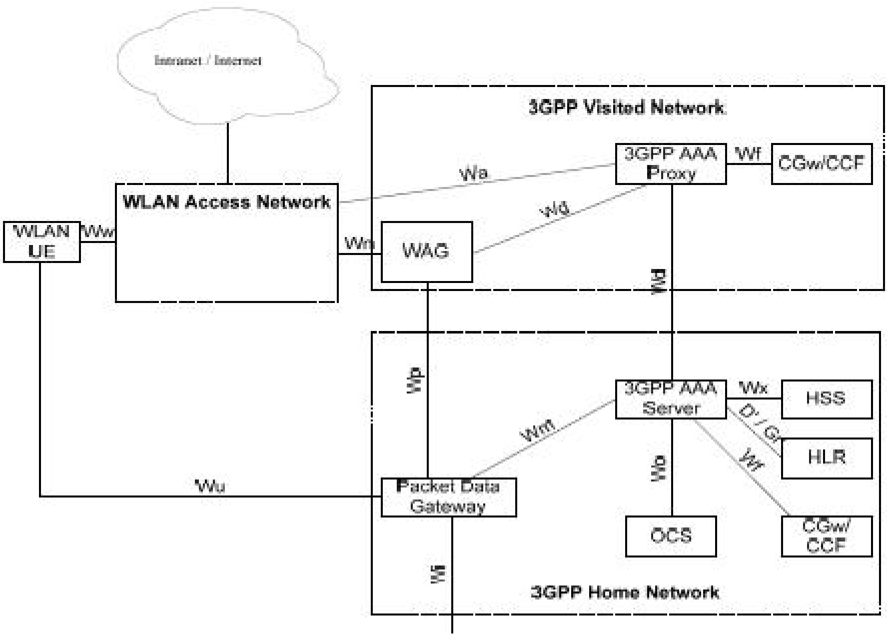


Figure 2.8. 3G/WLAN Interworking

kept as it is and new definitions were added.

As most of us would be aware, the main purpose of handover is to maintain an ongoing call. This is necessary as the user might be moving (maybe with high speed) and it would be annoying if the call keeps dropping when the user changes to another cell/area. Also it is possible that the number of users in an area changes while the call for a user is ongoing and for the call to continue the network needs to change the frequency of an ongoing call. Finally the user might enter an area where the UMTS network coverage ends and the user might be handed over to a GSM/GPRS network. Also one thing that should be noted is that all these procedures come into effect only when the call is ongoing (RRC Connection is established). Serving Radio Network Subsystem (SRNS) relocation , even though not strictly classified as handover, is explained as well.

Before starting discussing the handovers in detail here follows a list all of them for convenience of the reader:

1. Softer Handover
2. Soft Handover
3. Intra-frequency and Inter-frequency Hard Handover
4. SRNS Relocation
5. Combined Hard handover and SRNS Relocation
6. Inter-RAT hard handover

Softer handover

Strictly speaking softer handover is not really a handover. In this case the UE combines more than one radio link to improve the reception quality. On the other hand the Node B combines the data from more than one cell to obtain good quality data from the UE. The maximum number of Radio Links that a UE can simultaneously support is 8. In practice this would be limited to 4 as it is very difficult to make the receiver with 8 fingers. Generally speaking when RRC connection is established, it would always be established on one cell. The network initiates Intra-Frequency measurements to check if there are any other cells the UE can connect simultaneously to improve the quality of the data being transferred between the RNC and the UE. If a suitable cell is found then Active Set Update procedure is initiated. Using this Active Set Update message, the network adds or deletes more than one radio link to the UE. The only requirement is that from the start till the end of this Active Set Update procedure, one Radio Link should remain common.

Soft Handover

Soft Handover is the same as softer handover but in this case the cells belong to more than one node B. In this case the combining is done in the RNC. It is possible to simultaneously have soft and softer handovers. A more complicated soft handover would include a cell that belongs to a Node B in different RNC. In this case an Iur connection is established with the drift RNC (RNC 2) and the data would be transferred to the Serving RNC (RNC 1) via Iur connection. In a typical UMTS system, the UE is in soft/softer handover around 50% of the time. One of the very important requirements for the soft/softer handover is that the frames from different cells should be within 50ms of each other or this would not work. The last thing one needs to remember is that the soft/softer handover is initiated from the RNC and the core network is not involved in this procedure.

According to [32], when the UE (User Equipment) has a service in use the RRC connection with the UTRAN exists and is active. In this case, the UE continuously measures the radio connection and sends measurement reports to the SRNC (Serving Radio Network Controller). The handover algorithm located in the SRNC averages and investigates the contents of the received measurement reports. Based on the results the SRNC realizes that the UE has measured a cell located in a different (target) base station BS to have radio conditions fulfilling handover criteria defined in the SRNC. Based on the radio network information stored in the SRNC database the SRNC finds out that the target cell in the target BS does not belong to the same RNS (Radio Network Subsystem).

The SRNC starts arrangements on the UTRAN side by requesting through the Iur interface the DRNC (destination RNC) to set-up a new radio link. This triggers the DRNC to establish a radio link over the Iub interface between the DRNC and BS 2. After these steps the Iub and Iur bearers are established and frame protocols are synchronized in the downlink and uplink directions between the SRNC and BS 2. The frame protocols in the Iub and Iur interfaces (see appendix Dimplement the radio network user plane and carry actual user data flow. When the SRNC has received the uplink synchronization, it sends a RRC active set update message to the UE. In this message the SRNC indicates to the UE that a new radio link has been added to the active set of the connection through the cell located in the target base station BS and that the connection can be taken into use. The UE acknowledges this by responding with RRC active set update complete. The message flow related to a soft handover with radio link addition is illustrated in [33].

When the UE moves in the network during the transaction, it comes to the point where the SRNC finds out from the received measurement reports that a radio connection carrying the radio bearer through a cell located in the target BS does not fulfill the criteria set to the radio connection anymore. When this happens, the SRNC indicates to the UE that this particular radio connection can be removed from the active set. This is done by sending again an RRC active set update message to the UE indicating the radio connection to be removed. The UE acknowledges the radio connection removal by sending an RRC active set update complete message to the SRNC. Upon receiving the UE s acknowledgment the SRNC can now start the radio link deletion between itself and the target BS. When the radio link has been deleted both in Iub and Iur, the related Iub and Iur bearers are also released. The message flow related to a soft handover with a radio link deletion is illustrated in [33].

Hard Handover

Hard handover occurs when the radio links for UE change and there are no radio links that are common before the procedure is initiated and after the procedure is completed. There are two types of hard handover. First is Intra-frequency hard handover and the second is Inter-frequency hard handover. Intra-frequency hard handover will not occur for the FDD system. It would happen in TDD system. In this case the code spreading/scrambling code for UE will change but the frequency remains the same. Inter-frequency hard handover generally occurs when hierarchical cells are present. In this case the frequency at which the UE is working changes. This happens when the current cell is congested, etc. Hard handover procedure can be initiated by the network or by the UE. Generally it would be initiated by the network using one of the Radio Bearer Control messages. In case of UE initiated, it would happen if the UE performs a Cell Update procedure and that Cell Update reaches the RNC on a different frequency. The Core Network is not involved in this procedure.

SRNS relocation

SRNS Relocation procedure is not strictly speaking a handover procedure but it can be used in combination with the handover procedure. A simple SRNS Relocation can be explained with the help of figures present in [34].
The UE is active on a cell that belongs to a different RNC (than the one on which call was initiated) and a different MSC/SGSN. This arrangement causes unnecessary signaling between two RNC's. Hence the relocation procedure is initiated (see figure 2.9)In this, the CN negotiated the relocation procedure between the two RNS's. Once the procedure is completed the connection toward the old domain is released as shown in figure 2.10. The relocation procedures will generally be used for UE in Packet Switched mode. This procedure is time consuming and is not really suitable for real time services.

Combined Hard handover and SRNS Relocation

The combined procedure is a combination of hard handover and SRNS Relocation. Figures 2.11 and 2.12 explain the procedure.

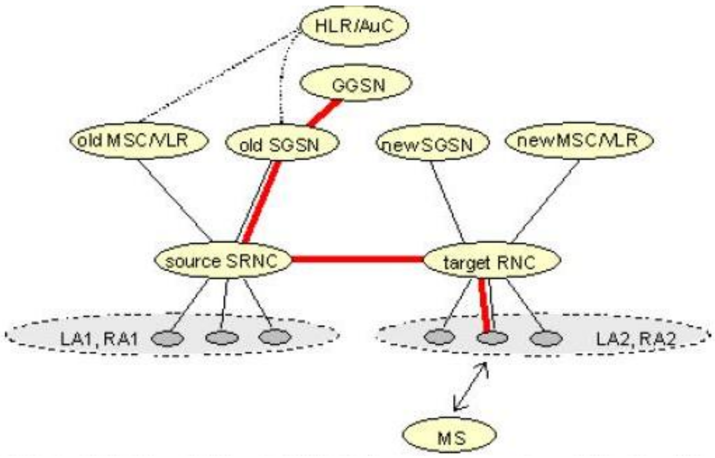


Figure 2.9. Data path before SRNS relocation

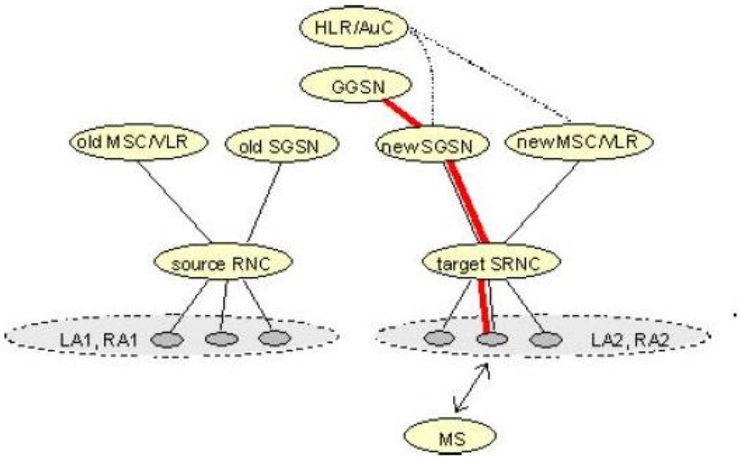


Figure 2.10. Data path after SRNS relocation

Inter-RAT hard handover

When UE reaches end of coverage area for UMTS services, it can handover to a 2G service like GSM (if the UE supports multiple RAT). Inter-RAT handover procedure can be initiated in variety of ways. RNS might send a Handover from UTRAN command explicitly telling the UE to move to a different RAT or the UE might select a cell that belongs to a different RAT or the Network may ask UE to perform Cell Change Order from UTRAN. Handover between Radio Network Subsystems connected to different 3G_MSCs is termed an Inter-3G_MSC handover/relocation. This category can be divided into three further sub-procedures:

- o the Inter-3G_MSC Handover procedure from UMTS to GSM, where the UE is

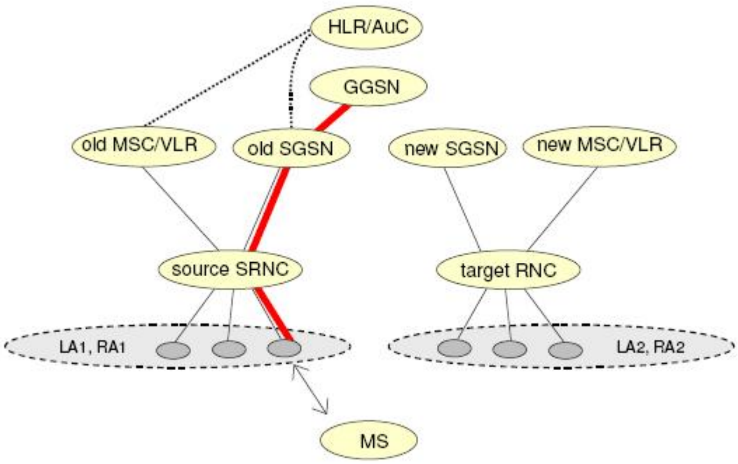


Figure 2.11. SRNS Relocation before procedure

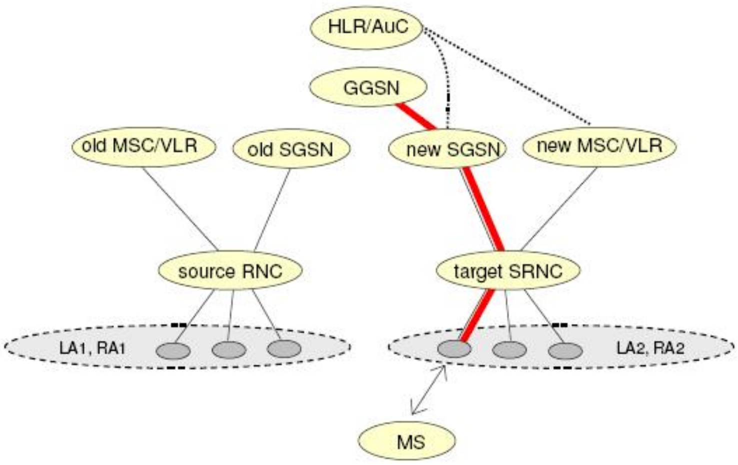


Figure 2.12. SRNS Relocation after procedure

handed over from a controlling 3G_MSC (3G_MSC-A) to an MSC (MSC-B)

- the Inter-3G_MSC Handover procedure from GSM to UMTS, where the UE is handed over from a controlling MSC (MSC-A) to a 3G_MSC (3G_MSC-B)
- the Inter-3G_MSC Relocation procedure, where the UE is relocated from 3G_-MSC-A to 3G_MSC-B. This procedure can also be combined with a hard change of radio resources (Hard Handover with switch in the core network)

2.3 3GPP System Architecture Evolution

To ensure competitiveness of the 3GPP systems in a time frame of the next 10 years and beyond, a long-term evolution (see [35]) of the 3GPP access technology needs to be considered (evolving from the one depicted in 2.13). In particular, to enhance the capability of the 3GPP system to cope with the rapid growth in IP data traffic, the packet-switched technology utilised within 3G mobile networks requires further enhancement. A continued evolution and optimisation of the system concept is also necessary in order to maintain a competitive edge in terms of both performance and cost. Important parts of such a long-term evolution include reduced latency, higher user data rates, improved system capacity and coverage, and reduced overall cost for the operator. Additionally, it is expected that IP based 3GPP services will

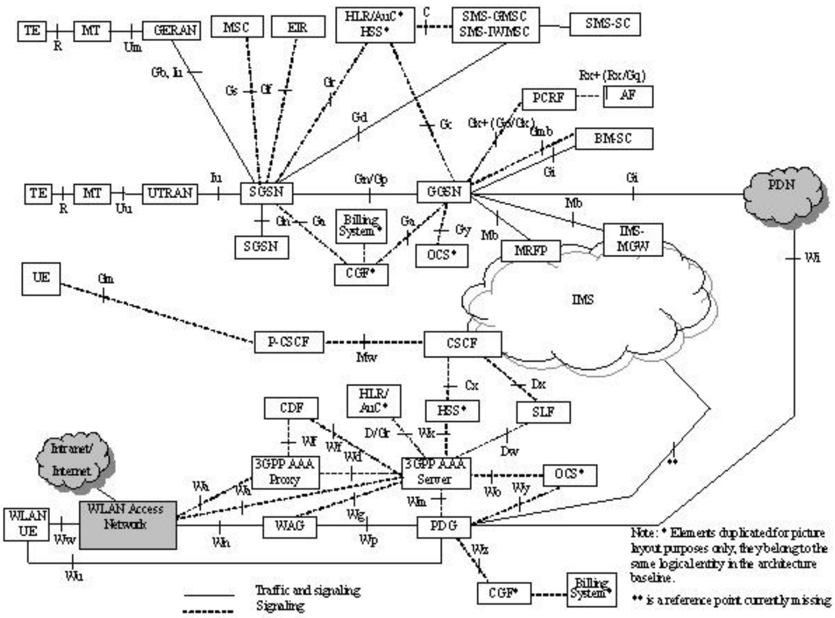


Figure 2.13. 3GPP network layout

be provided through various access technologies. A mechanism to support seamless mobility between heterogeneous access networks, e.g. I-WLAN and 3GPP access systems, is a useful feature for future network evolution. In order to achieve this, an evolution or migration of the network architecture, as well as an evolution of the radio interface, partly addressed already by individual WIDs, should be considered (see fogure 2.14). Architectural considerations will include end-to-end systems aspects, including core network aspects and the study of a variety of IP connectivity access networks (e.g. fixed broadband access). The evolved packet core contains 3

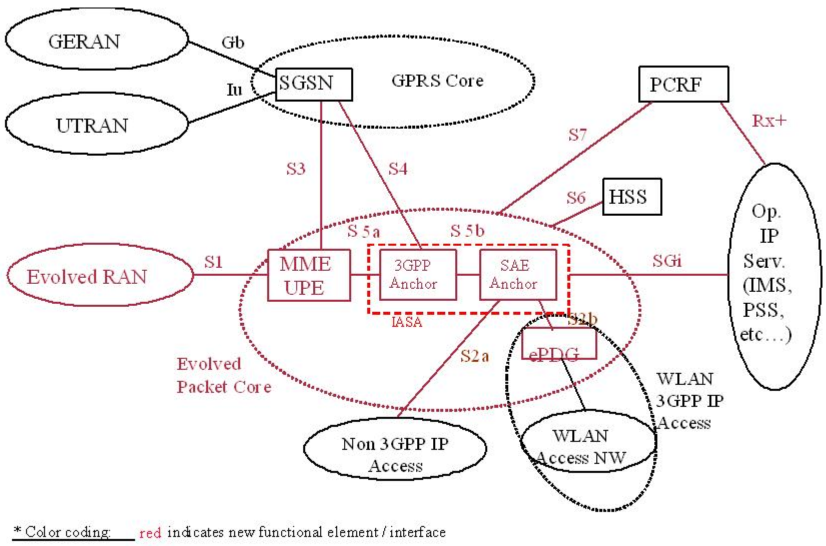


Figure 2.14. Long Term Evolution network layout

anchor points for mobility and handover:

1. MME + UPE anchor (anchor for LTE): The anchor point for intra-LTE mobility.
2. 3GPP anchor (GGSN in pre-SAE/LTE GPRS): The anchor point for handovers between 3GPP access systems.
3. SAE Anchor (HA in the case of MIP): Represents functions grouped around the anchor point for handovers between 3GPP and non-3GPP access systems for the mobility protocols and mechanisms. This anchor allocates IP address(es) for the UE as required by the used mobility protocol.

The NAS protocol states and state transitions for the Mobile are as follow:

- At Power-up, the Mobile enters in LTE-Detached state. It is not known by the network
- After performing its attachment, it is in LTE-Active state. It has Ids in the cell and in the Tracking Area (TA), owns 1 or more IP addresses, may have traffic in Uplink and/or Downlink channels and is know by the network at the cell level. In case of mobility, it performs the handover procedures.
- In case of inactivity, it remains attached to the network but moves to the LTE-Idle state. It has an Id in the Tracking Area only, owns 1 or more IP

addresses and is know by the network at the TA level. In case of mobility, it performs the cell re-selection (mobility) procedures

2.3.1 Intra-technology handover inside LTE access system

This procedure handles all necessary steps already known from state of the art relocation/handover procedures, like processes that precedes the final HO decision on the source network, preparation of resources on the target network side, pushing the UE to the new radio resources and finally releasing resources on the (old) source network side. It contains mechanisms to transfer context data between evolved nodes, and to update node relations on C- and U-plane. It is controlled by the LTE-RAN functions currently serving the UE (source LTE-RAN functions) which trigger the HO process after it has made a definite decision to serve the user by neighbor ("target") LTE-RAN functions. After the LTE-RAN functions on the target side have received the final confirmation from the UE on the completion of the HO process, the release of resources on the (old) source side is triggered. The U-plane handling takes the following principles into account to avoid data loss during HO and hence to support seamless/lossless service provision. During HO preparation a user plane tunnel is established between the source eNodeB (Radio Gateway) and the target eNodeB. During HO execution, user data are forwarded from the source eNodeB to the target eNodeB. The forwarding may take place in a service dependent and implementation specific way, e.g. it is FFS whether this scheme can be applied for real time services, and for non-real time services, the source eNodeB may stop sending of user data towards the source air interface and forwards user data towards the target eNodeB. Forwarding of user data from the source to the target eNodeB should take place as long as packets are received at the source eNodeB from the UPE and until the buffers in the source eNodeB are emptied, even if it has received the request to release resources. The source eNodeB might need to indicate the last received/sent packets to the target eNodeB in order to help re-synchronisation of user data streams. After the MME/UPE was informed by the target eNodeB that the UE has gained access at the target eNodeB, the user plane path is switched by the MME/UPE from the source eNodeB to the target eNodeB.

2.3.2 Inter-technology handover between non 3GPP access systems and LTE

The common denominator between 3GPP and non-3GPP access systems is that connectivity to packet services is delivered through the IP layer. The solution presented in [35] is based on the use of Mobile IP (MIP)[15] as a global mobility protocol providing host-based IP mobility, which is in required whenever network-based mobility support is not provided. Depending on operator requirements and/or deployment scenarios, network-based mobility protocols could be used as local or global mobility protocols in combination with MIP. Currently, LTE considers the following alternatives for this handover:

- MIP as a global mobility protocol, without an additional local mobility protocol, using only a common Home Agent
- MIP as a global mobility protocol and one of the local mobility protocols in the non-3GPP access system, using both a common Home Agent as a global mobility anchor, and separate local mobility anchors for the access-system. The global mobility protocol handles mobility events across access systems by associating the global IP address with the new local IP address at a fixed global mobility anchor, and forwarding UE traffic to the local IP address allocated by an access system. UE handovers within the access system are managed using a local mobility management protocol
- One of the network-based mobility protocols (as a global mobility protocol and any local mobility protocol supported in the access system), using SAE Anchor as a global mobility anchor and separate local mobility anchors for each access system. MIP is used for access systems that do not support the selected network-based mobility protocol. This means that the network-based mobility anchor for global mobility and the MIP HA both are located in the SAE Anchor.

2.4 WiMax-forum Network Architecture

Based on the IEEE 802.16 Standard [36], IEEE 802.16e amendment [37], IETF and Ethernet standards, the WiMax Forum Network Working Group defines an end-to-end network architecture for WiMax deployments. This section focuses on the mobility management in this architecture.
Figure 2.15 presents the architecture reference model. A Network Access Provider (NAP) offers connectivity to a Mobile Station (MS) through one or several Access Service Networks (ASN). The MS Network Service Provider (NSP) provides Internet services through the ASN and possibly the Core Service Network (CSN) of another NSP (Visited NSP), if the MS is roaming. Mobility management must be integrated to this architecture.
The mobility architecture should not preclude Inter-technology handovers, should support multihoming, seamless handover. The mobility management is split between ASN mobility (local) and CSN mobility (global). For IPv6, ASN mobility corresponds to mobility while the MS moves between Base Stations (BS) under the same Access Router (AR). When the AR changes, CSN mobility is involved.

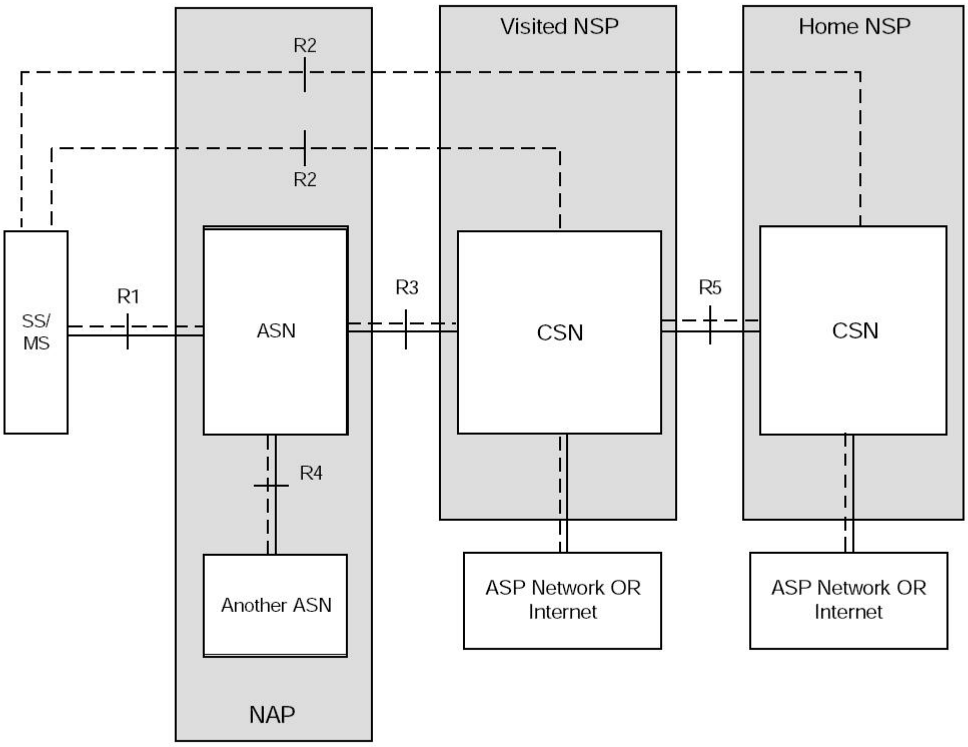


Figure 2.15. WiMax Reference Model

2.4.1 ASN Anchored Mobility

ASN anchored mobility should minimize packet loss, handover latency and maintain packet ordering. It shall comply with IETF EAP RFCs, support Mobile Initiated Handover (MIHO) and Network Initiated Handover (NIHO), soft handover, Fast Base Station Selection (FBSS) , MS in several modes (Idle, active, sleep), minimize handover related signalling in the ASN and be integrated with the WiMax Forum QoS architecture. Data path set up and handover control functions shall be independent of each other. ASN anchored mobility is functionally defined through three functions, data path set up, handover control and context transfer.
The data path function manages forwarding of L2 802.16 payloads and other payloads (e.g. IP) using forwarding methods such as IP in IP tunnels, GRE [38] or MPLS [39]. Several messages are defined to enable inter BS, inter AG and BS-GW path set up. The handover function involves a current attachment entity, a target attachment entity, and possibly relays. It ensures the handover decision and execution. The context function ensures the transfer/update of network related context from the MS to the network and MS related context from the network to the MS. It is based on a client server model and includes the update of states in the MS,

previous context function entity, and target context function entity. To ensure data integrity, both buffering and bi/multicasting can be used. Synchronization mechanisms are used between the involved entities. Resending of packets at L2 (a specific mechanism was defined in IEEE WiMax specification) during and after handover also is synchronized.

2.4.2 CSN Anchored Mobility

The WiMax Forum considers both IPv4 and IPv6 in general, and this is also the case for mobility management. For IPv4, the use of MIPv4 [40] and proxy-MIPv4 are described for CSN mobility management. For IPv6, no proxy version is used, only host MIPv6. We only describe IPv6 operations in this section. The standard which must be supported are MIPv6 [15], Authentication Protocol for Mobile IPv6 [41], Mobile Node Identifier Option for Mobile IPv6 [42]. MIPv6 is used without WiMax specific extensions.
CSN mobility is triggered by the network when the MS moves to a new Access Router. It is therefore executed consecutively to ASN mobility. The trigger can be possibly delayed until L2 handover completes. For the first attachment of the MS to the ASN, or when CSN mobility is triggered in the network, the MIPv6 client receives new Router Advertisement (new prefix) from its Access Router in the ASN. It is the trigger for the MS to register to its Home Agent or update its binding respectively. Route Optimization for MIPv6 is supported. Dynamic Home Agent assignation and Dynamic Home Link Prefix Discovery are supported using an AAA infrastructure and DHCPv6. Stateless and stateful Home Address configuration, multiple Home Addresses registration are supported, as well as several AAA schemes.

2.5 Conclusions

In this chapter the principles for mobility management for wireless mobile networks have been exposed starting from the early development of 2G wireless cellular systems up to the most recent efforts in different SDOs such as 3GPP and WiMAX forum. It has been shown how mobility management has constantly increased its complexity and what are current challenges mobile operators are facing when considering wireless heterogeneous deployments offering IP-based, seamless end-to-end services (e.g. IMS based services). Already in the early development of 2G networks *directed retry handovers*, presented in 2.1, offer the possibility for optimal network resources control by means of network controlled handovers. This capability, native in the CS domain, is implemented in nowadays 3G systems as well, however presents shortcomings when applied to the heterogeneous world envisioned in 2.3 and 2.4.

Specifically while the service based local policy control depicted in 2.2 works efficiently when applied to the UMTS network (since it has been designed for it), it has limitations when considering heterogeneous wireless access such as WLAN and WiMAX technologies. Hence, the thesis, departing form traditional handover capabilities explored in 2G and 3G networks (and presented in this chapter), investigates a network-based support for mobility management across wireless heterogeneous access. The approach is based on the upcoming IEEE 802.21 [3] (and summarized in 4) standard and considers the IP layer as convergence layer where required. This trend has been already illustrated in 2.3 and 2.4 and it is in contrast with the traditional host based mobility solutions produced by the IETF standardization body.

Chapter 3

Concepts for heterogeneous 4G Networking

The previous chapter 2 introduced mobility concepts from SDOs perspective. In the following we describe a potential architecture for 4G network currently being developed in the framework of the Daidalos project [14]. Based on this architecture we derive a set of functional components and protocol operations for advanced mobility procedures supporting both mobile terminal initiated handovers as well as network initiated handovers. The goal of this section is to show how NIHO technology improves network performance providing to mobile operators an useful tool to control user mobility, as already introduced in section 2.5.

3.1 The MARQS concept

The MARQS concept concerns the integration of Mobility Management, AAA, Resource Management, QoS and Security aspects. As shown in the mobility walk through the interaction of mobility procedures with authorisation and authentication, quality of service provisioning and resource control is of fundamental importance in mobile systems. In particular this work focuses on studying the impact of mobility on resource control and QoS guarantee and how network control improve better usage or wireless resource.
In this view, mobility management assumes a novel and fundamental role. The architecture recognizes the current trend in networks deployment to a heterogeneous landscape of access providers [2], [35]. In such environment it is important to give to the access providers (e.g. ISP or NAP) the flexibility of managing users mobility inside their own domain without requiring an interaction with the mobile operator domain. Thus, it is envisioned the splitting of mobility management into different levels: a global level associated with the Mobile Operator network and a local level

associated to network access providers. The key aspect of this splitting is the association of mobility management at administrative domain. This brings considerable flexibility to operators allowing each one to choose their preferred methods without being dependent of a particular scheme. The management of the mobility in these two levels is kept completely independent, this being a key characteristic of the architecture, absent in the traditional hierarchical mobility management approaches. The architecture addresses as well the case where the local mobility management domain is implemented either at layer three or at layer two. The advantage of making the local mobility management independent of the global allows the access provider to implement legacy technologies such as WiMax architectures [37], [35] architectures as well as layer two technologies such as IEEE 802.11r. To allow easy integration with the terminal side it is envisioned the specification of a single interface abstracting the communication with the local mobility management scheme. On the one hand the terminal always generates the same set of triggers/events and responds to the same set of commands independently of local mobility management scheme. On the other hand the network manages user mobility according to its own scheme transparent to the end user.
The mobility management is tightly coupled with Resource Management and QoS aspects focusing therefore on the MRQ of the MARQS concept. To efficiently support Resource management and QoS the architecture proposes the development of a single framework for signalling. Starting from the upcoming standard IEEE 802.21 [3] a new set of functionalities and extensions is being investigated to provide heterogeneous support for network/mobile initiated handover (NIHO/MIHO) as well as optimal QoS integration during handover. In this view protocols natively targeting handover improvement are extended opening possibilities for new research challenges.

3.2 An introduction to 4G Mobility Systems

Figure 3.1 depicts the Daidalos vision for future mobility architecture. The starting point of our architecture is based on the currently ongoing work in SDOs, which splits between local and global mobility. According to this concept, the network is divided into several local domains connected via a core network in which mobility is supported by means of a global mobility protocol (e.g. MIPv6 [15], HIP[16]). Terminal Mobility within a local domain is handled via local protocol operations [2] which are transparent to the core network i.e. independent of the global mobility protocol (GMP). Indeed the GMP only operates in case of terminal mobility across local domains. The design principles of our architecture are built upon the local and global mobility split and include the following advantages:

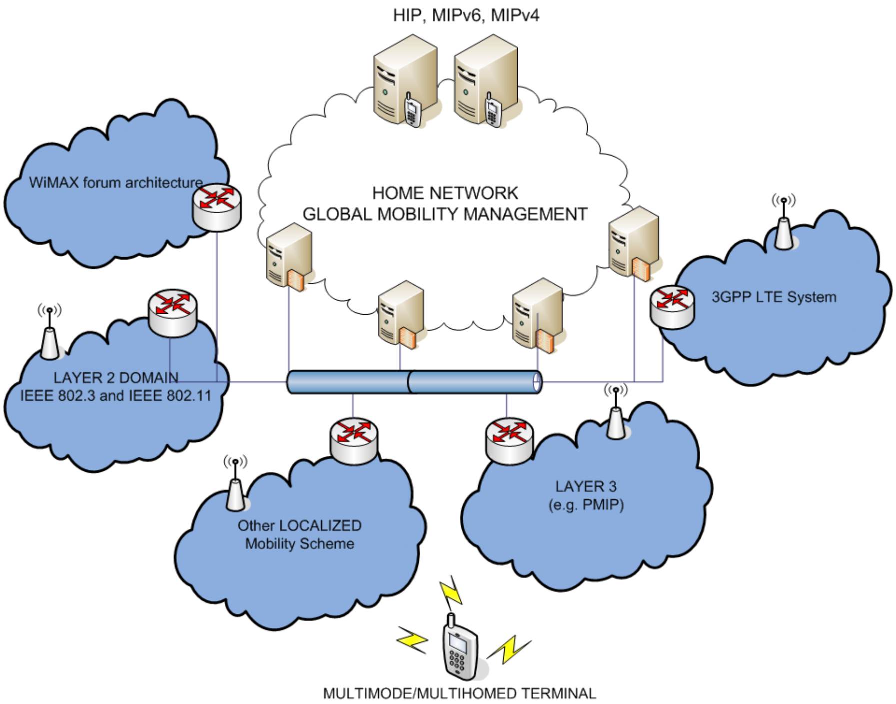


Figure 3.1. 4GArchitecture

- as a result of the independence between LMP and GMP, operators are provided with the flexibility to choose their preferred LMP or even avoid maintaining mobility infrastructure by directly using the GMP for mobility inside their networks
- LMPs are independent from GMPs
- improved performance by reducing signalling outside the local domain, as well as between the terminal and the access network (e.g. reduced signalling over the air and in the core)
- support for terminals with only global mobility protocols (e.g. HIP or MIPv6 installed)
- seamless handover support for terminals with enhanced mobility functions
- reduced overhead for data path in the air interface (compared to HMIP[18] - no tunnels)
- the splitting in LMM and GMM helps the location privacy issue as well as security related issues

- architecture of the terminals with enhanced mobility functions common to all LMPs and independent of their particularities. Standardization of these functions and associated signalling between the terminal and the access network

- interoperation with 3GPP and WiMAX networks which are seen as local domains from the global domain perspective

The operations of the terminals resulting from the above principles are further detailed in the following:

- Terminals with only global mobility support implement only the basic GMP with no enhancements. They are provided with transparent mobility inside local domains and can move between local domains using the GMP. Due to the lack of enhanced functions, handovers for this type of terminals are not optimized.

- Terminals with enhanced mobility functions implement the GMP plus some additional functionality for optimized operation, including seamless handovers. The enhanced mobility functions implemented by the terminal need to be standardized and are independent of the LMPs.

As result, LMDs can potentially implement network based mobility management schemes for resource control thus efficiently combining handover procedures with user allocation. Hence, the splitting of the mobility control in GMD and LMD enables network controlled handovers, regarded as an essential add on when targeting heterogeneous wireless access.
Going further, there are a number of possible choices that the above architecture gives to mobile operators:

- An operator has the flexibility to choose any LMP to handle mobility in its own network. Alternatively, a mobile operator may decide to directly use the GMP to support mobility in its own network and thus avoid installing any mobility related infrastructure. In this latter case mobility functions are supported by equipment located in other networks outside the operator's domain.

- Running its own LMP brings a number of advantages for the operator. On one hand, performance is improved as a result of avoiding signalling outside the local domain. Furthermore, running a LMP allows for more optimized and efficient operations (like e.g. handovers), as mobility is handled locally and closer to the terminal. Finally, from an operational viewpoint LMPs give the operator a greater control of mobility operations as these do not depend on functions external to the operator's network.

- One of the key advantages of the architecture is that it nicely integrates legacy networks that are running their own mobility management scheme, such as the 3GPP Long Term Evolution Architecture and the WiMAX Forum mobile architecture. Indeed, a terminal that supports the functionality described above plus 3GPP/WiMAX would be able to interoperate in our architecture, with 3GPP/WiMAX acting as local domains, without requiring any further modification.

With the above architecture, interconnecting different access operators becomes simpler, as each one can not only manage his network at will, but even select which technology is best for him, while retaining the overall interoperation. In addition, our architecture also relieves the requirements on the terminal side since as long as the operator is running a LMP, it can provide mobility transparently within the local domain to terminals that do not implement any mobility function. In our architecture we envision local domains running the following local mobility protocols:

- Layer 3 localized mobility based
- Layer 2 localized mobility for 802 technologies
- Legacy of 3GPP Long Term Evolution Architecture
- Legacy of WiMax Forum mobile architecture

The next sections detail the mobility splitting (reviewing state of the art) and present the Daidalos approach on network-based localized mobility management as framework for the development of this work.

3.2.1 Localized Mobility Architectures

Discussions on heterogeneous networks agree on the need of a common protocol for communication, the IP protocol. Mobility is also supported at the IP level, with Mobile IP [15] becoming intrinsically supported in IPv6 (or with novel proposals such as HIP [16]). MIP has nevertheless well-known deficiencies both in terms of performance and functionalities. Thus most of the research being done recently has been focused in these aspects, in particular along the lines of localized optimization of mobility behavior, separating the local mobility from the global mobility (MIP-based).
The localized mobility proposals aimed initially to reduce signaling outside the local domain, and improve efficiency by managing the "local" mobility closer to the mobile node MN (reducing the time needed for the signaling required by the mobility). Recently, operational exploitation considerations are gaining increasing relevance.

Host Based Localized Mobility Management

Initial localized mobility techniques were host-based, i.e. hosts had to handle signaling, and to be aware of local and global signaling protocols. Most relevant previous protocols were Hierarchical MIP and Cellular IP.
Hierarchical Mobile IPv6 [18] is a protocol that extends Mobile IPv6 by introducing a dedicated device, named Mobility Anchor Point (MAP), whose task is to handle the movement of a MN within a defined set of Access Routers (AR). Thus the MAP handles local mobility while Home Agent (HA) handles movements among different local domains. The introduction of this hierarchy (i.e. splitting of mobility management between HA and MAPs) aims at optimizing overhead during handovers among ARs of the same local domain: signaling control is reduced since it is exchanged only between Mobile Node (MN) and MAP and therefore handover latency is reduced. HMIPv6 is a host based solution which requires MN to control both local domain and global domain signaling. Another drawback of HMIPv6 is that it introduces an additional tunnel over the air.
Cellular IP (CIP) [43] is slightly different. MN registers as its CoA the IP address of a node (called Gateway) in the LMD. So all the traffic addressed to the MN will reach the Gateway. To send the traffic from the Gateway to the MN, host routes associated with the HoA of the MN are used inside the LMD. To create these host routes, the (non standard) routers of the LMD use the uplink traffic of the MN (or special purpose signaling packets) to update or refresh the route in the reverse direction. Each router will learn from the uplink traffic which is (for the downlink traffic) the next hop to which to send the packets destined to the MN. All the uplink traffic is forwarded hop-by-hop to the Gateway regardless of its destination. Cellular IP is a host based solution, as the host has to register explicitly in the Gateway when it arrives to the LMD. This allows the MN to discover the CoA that it must register, and it allows the Gateway to learn that it must start forwarding packets to/from the MN. Also route updates may require the MN to send special purpose packets.

Network Based Localized Mobility Management

Aspects of network control and operation have led to the renewed development of localized mobility solutions, including at standardization level in IETF. Unlike host-based mobility where mobile terminals signal a location change to the network to achieve reachability, network based approaches relocate relevant functionality for mobility management from the mobile terminal to the network.
The *NetLMM* [2] approach is currently being designed in the IETF NetLMM Working Group. [2] and [44] define the requirements and rational for NetLMM. The network learns through standard terminal operation, (such as router and neighbour discovery or by means of link-layer support) about a terminal's movement and

coordinates routing state update without any mobility specific support from the terminal. This approach allows hierarchical mobility management: mobile terminals signal location update to a global mobility anchor only when they change the LMD and, in the LMD, mobility is supplied to terminals without any support for mobility management. NetLMM complements host-based global mobility management by means of introducing local edge domains.
The entities involved in NetLMM are as follow. The Local Mobility Anchor (LMA) is a router defining the edge between the NetLMM domain and the core network. If a global mobility scheme is used, it is the boundary between GMD and LMD. The Mobility Access Gateway (MAG) is the Access Router for the MN. Note that the host routes are only configured in the LMA and the MAG; all intermediate nodes are totally NetLMM unaware, which considerably reduces the signalling in the LMD and avoids the extensive use of resources (routing tables) in the intermediate nodes (which is not the case with Cellular IP, for example).

The NetLMM area of operation is located between the LMA and the MAG. The forwarding method used between the MAG and the LMA (IPv6 in IPv6 tunnelling) can be extended to General Routing Encapsulation [38] or Multi Protocol Label Switching [39]. The definition of the interface between the MN and the MAG is not in the scope of the NetLMM WG. However,as stated earlier, in this work the use of a single interface based on the IEEE 802.21 is envisioned. The NetLMM protocol builds an overlay network on top of a physical network where the terminals are capable to roam across MAGs without changing IP address configuration. The basic protocol defines only reactive handover and does not consider the support for multiple technologies within the same LMD. We argue that both functions, enabling proactive handovers across the different technologies are required.

3.2.2 Daidalos Network Based Localized Mobility Management

The novel mobility architecture, called MobiSplit and described in [7], is being designed to meet the requirements of the operators in the future and covers the principles exposed so far. To efficiently support integration of LMD/GMD mobility with the "R" and the "Q" of the MARQS paradigm, network control of the handover procedure is therefore required. That is, network initiated and controlled handovers can be seen as the method to meet emerging operators requirements exploiting upcoming standards such as the IEEE 802.21 for media independent handovers. Traditional host based mobility is further compounded with network driven mobility leading to ultimate and optimal control of mobile subscribers.
In fact, in multi-access environments, handover decisions, and thus network selection, is not necessarily anymore based on access availability but further depends on

policies and roaming arrangements at access network, access provider and service provider levels. On top of it all, this information can be dynamic: the information required for target network selection might change periodically with such a frequency that maintaining all knowledge (and intelligence) in the mobile node might not be viable anymore, especially since some of this information is only available to network elements[1].
In this vision, we propose a detailed simulation study of the advantage of applying network controlled handovers showing possibilities and challenges.

3.3 IP Mobility: common practice

Host centric mobility protocols have obvious limitations across technologies. Thus, although multiple proposals have shown increased benefits of spectrum and network usage [45], [46], [47], they cannot be directly used in a multiple technology environment. Layer 3 protocols are required for this environment, and in particular IP-based protocols.
IP mobility (namely Mobile IP [15]) provides Internet connectivity to mobile nodes roaming from one access router to another, regardless of the access technology supported in the router. Mobile IP is based on the existence of a Home Agent, the creation of a Care Of Address when roaming, and the establishment of tunnels and/or specific route update mechanisms that reroute the traffic from the home to the visited network. To reduce handover latency and increase scalability, extensions have been developed (e.g.[17], [18]). Although some of these approaches [17] may potentially support network initiation of the handover procedure, none of them takes into consideration the existence of a backend combining mobility, resource management and roaming scenarios. Previous work [48] shows the advantages of having a mobile initiated handover considering information provided by the network, in wireless LAN environments where HMIPv6 is implemented. Both implementation and simulations results are provided, however the system considers only wireless LAN, and handovers are triggered only by terminal mobility. In [49], the IP2 Mobility Management Protocol was developped to satisfy mobile operator's requirements for next-generation mobile networks. IP2MM exploits the network controlled approach instead of a terminal controlled mobility management. The main conclusion is that with this type of protocols a better performance of the network can be achieved but the paper mostly addresses the performance in mobility control and packet throughput.

[1] A good example is radio resource management, expected to be a task of major relevance in future heterogeneous wireless environments. Mechanisms for RRM exploiting these concepts have been proposed in several technologies [45], [46], [47] but are constrained to technology-specific mechanisms

However, it should be noted that none of the mentioned approaches consider a scenario in which mobile initiated handovers (MIHO) are combined with network initiated handovers (NIHO). We argue that 4G networks will require this combination, allowing personalization in the user's terminal (network preferences) and resource usage optimization by the network. Also, the dynamism, cell coverage, and multi-technology environment is different from the traditional scenario of cellular networks, thus the results of network initiated handover in those networks are not directly applicable to 4G networks. In [4] initial simulation results and implementation experiences prove the feasibility of the 4G approach covering a wide range of access technologies.

3.4 Handover Framework for centralized NIHO

Traditional Mobile Initiated Handovers are triggered by mobile devices upon collection of events such as radio signal level degradation, application requirements or the like. MIHO mechanisms can be further improved by retrieving from the access network information [19] about available bandwidth, network load in a specific access point/access router, etc... However, we argue that disclosing such information to mobile devices is subject to access network policies and might not always be possible to provide such data. It would be desirable to gather information in the access network about load conditions (in a network-to-network relation) as well as from mobile devices (in a mobile to network relation) leading to the composition of an accurate and dynamic map that handover decision engines (located in the access network) could benefit of. Hence, NIHO via a centralized approach aims at improving network operations where required. The concept of MIHO and NIHO applies to both intra-technology case or inter-technology case, the former being potentially layer two specific, the latter leading to an IP based approach. We argue that understanding the benefit of NIHO, focusing on the intra-technology case does not affect the validity of the results. That is, without loss of generality, the simulation study focuses on the intra technology case, providing considerations for the framework design also at layer three.
A set of functionalities and associated protocol operations are required to support, in a common framework, MIHO and NIHO. The architecture specifies modules implemented in the terminal side, in the access part of the network and in the home domain. The mobile device offers a cross layer two/layer three design for wireless/wired technology management, compounded by an intelligent module for interface selection based on several parameters spanning from layer two related information up to user preferences and context aware applications. Protocol communications between the mobile device and the access router (first layer-3 hop in the access network) allow

exchange of information for neighbor discovery, handover preparation and handover execution. Handover target selection is done by combing mobility and resource management mechanisms such as admission control. That is, handovers could potentially be denied to mobile devices. To improve performance and avoid as much as possible these situations the architecture further proposes the possibility to initiate handovers from the network upon for instance load detection or conditions changed due to the availability of new access technologies.
To further show how NIHO technology can be efficiently supported in next generation mobile operator networks, modification and extensions to the ongoing IEEE 802.21 standardization effort have been proposed. Such extensions are based on the existence of a centralized entity and on the collection of relevant events from mobile devices. The proposed modifications are gathered in [12] explaining how the network configures the devices and how the intelligence triggers handover procedures. To better understand functionalities, figure 3.2 shows a high level signaling flow (for further details in [12]). The mobile node architecture recognizes the need

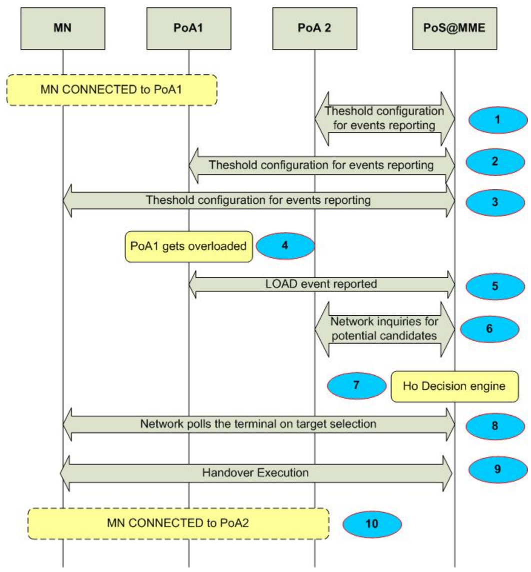


Figure 3.2. High Level procedures

for the abstraction layer design implemented by the MIH layer[2]. Such layer is also implemented in the network side components to provide 802.21 protocol operation exchange. The Mobility Managemet Entity (MME) implements the intelligence required for centralized handover decision. The novelty of the approach consist in a scalable event-driven notification system the network can leverage for detecting critical conditions either in the terminal or in the network. The proposal [12] in

[2]An optimized implementation for cellular/WLAN handover has been proposed in [5] and [6]

fact extends the current standard by adding network to network reporting capabilities. Steps 1 to 3 (in figure 3.2) are required for threshold configuration and event reports triggering. Since reports might potentially trigger NIHO procedures, it is fundamental to understand how often the intelligence can be triggered. The study in section 3.5.4 analyzes several timer values emulating different timings. Steps 5 and 6 are required for load evaluation and to collect input parameters for the handover decision engine. Step 7 is evaluated upon the algorithm selected for NIHO triggering (in the current work, the algorithm selected is shown in pseudocode 2, section 3.5.3). Finally step 8 and 9 evaluates if handover is possible from the terminal perspective. Step 10 concludes the handover procedure.

3.5 NIHO vs MIHO

Based on the definition of NIHO and MIHO in the previous sections we present in the following a simulation study by comparing network performance when MIHO and NIHO techniques are applied. NIHO provides improved resource allocation when heterogeneous wireless/wired access technologies are deployed. We aim at quantifying the benefits of this approach and at identifying conditions that affect the relevance of NIHO support. It should be noted that NIHO-related signaling performance per itself is not addressed in this work. Nevertheless, the simulation model emulates conceptualized versions of the protocol developed in [12]. Although the scenarios and the model used are mono-technology and simple, just showing the benefits of a combined solution of NIHO + MIHO is worthy, since this indicates a lower bound to the benefits achievable using this paradigm.

3.5.1 Simulation setup

Although this work is centered in inter-technology handovers, processed at IP-level, the design of such a test network, considering multiple technologies (such as WiFi, 3GPP, etc..), with different cell sizes, present simulation problems in terms of channel propagation models, layer-2 protocols, and overall cell interplay. For simulation purposes, we decided to simplify our model, and as such was developed a special-purpose simulator in C++, considering a single technology, and regular cell placements. Thus the reference simulation scenario is composed by six access points deployed in a hexagonal grid. It should be noted that even if we use the term Access Points, the simulator does not contain technology dependent definitions and the scenario presented is valid for any technology mix (provided path loss models are consistent). During the simulations two studies have been performed:

1 First, simulations have been performed in scenarios where only MIHO is used. This provides reference results for the scenarios.

2 In a second stage, the simulations combine both MIHO and NIHO techniques, which are then compared with the previous reference results.

In both simulations, Mobile Nodes appear and disappear (corresponding to service calls) according to a Poisson process, with variable frequency (variable system loads). The lifetime of the Mobile Node follows an exponential law with mean 180 seconds, but if no service can be provided (that is, the service call is rejected) the Mobile Node is immediately removed from the system. To cover different types of mobility, the speed of the Mobile Nodes has been selected randomly between 2 and 5 m/s. The Random Way-Point mobility model has been selected for both cases, MIHO and NIHO. During a simulation if the Mobile Node reaches a scenario boundary, the mobility pattern is altered and a new destination target is computed. The maximum number of users per Access Point is set to 10. Results are averaged for 30 simulation runs, taking confidence intervals of the 95% in all the data presented in this study. The Path Loss model used in the simulator is based on the Omnet++ Wireless LAN Path loss model, expressed by equation 3.1.

$$\begin{aligned} Losses(dBm) &= 40 - 10 * \rho Lexp * log(distance) \\ \rho Lexp &= 2.5 \end{aligned} \tag{3.1}$$

Studied Scenarios

To study the impact of wireless overlapping regions on the NIHO performance improvement, three different scenarios were evaluated. Figure 3.3 shows the three scenarios. The difference between them is the wireless coverage area. Each of the Access Points in figure 3.3 shows three different circles: (from outside to inside) sensitivity, MIHO and NIHO thresholds. This set of thresholds is needed since in our analysis we consider very simple algorithms for triggering the handover, based on the load of the Access Points and received signal levels. The algorithms used for NIHO and MIHO and the relation with the thresholds presented above will be explained in sections 3.5.2 and 3.5.3. Threshold values are displayed in table 3.1. These values were selected in order to evaluate all possible cases of overlapping areas for NIHO, leading to scenarios with different characteristics. Scenario I models a

Threshold	Scenario I	Scenario II	Scenario III
Sensitivity	-90 dBm	-87 dBm	-84 dBm
MIHO	-88 dBm	-85 dBm	-81 dBm
NIHO	-84 dBm	-81 dBm	-78 dBm

Table 3.1. Threshold Values for the different scenarios

system with a high number of overlapping areas. Due to this, the results derived

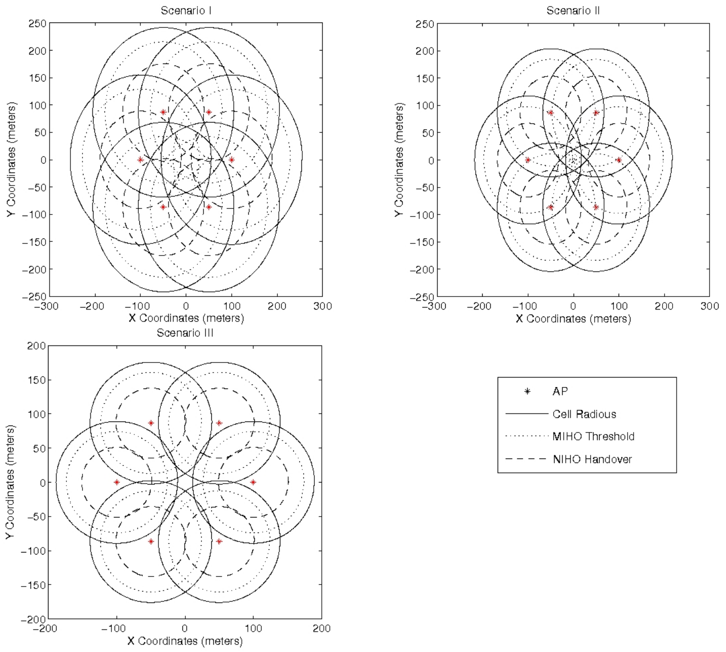


Figure 3.3. From left to right: Overlapping Scenario I, Overlapping scenario II, Overlapping scenario III

from the execution of MIHO should be quite near to the optimal behavior of the system, and probably will not leave much room for system optimization, without complex management algorithms. Scenario II shows a system with an average degree of overlapping areas. In this system, the introduction of NIHO should outperform MIHO-only performance. This is the expected usual scenario. Scenario III corresponds to a (atypical) poor overlapped scenario, where the Access Points do not present an overlapping enough degree to enable system wide optimization. In this case the nodes can only be moved between adjacent Access Points. Moreover, the NIHO overlapping thresholds do not cover the center of the scenario providing a ”hole” in the grid that may produce strange behaviors. We will show that even in the worst case scenarios the usage of NIHO will still be advantageous, improving both Mobile Node service probabilities and overall system performance.

3.5.2 Mobile Initiated Handover Algorithm

For the MIHO study, the Mobile Nodes perform a handover when the MIHO threshold is crossed. In this case the Mobile Node evaluates both the signal and load conditions of every neighboring Access Point. The handover will be performed to the Access Point with the best signal level providing required capacity is available.

Notice that we are considering the best case of MIHO, i.e. a MIHO that is performed not only based on information available in the mobile node but but is also aided information provided by the network. The information needed to evaluate the algorithm presented, such as the Access Point's load, is expected to be provided by a framework such as IEEE 802.21. Pseudocode 1 shows the algorithm the Mobile Node executes when reaches a MIHO threshold. A similar procedure is followed when a new Mobile Node is created in the system.

```
for all AP seen by this Mobile Node{
        if load of this AP is lower than MAXLOAD{
                add AP to the Available APs list
        }
}
get AP with best signal from the list of available APs
do handover to the AP with best signal
```

Pseudocode 1: MIHO Algorithm

3.5.3 Network Initiated Handover Algorithm

```
for all Mobile Nodes{
        get the list of APs which this MN is inside their NIHO threshold
        for all APs in the list{
                if the load of this AP is lower than the load of the current AP
                the MN is connected to{
                        add AP to the Available APs list
                }
        }
        get the AP with best signal from the list of available APs
        do handover to the AP with best signal
}
```

Pseudocode 2: NIHO Algorithm

When the combined solution of MIHO and NIHO is applied, the algorithm explained in section 3.5.2 is still applied by the Mobile Node. However, now the network also can move target Mobile Nodes each time a timer expires (corresponding to an optimization run in many RRM proposals [45], [46], [47]). Mobile Nodes reallocation can be potentially implemented according to more complex or simple algorithms. In our case, when the timer expires, all the Mobile Nodes that are inside a NIHO threshold of a target Access Point are moved to that Access Point, provided the load is less than the load of the current Access Point the Mobile Node is attached to. In case of having several overlapping NIHO thresholds, the one with best signal level is selected. Note that this NIHO algorithm is quite simple, and results presented are probably a lower bound on overall system performance improvement.

The timer on which NIHO depends is one of the critical variables studied during the simulations. Pseudocode 2 shows the algorithm executed each time the timer expires (emulating events report triggering).

3.5.4 Metrics

The performance metrics analyzed are the following:

- Mean number of users in the system.
- Probability of Rejection at first connection.
- Probability of Rejection while performing handover.
- Decrement in the number of Handovers (Mobile Initiated) between MIHO and MIHO plus NIHO.
- Ratio between Mobile Initiated Handovers and Network Initiated Handovers in the MIHO plus NIHO case.

For each of these metrics, a study on the effect of the degree of overlapping, system load, and the effect of the timer duration has been performed. It should also be noted that all the mobile nodes in the system have equal priorities and similar profiles i.e. no gold/silver/bronze users are considered, and are generating the same type of traffic. As a general consideration we have to note that, for completeness, the system is also analyzed in saturation conditions. When the system (all the cells) operates close to 100% of the total load, resource optimization techniques (NIHO) are not expected to provide additional benefit, but simulations have been run nevertheless.

3.5.5 Mean Number of Users in the system

Figure 3.4 shows the mean number of users in the system for the three different scenarios depicted in figure 3.3. The system designed closely follows an M/M/1 system, with differences due to the removal of the users when they are rejected. The maximum number of users depends on the degree of overlapping in the system. In a system with a 100% of overlapping between all the Access Points the maximum number of users in the system is equal to 60. In fact, by decreasing area overlap, the mean number of users decreases as well (since users' mobility becomes constrained). Figure 3.4 shows how the use of a combined solution of MIHO and NIHO produces an increment of the number of users that can be supported by the system. The maximum difference between MIHO and MIHO+NIHO appears in the Scenario II (figure 3.3) and corresponds to just 6%. Although the maximum performance

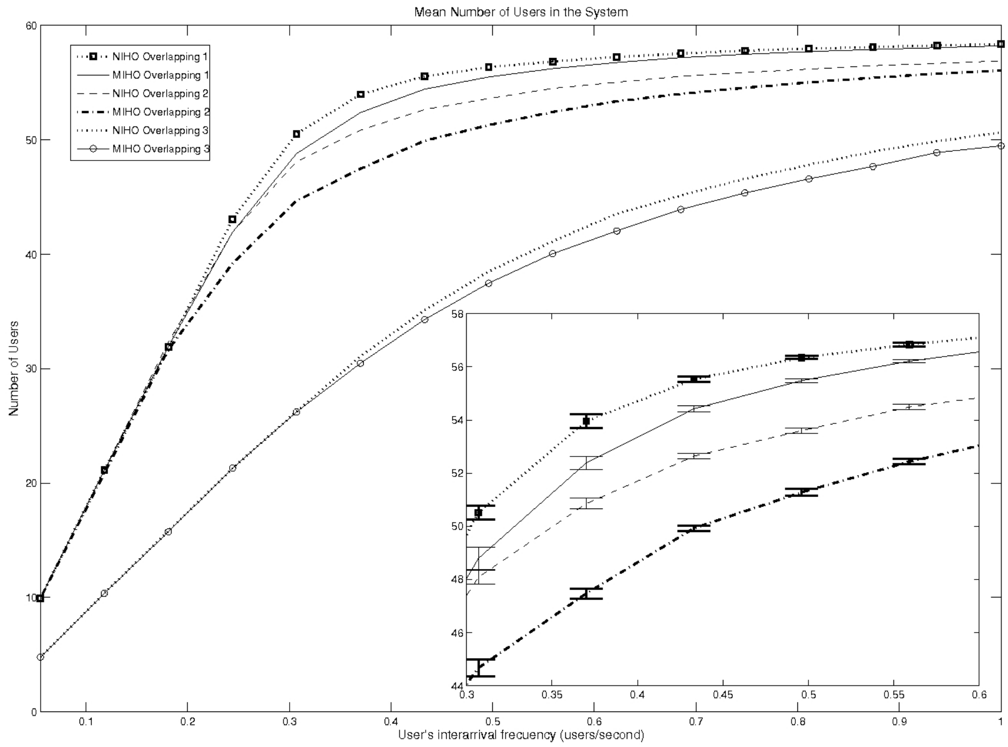


Figure 3.4. Mean number of users

improvement between MIHO and MIHO+NIHO appears for the usual Scenario II case, the maximum number of users in absolute values is reached for the Scenario I. The effect of changing the overlapping area corresponds to a flattening of the curve in figure 3.4, showing that the maximum number of users is reached with lower frequencies. The maximum number of users reached for the different overlapping areas decreases with the overlapping.
Figure 3.5 shows the effect of increasing the timer which triggers the execution of NIHO. Decreasing the timer does not affect the maximum number of users although the utilization of the system is slightly higher when shorter values for the timer are used. This is due to the fact that, in the case of small inter-arrival times, the system with shorter timers (e.g. more constant optimization updates) supports more users.

3.5.6 Rejection probability in first connection and during a handover

Figure 3.6 shows both the Probability of Rejection at first connection (figure 3.6(a)) and the Probability of Rejection during a handover (figure 3.6(b)) for the scenarios

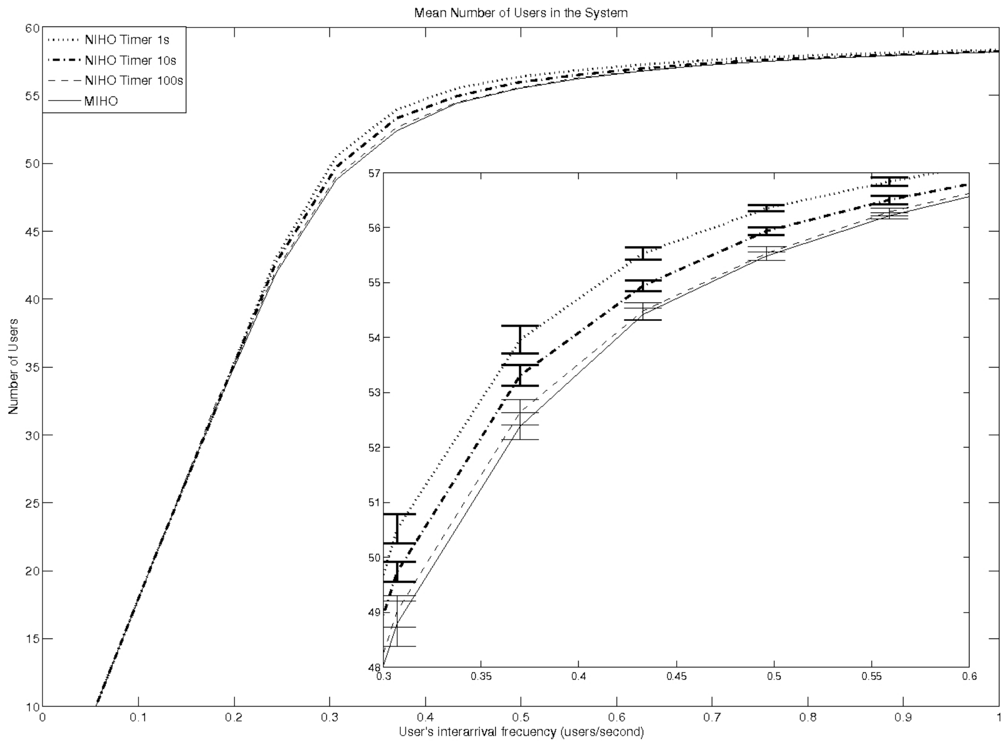
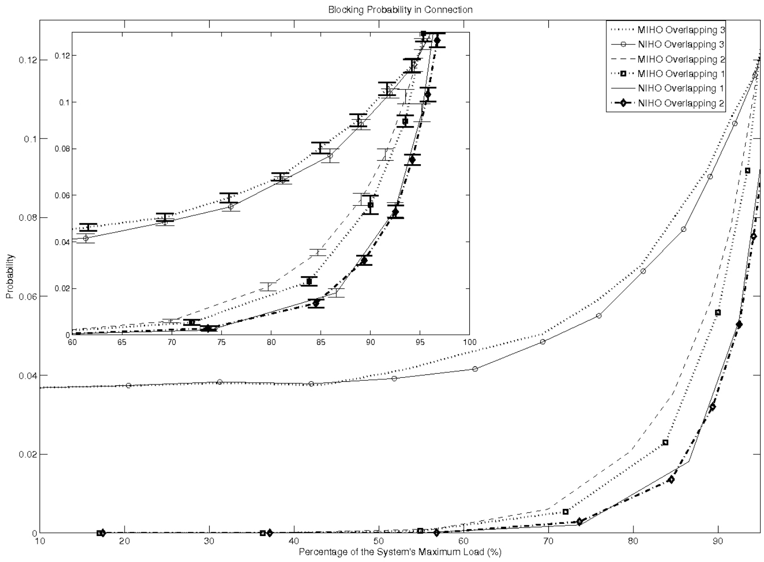
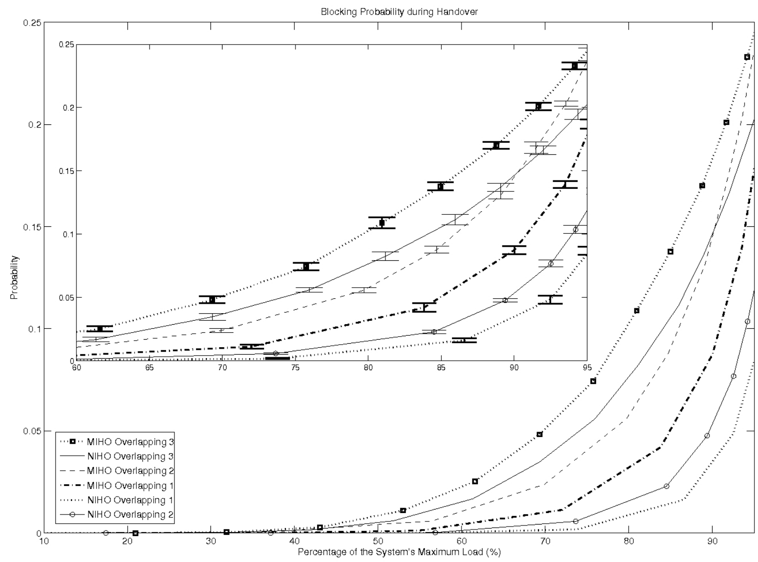


Figure 3.5. Number of users (varying timers)

depicted in figure 3.3. The Probability of Rejection at first connection represents the probability of a Mobile Node not finding a free Access Point when arriving at the system. As can be seen, the combined solution MIHO+NIHO decreases this probability when the load starts to reach values higher than 60% of the maximum load in the system. For instance, for the second scenario, heavily loaded (90%), this probability is decreased by 50%. When area overlap is decreased, similar behaviour is noticed. The graphs tends to smooth, achieving the form of the graph corresponding to the scenario III as system becomes saturated, and no more Access Points are available. The Probability of Rejection during a Handover represents the probability of the handover being rejected due to admission control when the Mobile Node is performing a Handover. In this figure we can see how the probability decreases always when MIHO+NIHO is used, and the difference is appreciable for loads higher than 60%. In the case of load 90% the second scenario is decreasing the rejection probability in 64%. The effect of the overlapping on the Probability of rejection during a handover, is to increase the blocking probability while decreasing the overlapping. This is due to the fact that as less overlapping exists in the system, the load balance mechanism works worse, so the Access Points have higher loads and the blocking probability in connection increases. The same effect can be observed



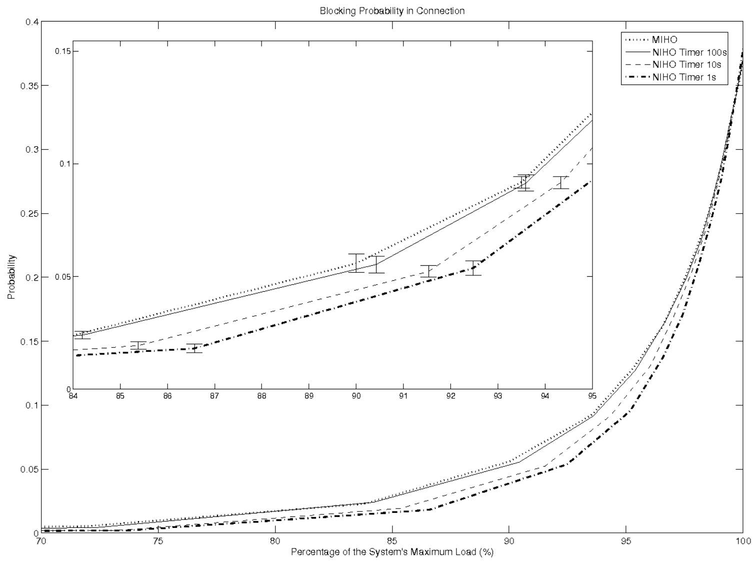
(a) Probability of Rejection in first connection



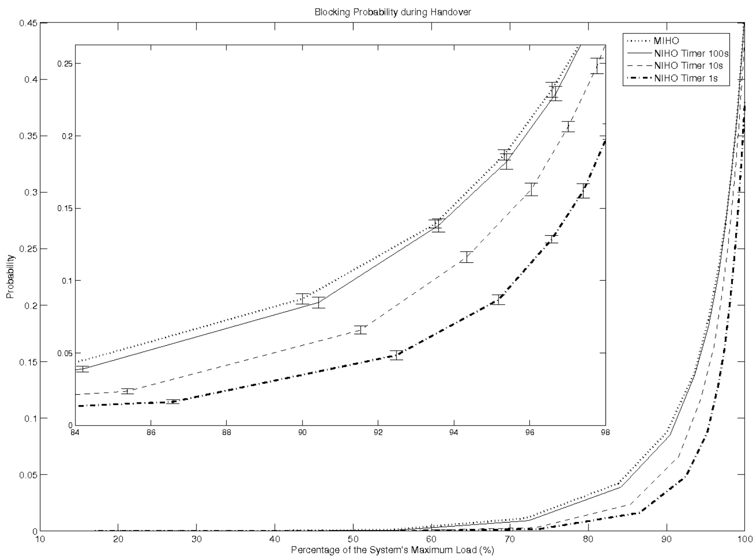
(b) Probability of Rejection during a Handover

Figure 3.6. Probabilities of rejection

in the blocking probability during a handover. It is worth to notice the important reduction in the probabilities achieved using MIHO+NIHO, although the number of users is increased by a 6%, the probability of rejection in connection is decreased in a 50%. Being this decrement in the probability and increment in the number of users, very important from the operators' point of view.



(a) Probability of Rejection in first connection (varying timers)



(b) Probability of Rejection during a Handover (varying timers)

Figure 3.7. Probabilities of rejection varying timers

Figure 3.7 shows the effect on the Blocking Probabilities at first connection (figure 3.7(a)) and during a handover (figure 3.7(b)) for variable NIHO timer values. As can be seen, the effect of increasing this timer corresponds to increase the blocking probability in both situations, bordering the MIHO behavior when the timer is very long (100 seconds).

3.5.7 Number of Handover Operations

Figure 3.8 shows the metrics related with the number of handovers performed. These two graphs show the NIHO impact from the perspective of the user and of the network. The decrement in the number of Handovers shows how the Network Initiated

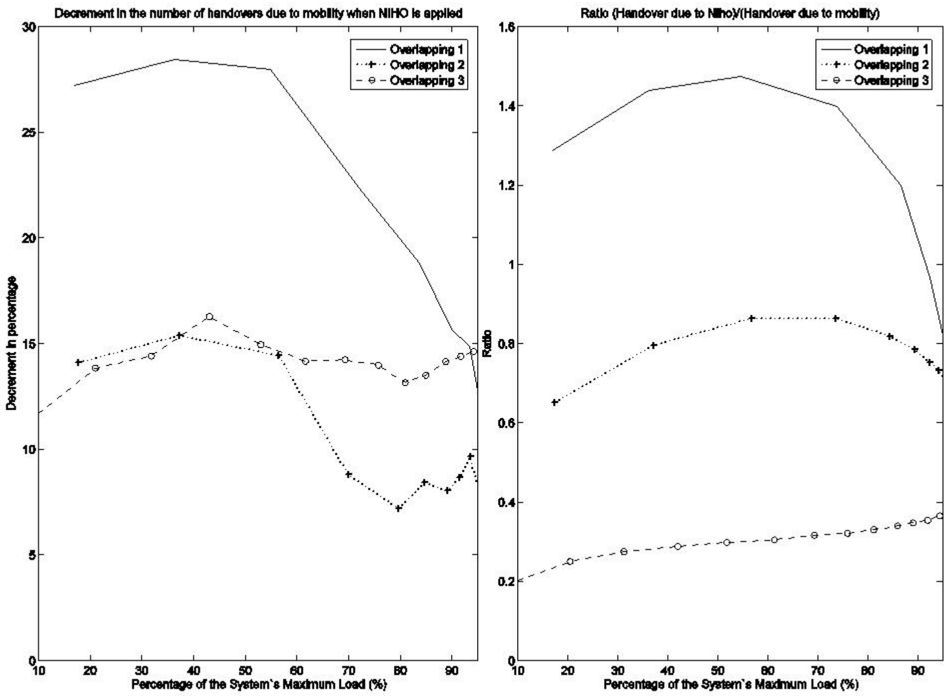


Figure 3.8. From left to right: Decrement in the number of Handovers (Mobile Initiated) between Miho and Miho+Niho, Ratio between Mobile Initiated Handovers and Network Initiated Handovers in the Miho+Niho case

handovers are decreasing the number of Mobile Initiated handovers due to mobility. This decrement shows that the NIHO algorithm used always improves the receiving situation of the Mobile Node, by moving it to a position where the probability of doing another handover due to signal conditions is lower or equal than in the previous situation. As in the previous graphs, the percentage of decrease depends on the load of the system and as it increases the performance of the combined solution NIHO plus MIHO decreases. It is worth to notice the important reduction in the number of handovers due to mobility that occurs for the first scenario, where up to 28% of reduction is achieved. As the overlapping decreases the reduction in the number of handovers also decreases. This is due to the fact that there is less area where NIHO is usefully exploited. As the area is smaller, the effect of NIHO is diminished providing only movement between adjacent Access Points. In the limit, in the case of the third scenario, the decrease in the number of handovers is roughly constant,

and to some point independent of the load in the system.
The Ratio between Mobile Initiated Handovers and Network Initiated Handovers presents the relative cost of applying NIHO to the system. It represents how much the total number of handovers is increased when NIHO is applied. As can be seen, for the scenario I the peak is situated in 1.5, which means that the total number of handovers in the reference scenario is multiplied by this quantity while using NIHO. As in all the previous graphs, as the system becomes saturated this ratio decreases because the possibilities of moving a node decreases. As the overlapping area decreases this ratio decreases because Network Initiated handovers are performed with greater difficulty. Figure 3.9 presents the effect in the metrics related with the number of handovers when the timer is increased. As expected the decrease in the number of Mobile Initiated Handovers is reduced while the timer is larger. This effect is similar in behavior as when the overlapping is decreased. As the timer is larger the number of Network Initiated handovers diminishes and the Mobile Nodes are situated in the area of influence of NIHO less frequently. The Ratio between Mobile Initiated Handovers and Network Initiated Handovers presents the same effect decreasing with the load of the system and with the duration of the timer. Through

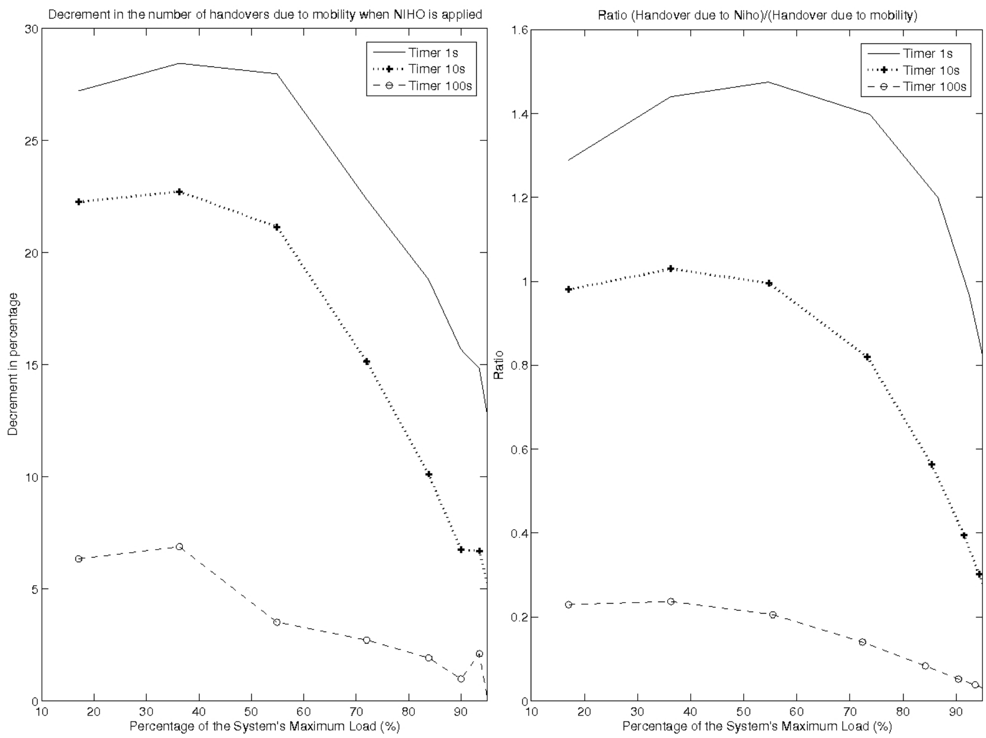


Figure 3.9. From left to right: Decrement in the number of Handovers (Mobile Initiated) between Miho and Miho+Niho, Ratio between Mobile Initiated Handovers and Network Initiated Handovers in the Miho+Niho case (varying timers)

this results we argue that the use of NIHO created an interchange between handovers performed by the terminal and handovers performed by the network. When the NIHO effect is greater the number of handovers due to mobility decreases and the number of handovers performed by the network increases. Although it could seem that this interchange does not provide any benefit to the provider, is worth to notice that the fact that the network is controlling the handover gives several benefits for QoS and load balance that cannot be achieved with mobile initiated handover mechanisms.

3.6 Increased advantage of using NIHO in asymmetrical scenarios

Last section presented simulation results considering evenly distributed mobile nodes over a limited region with different wireless overlapping cells. The mobile nodes are uniformly distributed and are dropped from the network as soon as the terminal is denied connection, either because of rejection during handover or because of rejection at first connection. These are reasonable assumptions when studying the performance of the network focusing on the blocking probability values of the system under evaluation. However, to present the full potential exploitation of the NIHO technology we have to introduce some more specific cases where distribution of the nodes is not uniform. In fact, this is a common situation in some scenarios where physical conditions create concentrations of users (e.g. airports). Another situation with the type of asymmetrical distributions in which NIHO can provide increased benefit is the multi-technology case, where the asymmetry is created by the different characteristics of the technologies.
The new simulation scenario developed considers mobile nodes generated with higher probability in the same region, thus leading to an overload of certain access points. In this new scenario, the overlapping regions allow the network to move terminals around, aiming at redistributing the load and increasing the network capacity. It should be noted that without NIHO technology the network would be overloaded only in some portions and the rejection probability (mainly because of admission control) would increase beyond acceptable values. The necessary condition to avoid this is a good planning of the overlapping area across technologies. If we consider a single wireless technology, this overlapping is strictly related to physical channels availability, whereas in case of heterogeneous wireless technologies the cell overlapping planning can become quite complex. In both cases the overlap percentage should be sufficient to move terminals to another cell while keeping (if not improving) similar link characteristics. This can be implied by the results in the previous section.

To check experimentally that NIHO achieves an increased performance benefit in situations with asymmetrical distribution of nodes, we analyze the following scenario. We have a set of three access points with sufficient overlapping area. Each access point is able to accept at the maximum 10 mobile nodes (admission control). To simulate a more challenging environment we let mobile nodes always being generated in the middle access point area. Movement is allowed within the overlapping area, never leading to disconnected terminals. This is a realistic scenario, for instance, in airports where people getting off at the gate switch on their mobile devices while leaving the plane. In such case mobile users generate extra load in the middle access point tending to saturate the system and increasing the rejection rate for people newly connecting to the network. It would be desirable to have intelligence implemented in the network able to react upon a configured threshold and instructing mobile nodes to connect to alternative access points. The scenario provides insightful results on how overlapping should be configured to allow network intelligence to perform NIHO, even across multiple technologies.
The decision algorithm implemented is as follow. Besides the timer based control, the algorithm (pseudocode 2) is also triggered when the NIHO LOAD THRESHOLD is crossed (set to 5 in the simulations). This simple but efficient mechanism shows the effects of the NIHO technique on the previously introduced metrics.
The results are summarized in table 3.2. The first column ("λ") indicates the user

λ	NumberUsers	RejectHOProb	RejectConnProb	NumberHO	Load
0.04	9.53%	83.2%	86.78%	14.16%	50.52%
0.06	7.64%	85.57%	85.6%	16.57%	63.9%
0.12	24.9%	64.73%	55.04%	84.8%	84.7%
0.31	30.52%	28.12%	44.8%	14.93%	92%
1	31.15%	9%	21.8%	56.13%	100%

Table 3.2. Metrics values for different network loads (lambda)

interarrival frequency used to increase the load in the network following a Poisson law (mean connectivity to the network is fixed to 180 seconds). The second column, (**"NumberUsers"**) indicates how much in percentage the number of users is increased in the same scenario when NIHO+MIHO is applied compared to pure MIHO only. The third and the fourth columns (**"RejectHOProb"** and **"RejectConnProb"**) indicate the decrement (in percentage) respectively of the reject probability during handover and the reject probability at connection. The fifth column (**"NumberHO"**) represent the percentage of reduced number of handovers triggered for mobility reasons. Finally the last column (**"Load"**) represents the load of the system for the lambda used.
The results show that the total increment of users, when NIHO is applied, may reach

30%. Probability of rejection during handover and at connection time is reduced, confirming the tendency already presented in the previous section. It is worth to notice how using NIHO+MIHO the number of users is incremented while the probabilities of rejection during a handover and at connection are reduced, showing a clear benefit for operators. We argue these results clearly show the benefit of NIHO techniques, being this kind of scenarios likely to happen in open environments such as airports, shopping malls or public hotspots. Mobile operators have therefore the possibility to better control terminals in the network and potentially increasing the number of users consuming services. That is, the technology opens new business and revenue opportunities for mobile/fixed operators.

3.7 Conclusions

Starting from the mobile architectures briefly summarized in chapter 2 we present in this chapter design principles for future 4G Mobile Networks taking into account current trends in standardization bodies. In this view the Daidalos architecture has been analyzed as an example showing how new mobility paradigms (e.g. the splitting between local and global) evolve to efficiently support IP-based wireless heterogeneous access. In this new architecture mobile subscribers can freely roam within the same wireless access network as well as across different access technologies enjoying seamless end to end services. The support for such optimized handover is two folded. On the one hand the terminal architecture, following the IEEE 802.21 philosophy, offers a common standardized interface toward the access network providing a well defined set of events/commands. On the other hand the network, by means of the events/commands provided by the terminals, can better optimize device mobility performing handovers where required. Hence, in this framework, handover procedures can be triggered either by the terminal (leading to traditional host driven mobility as shown in 3.3) or by the network leading to optimized handover procedures and resource optimization control. That is, the control plane for handover initiation and execution completes the control plane for data plane routing update introduced before as LMD and GMD protocols.
The challenges imposed by the novel mobility management scheme are conceptually analyzed and through an extensive simulation study we present insightful results on the advantage of applying network controlled handovers in future all IP networks networks, including some basic recommendations on deployment aspects for improved performance. We argue future mobile operators, aiming at the delivery of end to end seamless services across heterogeneous wireless/wired access technologies, will benefit from the analysis of this framework. It should be noted that the study focuses on the conceptual analysis of network initiated handovers in IP environments abstracting from technology specific radio resource management mechanisms. This

first step is required in order to assess the gain in performance by applying the approach. That is, as shown in figure 3.2, the network control relies on a central entity[3] processing the events data flowing from different access points/access routers in the access part of the network. Through algorithms, potentially complex, implemented in the central entity, network selection is performed and, if radio conditions at the terminal side are favorable, the handover takes place.
The second step, presented later in 6, consist of designing functions and associated protocol operations to support the desired mobility management scheme. As mentioned in chapter 1 the IEEE 802.21 protocol has been selected as the framework for centralized network controlled handovers. The reason for this choice are several. First of all the upcoming standard is at an early stage of development, thus it is still open for contributions likely to be accepted if provided with solid analysis and experimental results. Second, the scenarios and procedures the standard is considering nicely match the considerations on 4G networks presented at the beginning of this section. It should be noted that the design of an alternative protocol is possible. However, since we wanted to focus on the feasibility study of IP-based network control mobility for multi wireless access, we preferred to adopt undergoing standardization efforts and contribute to the working group proposing enhancements aiming at better performance as shown in [12].

[3]It should be noted that the selection of distributed approaches is possible although the complexity for large scale networks drastically increases, hence the selection of a centralized solution.

Chapter 4

IEEE 802.21 as enabler for enhanced network controlled handover

This chapter provides a brief overview of the IEEE 802.21 standard [3], highlighting, where possible, information relevant for the development of the thesis.

4.1 Definition

This is a standard from the IEEE whose purpose is to define extensible media access mechanisms that may facilitate handovers between 802 and cellular systems, as well as optimizing handovers between 802 systems, whether they are wireless or not. More specifically, it aims to provide link layer intelligence and other related network information to upper layers, or the mobility management entity responsible for handover decision making, to optimize handovers between heterogeneous media.

The standard supplies a framework allowing for transparent service continuity while a mobile node is switching between heterogeneous technologies. For session continuity it is important that the framework can properly identify the mobility-management protocol stack residing in the network elements supporting the handover.

Also, the network elements will feature a new entity, the Media Independent Handover Function, within their protocol stack, with correspondent Service Access Points and associated primitives, to access the services therein.

A primitive is a unit of information which is sent from one layer to another. There are four classes of primitives: Request, Confirm, Indication and Response. The request is issued by the layer that wants to get the services or the information from another layer, and the confirm is the acknowledgment of the request. The indication is the notification of the information to the layer that requested the service, and the response is the acknowledgment of the indication. In this architecture, a layer can evenly communicate with each other.

The primitive consists of five fields: the protocol layer id to which this primitive should be sent, the protocol id to which protocol entity this primitive should be sent, the primitive class (i.e., request, confirm, indication, or response), the primitive name, and parameters.

There are three different usages of "Primitives":

- **To provide L2 information to upper layers immediately.** A "Request" primitive is an acquisition request for L2 information. As a "Confirm" primitive, L2 information returns immediately.

- **To notify upper layers of L2 events asynchronously.** "Request" and "Confirm" primitives are used just for registration. When an event occurs, an "Indication" primitive is asynchronously delivered to an upper layer.

- **To control L2 actions from upper layers.** A "Request" primitive is a request for operation. Ack or nack returns immediately as a "Confirm" primitive.

The services are:

- Media Independent Event Service, which analyzes/delivers local and remote events;

- Media Independent Command Service, which provides a set of commands for MIH users to control handover states in the links;

- Media Independent Information Service, which provides an information repository, for query and response.

The primitives' purposes are to collect link information and control link behaviour during handovers. The MIH is a logical entity which has no implication on the way its functionality is implemented either in the terminal or in the network. The MIH is able to receive and transmit information either locally, from the link layers through the Service Access Points, or remotely, through messages exchanged through peer MIH functions existing in network elements. The specification defines mechanisms to support MN-initiated, MN-controlled, network-initiated and network-controlled handovers.

4.2 Handovers

This standard supports two types of handovers: for mobile users and stationary users. In the first case a handover can occur due to changes in wireless link conditions, or due to gaps in wireless coverage that result from mobile node movement. In the second case, the environment surrounding the stationary user can change, making one network more preferable than another. Another example can be the selection of an application which requires a transition to a higher data rate link.

The standard aims to facilitate handovers of different methods, classified as "hard" or "soft" depending on whether they are made break-before-make or make-before-break.

In general, handovers will be more efficiently done through cooperative use both the mobile node and the network infrastructure. One has to note that handover control, policies and algorithms are handled by communication system elements which fall away from the scope of the standard. Nevertheless, some aspects of the overall handover procedure must be described in order to better clarify the role of the MIH function services.

Handovers can be affected by diverse factors such as service continuity, application class, etc. The standard supplies essential elements which address the following handover factors:

- **Service Continuity:** this refers to the continuation of the service during and after the handover, minimizing data loss and break time without requiring user intervention, for the cases where the handover is done between two different access networks or between two different points of attachment of a single network. The standard can, for instance, supply information to an application regarding the QoS available on a candidate network, and determine if a handover is viable of not, considering if the required QoS is supported.

- **Application Class:** the standard can provide characteristics for application aware handover decisions, taking into consideration the different tolerance for delay and data loss.

- **QoS:** this is a very important factor to consider in handover decision making. In general, the decision is taken by considering the network which best provides the most appropriate level of QoS. This standard specifies the means by which QoS information can be obtained for each of the supported access networks and be made available to upper layers involved in the process of handover decision making.

- **Network Discovery and Selection:** the standard defines the network information to aid in providing new possibilities for network discovery and selection, as well as defining the means to obtain it.

- **Security:** the message exchange between the MIH services of the MN and a Point of Attachment must be secured until the MN has a secure connection with the PoA. This association can either be achieved through lower or higher layer security mechanisms. The standard supports the means for security information to be made available to upper layers for setting up secure connections.

- **Power Management:** the standard allows the availability of media dependant information to higher layers and remote entities, without having to use the specific media to obtain it. This allows for efficient "sleep" or "idle" modes that optimize the use of battery.

- **Mobile Node Movement:** the standard allows for the supply of fresh link information to local and remote entities for efficient handover decision making.

The standard also supports cooperative use of both the mobile node and the network infrastructure, allowing for access to handover related information such as neighbourhood cell lists, location of mobile devices, high-level services available. The aim is to optimize network selection. Both the mobile node and the network can make network selection decisions, contributing to an optimum network selection, based on the information available.

4.3 The Media Independent Handover Function

The Media Independent Handover Functions is a logical layer in the mobility management protocol stack, both in the mobile node and the network elements. Its purpose is to aid and facilitate handover decision making though the supply of inputs and context to the upper layers, for handover decision and link selection. One of the key goals of the MIHF is to facilitate the recognition of handover occurrence, as well as the discovery of information on how to make effective handover decisions.

The MIHF provides abstracted services to higher layers, offering a single unified interface to them, through technology independent primitives. The MIHF itself relies on technology specific interfaces to communicate with the lower layers. The specification of these interfaces is not in the scope of this standard, since they are already defined as Service Access Points within their respective standards.

4.3.1 The Communication Model

MIH Functions in different entities can communicate with each other, for instance, to exchange information about the network with the terminal, in order to aid in the handover decision making process. The standard defines the communication

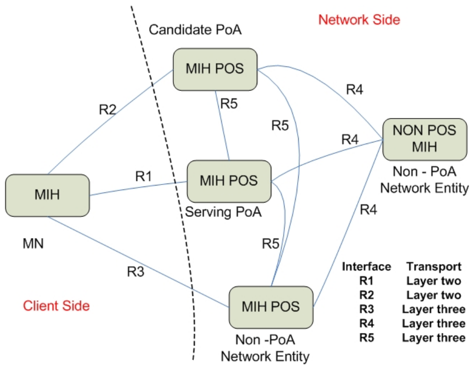


Figure 4.1. IEEE 802.21 reference model

relationships between the elements of the network that have a MIHF. The IEEE 802.21 communication reference model (figure 4.1) specifies interfaces between mobile devices and points of attachment to the network and between network nodes in the network. A MIH Point of Service (PoS) is a network MIH-enabled entity that exchanges MIH signaling with a MIH-enabled terminal providing, for instance, MIIS information services located deeper in the access network. The information exchange occurs between lower layers and higher layers, taking always as a reference the MIH Function. Furthermore, the information can be shared locally, within the same protocol stack, or remotely, between different network entities. As shown in figure 4.1 interfaces R1 and R2 are specified at layer two, while interfaces R3, R4 and R5 are specified at layer three aiming at technology independence, thus allowing approaches as NIHO.

The PoA is an endpoint of the network side that includes a MN as an endpoint. This is associated to an interface instead of the whole node.

The PoS entity is an element in the network side whose MIH Function exchanges messages with a MN's MIH. One has to note that a network entity can supply more than one Point of Service and provide different combinations of MIH services to a MN, based on subscription or roaming conditions. Also, a network entity composed of more than one interface has the PoS associated to the network entity itself and not with just one of its interfaces.

In case of a network model that includes a MIH proxy, the MIH network entity that communicates with that proxy does not have a direct communication with the MN and thus is not a PoS for the MN. Nevertheless, the same network entity may still act as a PoS for a different MN.

Between the different instances of MIH Functions, the communication can be made as following:

- MIH on MN and MIH PoS on the serving PoA, where L2 or L3 communication can occur;

- MIH on MN and MIH PoS on a candidate PoA where L2 and L3 communication can occur;
- MIH on MN and the MIH PoS on a non-PoA entity where L3 communication can occur, and also L2 is possible through Ethernet bridging, MPLS, etc.
- MIH on the PoS and a non-PoS in another network entity can encompass L3 communication;
- MIH on two PoS instances in distinct network entities can encompass L3 communication.

4.3.2 The MIH Services

The MIH Function provides synchronous and asynchronous services through well defined Service access points for link layers and MIH users. These services have the purpose to manage, determine and control the state of the underlying interfaces.

Media Independent Event Service

Mobile nodes using MIH services receive indications from link layers for asynchronous operations like Event service. Events can indicate changes in state and transmission behaviour of the physical, data link and logical link layers, and also, with a pre-indicated confidence level, predict changes in these layers.

Events can be originated from the MIH Function, called MIH Events, or from the lower layer, called Link Events. The typical flow of events has its origin at lower layers and are sent to the MIH Function. Upon registration to the MIHF, a high layer entity can receive the events indicated in the registry message.

Events can also be local or remote. Local events are propagated across layers within the local stack of a single device, whereas remote events traverse across the network from one MIH function to a peer MIH function. These events can then traverse from the local MIH function to the local upper layer entity, supposing prior registration to receive that event.

Event registration is a mechanism that allows upper layers to indicate to the MIH which events they are interested in receiving. The event service typically is used to detect the need for handovers. For example, it can supply an indication to the higher layers that the link will go down in a near future (through analysis of the signal level and crossing a threshold) which can be used to prepare a new point of attachment ahead of the current one going down.

From the recipient's point of view, these events are mostly advisory in nature and not mandatory. Also, higher layer entities might have to deal with freshness, reliability and robustness issues related to these events, specially in the case that they are remote.

The Media Independent Event Service supports several types of events:

- MAC and PHY State Change events: which correspond to changes in MAC and PHY state;
- Link Parameter events: triggered due to change in link layer parameters. Can be triggered synchronously (i.e. regularly) or asynchronously (i.e. when a threshold is crossed);
- Predictive events: express the likelihood of a future change in a certain property, with a certain degree of certainty, based on past and present events;
- Link Synchronous events: give indications of precise timing of L2 handover events that are useful to upper layer mobility management protocols;
- Link Transmission events: indicate the transmission status of higher layer PDU's by the link layer. This information can be used by upper layers to improve buffer management for achieving low-loss or loss-less handovers.

When exchanging events and commands between hosts, extreme caution needs to be exercised in establishing communications securely. Unless endpoints are identified and authorized for communications, one or more service entities may be affected by state changes as a result of inappropriate registration, event or command reception. [50] identifies that unauthorized third parties impersonating legitimate ES entities can generate hints, attackers can cause damage to communications to or from a mobile node. Event indications are therefore likely to be interpreted as hints by other protocol layers, without necessarily modifying protocol state. Unless appropriate security mechanism and a security model are adopted, attacks may be particularly simple on a wireless medium, where even valid event messages may be replayed at a later stage by an attacker. Command services experience most of the same attacks as event services, although their effects may be even more severe, since commands imply state changes.

Media Independent Command Service

The Media Independent Command Service allows higher layers to configure, control and get information from the lower layers. The information provided by these commands is dynamic in nature comprising of link parameters such as signal strength, link speed, etc. These commands can be issued by higher layers, called MIH commands, as well by the MIH Function, called Link Commands. Typically, messages propagate from the upper layers to the MIH Function, and then from this to the lower layers.

MIH Commands may be local or remote. Local MIH Commands are sent by Upper Layers to the MIH Function in the local stack, whereas remote MIH Commands are sent by Upper layers to the MIH Function in the peer stack.

The commands generally carry the upper layer decisions to the lower layers on a local or remote device entity. An example is a policy engine entity to request a mobile node to switch link.

Media Independent Information Service

The Media Independent Information Service provides a framework and corresponding mechanisms by which a MIHF entity can discover and obtain network information, with the purpose to facilitate handovers.

This service provides a set of Information Elements, the structure to store them and its representation, and a query/response mechanism for transferring the information. Different types of Information Elements may be necessary depending on the type of handover. For example, for horizontal handovers across different PoAs of the same access network, information from lower link layers can be sufficient. But, in the case of vertical handovers, the mobile node may move across different access networks. Then, it is necessary to select an appropriate PoA in the new network based in good lower link connectivity as well as in the availability of higher layer services.

This information can be made available via both lower and upper layers, and, if necessary, be obtained through a secure port. The Information service also provides access to static information such as neighbour reports, which help in network discovery. It also includes more dynamic information such as channel information, MAC addresses, security information, etc. This, in conjunction with high layer information (such as application requirements) may help in a more effective handover decision. The set of different Information Elements may evolve. Also, there is a need for flexibility and extensibility in the way this service provides the information, since, for example, the list of available access networks is always evolving. For this, the standard defines a representation schema, which allows a client of MIIS to discover the entire set of different access networks and Information Elements supported, in a flexible and efficient manner. This schema can be represented in multiple ways, such as Resource Description Framework (which is based on XML), ASN.1 (which is used in 802 MIBs), variants or a simple TLV representation of different information elements.

This service allows access to heterogeneous information about networks, to be accessible by both the mobile node and the network. A media-independent neighbour graph may be abstracted through the neighbour reports of specific technologies.

This capability allows the terminal to use its current access network technology to query information about other technologies without activating that interface. One can also, for example, obtain knowledge of supported channels by different PoAs without resorting to scanning or beaconing. The MIIS and MICS information could be used in combination by the mobile node, or network, to facilitate the handover.

The information elements can be classified in three groups:

- General Access Network Information: provide a general overview of the different networks, such as list of available networks, operators, roaming agreements, cost of connections, security and quality of service;
- Points of Attachment information such as addressing, location, data rates, etc;
- Other information specific information and vendor specific.

In [51] the deployment of information services is discussed. For these information services, it is possible that network information may be either centrally stored on a server or distributed in each individual access network. Presumably, an L2 or L3 based mechanism to identify or discover a valid information server would be required. In order to accomplish this, it will be necessary to describe IS discovery and specify transport services over IP. Interactions with IP in delivering handover services over IP therefore need consideration in the IETF, both for use with 802.21 and for other instances of handover services.

Information Representation

A schema defines structure of information. A schema is used in the 802.21 information service to define the structure of each information element as well as the relationship among different information elements supported. The MIIS schema is classified into two major categories.

- Basic schema that is essential for every MIH to support
- Extended schema that is optional and can be vendor specific

In [52] a new DHCPv4 option is defined for discovering MIIS information.

4.3.3 Service Access Points

Service Access Points are used to exchange messages between the MIH Function and other planes, using a set of primitives that specify the information to be exchanged and the format of those information exchanges.

The standard includes the definition of media independent SAPs, the MIH_SAP, that allow the MIH Function to provide services to the upper layers. These upper layers are called the MIH Users and use the services provided by the MIH Function through the MIH_SAP. The MIH Users have to register to the MIH Function in order to obtain access the MIH generated events and the Link Events, which are generated by the layers below the MIH but are passed on upwards through the MIH Function. MIH Users may also send commands to the MIH Function. Also, MIH Function entities may also send remote commands to other remote MIH Function entities.

The standard also includes recommendations to define or extend existing media-dependent SAPs. These allow the MIH Function to use services from the lower layers of the mobility-management protocol stack and their management plane. All the Link Events generated at lower layers and all the Link Commands sent through the MIH Function are part of the media specific MAC/PHY SAPs and are already defined by their specific technologies.

These concepts can be combined in the following general MIH Reference Model:

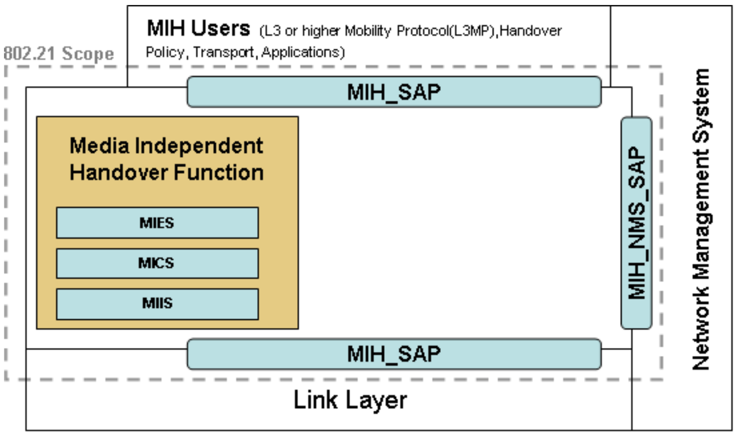


Figure 4.2. MIH Reference Model

4.3.4 The MIH Protocol

The MIH protocol defines the format of the messages (i.e. MIH packet with header and payload) that are exchanged between remote MIH entities and the transport mechanisms that support the delivery of the messages. The selection of the transport mechanism is dependent on the access technology that connects the MN to the network. These messages are based on the primitives which are part of Media Independent Event service, Media Independent Command service and Media Independent Information service.

MIH messages require reliability for remote communication on an end-to-end basis to ensure the receipt of data to the destination. Reliability may be provisioned with an optional acknowledgement service as part of the MIH protocol. The source endpoint may optionally request for an MIH ACK message to ensure successful reception of a certain event, command or an information service message. When this MIH ACK is received by the source, it may conclude that the message was reliably delivered to the destination. In case of a lost MIH ACK message, the source shall timeout and retransmit the same MIH message. This timer may be related to the RTT between the two nodes.

This mechanism is used through two bits in the MIH message header: the ACK-Req bit is set by the source and the ACK-Rsp is set by the destination. The underlying transport layer takes care of verifying the MIH message integrity, and thus not required at MIH Function level.

The packet payload for these services may be carried over L2 management frames, L2 data frames or other higher layer protocols.

Services Provided by the Protocol

The MIH Protocol provides the following services:

- MIH capability discovery: so a MIH Function can discover MIH Functions on other entities. This allows for the negotiation and selection of an optimum transport for communication, as well as discovering the list of supported events and commands.

- MIH remote registration: so that a MIHF in an entity can receive remote events;

- MIH message exchange: using the messages supplied by the MIH services.

Protocol Identifiers

Successful communication between two MIHF peers requires addressing and identifying the session between them. Three identifiers exist to serve this purpose.

- MIHF ID, which is used to establish and initial connection between two MIHF peers after MIHF discovery and before the creation of a session;

- Session ID, used to identify an active session uniquely between two MIHF peers;

- Transaction ID, used to match uniquely the received responses with the requests previously sent.

Frame Format

The frame format for MIHF has the following aspect:

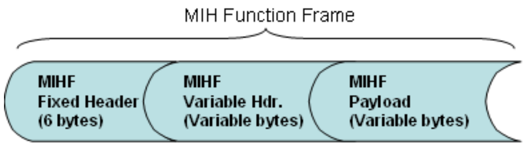


Figure 4.3. MIH Function Frame Format

The MIH Function Header consists of two parts: one with fixed length and another with variable length. The first one accommodates the essential information which is present in every packet and is used for parsing and quick analysis. The second carries information which is optional in some cases.

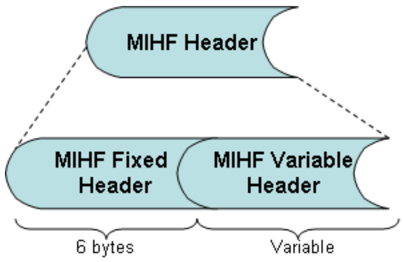


Figure 4.4. MIH Function Header

Table 4.1 lists the fixed header fields.

The variable header presents additional elements that help analyzing and coordinating the payload. These identifiers are represented in Header-TLV format.

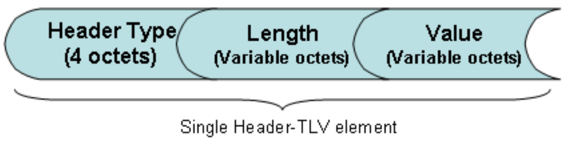


Figure 4.5. Header TLV Format

The Header Type field indicates the type of header identifier embedded in the Value field.

Table 4.2 lists the function messages.

The parameters in MIH Protocol Messages are expressed through TLV encodings.

The messages are divided in messages for System Management Service, for Event Service, for Command Service and for Information Service Category.

Field Name	Size	Description
Version	4	This field is used to specify the version of protocol used.
ACK-Req	1	This field is used for requesting an acknowledgement for the message.
ACK-Rsp	1	This field is used for responding to the request for an acknowledgement for the message.
Reserved	4	This field is intentionally kept reserved. In un-used case, it all the bits of this field are to be set to '0'.
MIH Message ID - Service Identifier (SID) - Operation Code (Opcode) - Action Identifier (AID)	16 4 3 9	Combination of the following 3 fields. Identifies the different MIH services, possible values are: 1:System Management 2:Event Service 3:Command Service 4:Information Service Type of operation to be performed with respect to the SID, possible values are: 1:Request 2:Response 3:Indication This indicates the action to be taken w.r.t. the SID
Number of additional header Identifiers	8	Indicates the no. of header identifiers (TLV for each) included in the variable MIHF header part
Transaction ID	16	This field is used for matching Request and Response as well as matching Request, Response and Indication to an ACK.
Variable Load Length	16	Indicates the total length of the variable load embedded into the MIH Function frame and is the sum of MIH variable header length and MIHF payload length.

Table 4.1. MIH Function Fixed Header Description

No	MIH Action Identifier	MIH Opcode	MIH Service ID
1	MIH Capability Discover	Request, Response	System Management
2	MIH Event Register	Request, Response	Event Service
3	MIH Event Deregister	Request, Response	Event Service
4	MIH Link Up	Indication	Event Service
5	MIH Link Down	Indication	Event Service
6	MIH Link Going Down	Indication	Event Service
7	MIH Link Detected	Indication	Event Service
8	MIH Link Parameters Report	Indication	Event Service
9	MIH Link Event Rollback	Indication	Event Service
10	MIH Link Handover Imminent	Indication	Event Service
11	MIH Link Handover Complete	Indication	Event Service
12	MIH Get Status	Request, Response	Command Service
13	MIH Switch	Request, Response	Command Service
14	MIH Configure	Request, Response	Command Service
15	MIH Configure Thresholds	Request, Response	Command Service
16	MIH Scan	Request, Response	Command Service
17	MIH Handover Initiate	Request, Response	Command Service
18	MIH Handover Prepare	Request, Response	Command Service
19	MIH Handover Commit	Request, Response	Command Service
20	MIH Handover Complete	Request, Response	Command Service
21	MIH Network Address Information	Request, Response	Command Service
22	MIH Get Information	Request, Response	Information Service

Table 4.2. MIH Function Messages

Capability Discovery

The MIH Function in the terminal, or in the network, may discover which entity in the network, or terminal, supports MIH capability by using the MIH capability discovery procedure. This procedure consists of a handshake and capability advertisement, and is achievable by exchanging MIH messages.

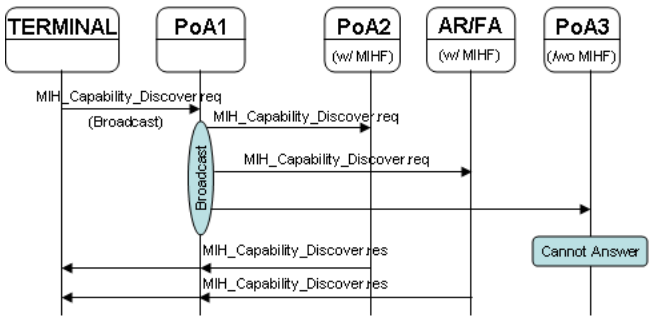


Figure 4.6. MIH capability Discovery Procedure

The mechanism depicted here is directly invoked by the MIH Service. In [53] it is discussed the possibility of integrating the capability discovery in the common protocol functionality being defined in IEEE 802.21 and IETF. In this case, the MIH service would simply request the delivery of a message from the common protocol functionality, and leave the discovery and resolution procedures to the lower layers. Regarding candidates for integration, we can think of DHCP, SLP and mDNS. More information on IETF involvement is discussed in section 4.5.

Encapsulation

Regarding encapsulation, [54] suggests that the MIH message shall be inserted inside a UDP datagram which can fit in either an IPv4 or IPv6 packet. Nevertheless, the draft, for IPv4, does not mention problems such as firewalls or NAT traversal.

MNs will feature a MIH Application that sends and receives MIH messages through UDP on a unique port number that shall be registered and obtained from IANA. It is also assumed that the Mobility Management Entity, in case it exists and it is external to the MN, will have it's IP address discovered as per DHCP special option for discovering IEEE802.21.

The process of a MIH message received in an MN has the following steps:

- The Network layer receives an IP packet from its lower layers and strips off the IP header, processes it and then forwards it to the appropriate Transport protocol.

- The Transport layer then receives a UDP datagram. Its headers are in turn removed and processed. The UDP protocol then forwards the contents of its data field to the appropriate Application layer. This is determined by the value of the destination port number. The MIH Application shall have a newly defined port number. Therefore the MIH message would be forwarded to the MIH Application.

- The MIH Application would then decode the MIH message according to the IEEE 802.21 specifications and shall then react as required.

The steps taken by the MN to transmit a MIH message are symmetric to the steps explained above and the flow shall be in the reverse path as follows:

- The MIH Application shall generate an MIH message and pass it to the Transport Layer through the newly defined port.

- The UDP shall encapsulate the data in a UDP datagram and shall set the header fields accordingly.

- The datagram is then sent to the Network Layer where it is in turn encapsulated in an IP packet and all the header fields of the packet are set accordingly. This packet is then sent to the appropriate lower layer for transmission to the network.

These processes are similar in network nodes also.

Reliability

[54] refers to the optional ACK mechanism present in the IEEE 802.21 specification. It proposes timers as a solution for lost or delayed MIH messages. Because the contents of certain MIH messages are more sensitive to delay than others, the values of the timers should be different for the three MIH message types. For example, messages that contain information can be sent periodically to update the mobile node and can have the longest timer. On the other hand, in a network controlled handover scenario for example, the MM may issue a command to a mobile node to handover to a target access technology. Since this node manages the available network resources, such a message would be required to arrive as fast as possible. Thus, the timer associated with command messages should be shorter than those of messages with information. Thus, three timers should be used depending on the type of MIH message that is sent:

- Information timer that is set after the transmission of a message that is related to Information Elements.
- Event timer that is set after the transmission of a message that is related to Events.
- Command timer that is set after the transmission of a message that is related to Commands.

In addition, relying on the service layer to handle all reliability issues opens the question of whether timer values should be based on message transfer latency or application processing latency, and these two can differ significantly.

During the course of this project, several versions of the IEEE802.21 specification where released. In version D1.00 this acknowledgment feature was included.

Reliable delivery for the mobility services may be essential, but it is difficult to trade this off against low latency requirements. It is also quite difficult to design a robust, high performance mechanism that can operate in heterogeneous environments, especially one where the link characteristics can vary quite dramatically. The option of an Acknowledgment mechanism, such as the one used in 802.21, has a number of disadvantages associated with it. The protocol designs ends-up re-inventing a lot of the functionality already available in lower layers at a higher layer where access to information about what is going on in the network is restricted. It also adds to the complexity of the higher layer protocol, and makes successful deployment less certain.

Nevertheless, allowing the option of a reliable transport service means that the additional recovery mechanisms within the service layer can be made very simple and robust because they do not need to be optimised for efficient recovery of message loss within the network.

4.3.5 802.11 Integration

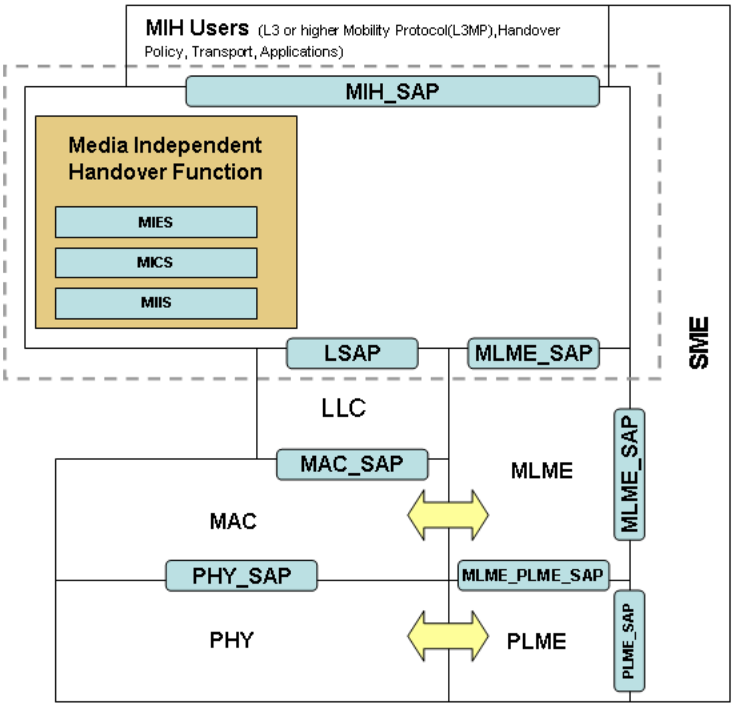


Figure 4.7. MIH Reference Model for 802.11

This figure shows the MIH functions for 802.11 stations and network PoA (APs). The LSAP defines the MIH interface to the data plane and may encapsulate MIH payload in data packets. However, since 802.11 does not currently support Class 1 data frames, traffic may be sent over the data plane only when the client has associated with the AP.

The MLME_SAP specifies the interface between MIH and the management plane (MLME) and allows MIH payload to be encapsulated in management frames (such as action frames). Thus primitives specified by MLME_SAP may be used to transfer packets before a station has associated with an AP, whereas the LSAP SAP may be used to transfer packets after association has been established with an AP.

The MIH_SAP specifies the interface of MIH Function with other higher layer entities such as transport, handover policy function and L3 Mobility protocol.

The MLME_SAP includes primitives for system configuration and link state notification/triggers.

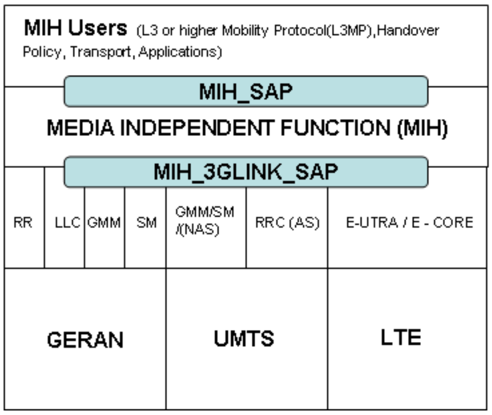


Figure 4.8. MIH Reference Model for 3GPP

4.3.6 3GPP Integration

This figure illustrates the interaction between MIH Function and 3GPP based system. The MIH Function services are specified by the MIH_3GLINK_SAP. However no new primitives or protocols need to be defined in 3GPP specification for accessing these services. The MIH Function services may be easily mapped to existing 3GPP primitives. The architecture placement of the MIH Function shall also be decided by the 3GPP standard. The figure above is for illustrative purposes only and shall not constrain implementations.

For example events received through LAC layers SAP such as "L2.Condition Notification" may be mapped and generated through the MIH-3GLINK-SAP as a Link Up, Link Down or Link Going Down. Likewise events generated at the PPP SAP within the PPP layer, such as LCP-Link-Up or IPCP_LINK_OPEN could be mapped and generated through the MIH-3GLINK-SAP as a Link Up event.

4.4 Media Independent Neighbor Graphs

Neighbor graphs are a mean to represent MIIS information regarding neighborhood. In the specific case of homogeneous networks, network PoAs are of the same kind whereas for heterogeneous networks they are different. Media Independent Neighbor Graphs, or MING, are then composed of heterogeneous and homogeneous elements. Mobile Nodes may obtain media specific graph information directly from the access networks. In those cases, however, the neighbor graph is limited to the media type the mobile terminal is directly attached. 802.21 media independent neighbor information, on the other hand, may help obtain a global view of the network neighbor graph consisting of multiple media types.

The MING contains a set of different types of neighbors relative to a given PoA.

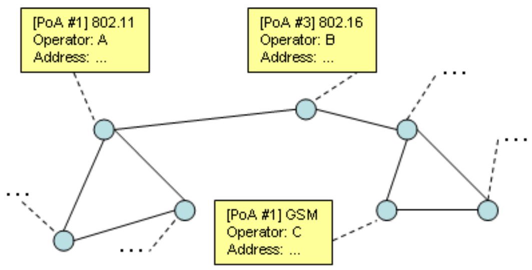


Figure 4.9. Media Independent Neighbor Graphs

This set may be kept by the MIIS functional entity and may eventually help a MN to quickly identify potential candidate PoAs for handover. Other uses exist for MING. For example, the neighbor list supplied by MING can inform the MN about the media types of neighboring networks, in order to avoid powering up unnecessary interfaces, and then scan for neighbor information.

The MING is compiled by the MIIS in the network side. A MING may be manually configured, e.g. manually introducing the neighbors for a given AP, or obtained via the management interface, or other access networks. Rather than incurring such management overhead, the PoA may learn about its neighbors belonging to other media type dynamically through the course of message exchanges. However, how this information is reported and the corresponding responses are outside of the scope of the standard.

A neighboring information element only contains entries of neighboring PoAs that are legitimate neighbors relative to a given PoA satisfying the query. A MING also prevents the addition of fake neighbours. The exact form of implementing the MING is vendor dependent and it is outside the scope of the standard.

If a MN is anticipating a handover, it may request information service from the MIIS entity at the network side. Whenever such request is received, this MIIS entity at the network side replies with a partial set of the MING. This partial concept contains only entries of neighboring PoAs with legitimate relationship of the PoA the MN now makes a connection to. If supported, unsolicited advertisement may also be used for distributing the partial set as well.

4.5 IETF Involvement

The IETF has been working on how handover services can be used to assist mobility signaling protocols, and has been analyzing interactions between handover services and network/transport layers. At the same time, other groups (e.g. IEEE 802.21) have been taking a more generally applicable view.

The MIPSHOP working group is currently working on common functionality necessary for the support of media independent handover (MIH) protocols, initially focusing on the architectures being developed with the 802.21 working group of the IEEE. Although the MIH protocols carry link layer information, the protocols themselves are not tightly bound to any specific link layer. Instead, they can be carried at the network layer, both within the radio access infrastructure and over the air.

There are on-going activities in the networking community to develop solutions that aid in IP handover mechanisms between heterogeneous wired and wireless access systems including, but not limited to, IEEE802.21. Intelligent access selection, taking into account link layer attributes, requires the delivery of a variety of different information types to the terminal from different sources within the network and vice-versa. The protocol requirements for this signalling have both transport and security issues that must be considered. The signalling must not be constrained to specific link types, so there is at least a common component to the signalling problem which is within the scope of the IETF.

A problem statement [55] is in progress, decomposing the overall MIH protocol problem into a common part, and a set of specific MIH services layered over it. The problem statement itself outlines a division of functionality between the common part and the individual services, with the intention that the common part will be generally useful even in non-802.21 architectures. The expectation is that the MIPSHOP working group will develop a solution for the common part which meets the 802.21 requirements as expressed in the problem statement draft.

A second draft [53] outlining more detailed design considerations for the common part has also been prepared which formalises some of the open issues the scope of the common functionality, and lists the key design choices that have to be made and the criteria that should be taken into account in doing so. Although it refers to components of possible solutions as examples, it does not intend to be a solution proposal.

The IETF view on MIH Services is consistent with the architecture defined by 802.21, where the services in question have been identified as the Event, Command and Information Services (ES/CS/IS). A draft [50] further analyzes the main relevance of ES and CS to IETF and the MIPSHOP WG is the exchange of information related to ES and CS between peer nodes. This is referred to as Remote ES and Remote CS.

4.5.1 Conclusions

This chapter provided a brief overview of the IEEE 802.21 standard. It should be noted that while this thesis is being written the standard is not yet finalized, potentially making this section outdated in some parts.

Chapter 5

Mobile centric speedy handovers

Chapter 3 presents the framework where MIHO and NIHO handovers co-exist. Chapter 4 details the IEEE 802.21 standard describing the Media Independent Handover Function and associated protocol operations. In this chapter we first evaluate the design for the mobile devices implementing the cross layer design advocated by the IEEE 802.21 standard. The design is supported by an extensive simulation study showing how the interaction of lower layers (e.g. WLAN and 3G technologies) with the upper layers (e.g. Mobile IP) produces optimized handover performance. The terminal design for speedy handovers is the basis for the follow up work presented in chapter 6 featuring network and terminal side components for network controlled handovers.

5.1 Motivation

IP mobility across WLAN and 3G has been widely studied in terms of handover performance (as described in 3.3). Tomorrow's customers will widely exploit multi-mode terminals (i.e. integrating one or more access technologies) to get better services depending on the environment (e.g. indoor, outdoor). Scenarios in which 3G coverage is complemented by 802.11 or 802.16 access technologies are becoming available. Upcoming standards, such as IEEE 802.21, propose methods to support mobility across heterogeneous technologies. However, while standards specify functional entities (either implemented in the terminal or in the network) and associated protocol operations, they do not specify configurations of terminal or network components, upon which events are generated.
Considering scenarios in which a terminal can freely move across 3G and WLAN coverage cells, the configuration of the terminal for network detection (e.g. WLAN

signal level detection) and attachment is a critical issue. For instance, a user preferring WLAN connectivity (when available) over 3G may need a threshold configuration different from a user preferring 3G. IEEE 802.21 provides a method to configure (upon events or timers) specific thresholds for vertical handovers between 3G and WLAN. However, the values required for a particular scenario are not specified. In this chapter, through an extensive simulation study, and by using a realistic WLAN signal level path loss model ([56] and [57]), the effect of terminal speed on handover performance has been investigated.

In the simulation environment, terminals move according to the random way point model at different speeds. Performance of handovers is measured based on Wireless LAN time utilization, packet loss and number of handovers processed. According to the 802.21 standard, the handover algorithm configures the power thresholds, and then handovers are triggered by signals received from lower layers. In this paper we analyze the effect of the mobile terminal speed into the configuration of the optimal thresholds. The results indicate the configuration to be used depending on the value of the primitive *"Link_Configure_thresholds→Link speed"* of the IEEE 802.21 specification [3]. A potential application scenario, could be a IEEE 802.21 based terminal with built-in GPS devices, that could dynamically adjust thresholds' configuration and sampling techniques for WLAN signal level prediction, according with to speed variation.

A number of papers in the literature [58], [59] and [60] have analyzed performance issues of handovers based on Mobile IP between cellular networks. However these works only study the problems related with upper layers (mainly TCP) due to the differences between the two technologies involved. Some previous works (e.g. [61]) study the integration of WLAN hot-spots into 3G networks; these previous works however, are not based on the 802.21 framework in contrast to ours. The first work, to our best knowledge, that treats the specific problems of inter-technology handovers based on IEEE 802.21 (taking as Mobility handler SIP) is [62]. However, [62] does not analyze the effect of terminal speed. The WLAN signal level model used in our work is based on the model of [56] and [57], where an accurate study on indoor environments is proposed. We argue that indoors WLAN environments complemented by full 3G coverage will be of a great interest in the future.

5.1.1 Terminal Architecture

The IEEE 802.21 specification defines a middle layer called the Media Independent Handover to centralize functionality related to handover. The Media Independent Handover (MIH) functionality has been implemented in the OMNeT++[1] simulation

[1] www.omnetpp.org

tool. It consists of three elements: the MIH Function, the Service Access Points (SAPs) with their corresponding primitives, and the MIH Function Services (Figure 5.1). The MIH Function (MIHF) is defined in the current IEEE 802.21 specification

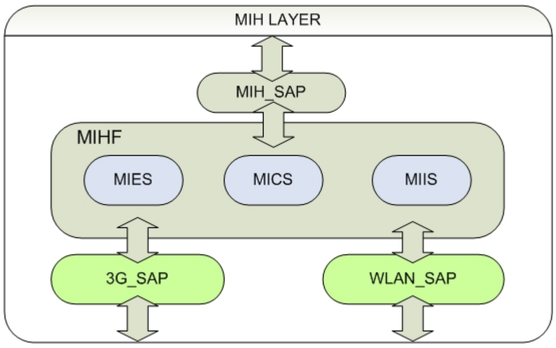


Figure 5.1. MIH Architecture

[3] as a logical entity and the specific MIH implementation of the Mobile Node and the network are not included. In fact, it is important to note that in order to facilitate the overall handover procedure, the MIH Function should be defined following a cross-layer design, allowing the communication with the management plane of every layer within the protocol stack. We have implemented the intelligence of the handover as part of the MIH Function.
The Service Access Points (SAPs) are used to enable the communication between the MIH Function and other layers. In the presented architecture there is one technology independent MIH_SAP which allows the communication between the MIH function and upper layers, namely IP, transport, and application. Two technology dependent SAPs are also specified: WLAN_SAP and 3G_SAP, which communicate the MIH Function with the management plane of the 802.11 link layer and the 3GPP link layer, respectively. Note that every SAP defines certain number of primitives that describe the communication with the services in the MIH Function. Since the implemented scenario does not cover all possible use cases, we have only defined here the primitives needed for our scenario.
The MIH Function is supported by three basic services: events (Media Independent Event Service, MIES), commands (Media Independent Command Service, MICS) and information (Media Independent Information Service, MIIS). These services can be defined as local, when the origin and the destination of the service are a single MIH entity; or remote, when the origin and the destination are different MIH entities. Since we focus in this chapter on specific scenarios where the terminal does not need to discover neighborhood (Information Services) or to receive remote events/commands from the network, only local communication is taken into account. The MIH Function has always information up to date of the state of both higher

layers and lower layers. Therefore, it will be able to decide when and how a handover procedure has to be performed.

5.1.2 Modification to the Mobile IPv6 stack

In order to have a reasonable control over the handover performance, some modifications to the Mobile IP stack were required.
Mobile IPv6 [63] signaling (Binding Update BU and Binding Acknowledgement BA) sent by a node for WLAN-3G inter-working, could be lost in the network before reaching the destination or could be lost in the wireless medium when the Mobile Node has poor signal conditions. Taking into account that the signaling is always sent through the new link in our scenario, a signaling loss may occur due to varying WLAN signal conditions when moving from 3G to WLAN. When a BU or BACK is lost the handover at layer 3 is supposed to fail. When the handover fails, the state of the signaling flow can be:

- The BU has not arrived at the Home Agent: the packet flow is reaching the Mobile Node through the old link so no packet loss happens (no handover).
- The BU reaches the Home Agent but the BACK is lost: in this case the packet flow starts arriving to the Mobile Node through the new link.

Binding Updates are usually retransmitted upon timeout. If a BA is not received after a timeout expiration, a retransmission is scheduled and the next timeout is set to the double of the original one. This policy is kept until the timeout reaches a maximum (MAX_BINDACK_TIMEOUT is 32 seconds as specified in the Mobile IP RFC [15]).
Since the Mobile Node has no way of knowing if the Binding Update has reached the Home Agent or not after a handover failure, the handover algorithm must proceed with an action to stabilise its state. This action is to perform a handover to the 3G leg. The major modification introduced into the Mobile IP stack is about the way the retransmission of the Binding Updates is handled. The retransmission algorithm as specified in [15] has been omitted and replaced by MIH intelligence which takes the required actions (namely rolling back to the 3G channel) in case BU are lost and timers (about 1.5 seconds) expire.

5.1.3 Handover Algorithm

Our handover algorithm is based on signal thresholds. It relies on the information provided by the Media Dependent layers and the Mobile IP Layer. The handover algorithm reacts upon the reception of three possible signals, which are:

- RSSI (Received Signal Strength Indicator) sample

- Notification about the status of the handover
- Wireless LAN link off message

The handover algorithm is based on two thresholds. The first one, $3G \rightarrow WLAN$ threshold, defines the minimum wireless LAN signal level that must be received in the Mobile Node to trigger a handover from the 3G to the wireless LAN. The second one, $WLAN \rightarrow 3G$ threshold, defines the wireless LAN signal level below which a handover to the 3G leg is triggered.
A handover to 3G can be triggered by two events, when the signal level goes below the $WLAN \rightarrow 3G$ threshold, or when a wireless Link Off message is received.
After the MICS (Media Independent Command Service) triggers a handover to the Mobile IP Layer, the handover algorithm is not allowed to perform another handover until the reception of a handover status message informing of the last handover result. If a handover is not successful, the algorithm performs a handover to the 3G part to fix the state of the algorithm. There are different causes for the failure of a handover. The BU may not reach the Home Agent or the BU reaches the Home Agent but the Binding Ack is lost.
Before performing a handover some conditions must be satisfied. The interface should be completely configured, with a global routable IPv6 address and default router (DAD procedure completed) associated. Also, all previous handovers should have been completed. If these conditions are not fulfilled the handover is delayed. In the case of handover to WLAN, if the conditions are not met, the handover is skipped until another signal sample arrives. In the case of handover to 3G, the handover is delayed by a timer, waiting for the conditions to be satisfied. The timer has been fixed to 100 ms (default period of the beaconing in WLAN).

5.2 Simulation Setup

In this section we describe the simulation setup of our experiments.The handover study is conducted by simulating a Mobile Node attached to the 3G network and performing several handovers between 3G and wireless LAN, varying terminal speeds and round trip time on the 3G leg.
The specific scenario analyzed is based on an indoor environment with a wireless LAN cell and full coverage of 3G technology. We argue that this represents a scenario that will be a typical deployment in the future. Notice that the paper does not cover the WLAN to WLAN handover case. The reader is referred to [64] for an extensive study of WLAN to WLAN handover which complements the work presented here. The work considers wide space with indoor characteristics (such as an airport) in which the user can move at different speeds.
The Mobile Node speed is varied between 2 m/s and 10 m/s. This value represents

an upper limit of the speed expected in the big size indoor scenario. Indeed, all pedestrian speeds are below this threshold.
The movement pattern selected is the Random WayPoint Model. With this model each node moves along a zigzag line from one waypoint to the next one, all the waypoints being uniformly distributed over the movement area.
The traffic studied is a downstream video, with a packet size of 160 bytes at application layer and interarrival packet time of 20 ms (83 kbps)[2]. 60 simulation runs were performed for each experiment. This number was chosen as a tradeoff between simulation time and confidence interval size.

5.2.1 WLAN Model

The standard wireless LAN propagation model defined in OMNeT++ is based on free space losses with shadowing and a variable exponential coefficient. The original model implemented in OMNeT++ is suitable for studies that do not analyse in depth the effect of the signal variation. However, the objective of this paper is to have a realistic wireless LAN model, suitable for indoor scenarios based on empirical results. For this purpose, we used the empirical model in [65], which includes variation in the signal due to shadowing and different absorption rates in the materials of the building. The path loss model is the following:

$$\begin{aligned} Losses &= 47.3 + 29.4 * log(d) + 2.4 * Y_s \\ &+ 6.1 * X_a * log(d) + 1.3 * Y_s * X_s \\ X_a &= normal(0,1) \\ Y_s &= normal(-1,1) \\ X_s &= normal(-1.5,1.5) \end{aligned} \tag{5.1}$$

Where d is the distance between the Access Point and the Mobile Node.
The power transmitted by the AP and Mobile Node are defined in the UMA specification [66]. According to this specification, the AP transmission power is 15dBm while the Mobile Node transmission power is 10 dBm. Following these specifications, the AP antenna gain is set to 0 dBi while the Mobile Node antenna gain is set to -10dBi. The transmission rate of the wireless LAN is fixed to 11 Mbps.
The OMNeT++ wireless model defines two thresholds, the Sensitivity threshold and the Active Scanning threshold. The Sensitivity threshold is the minimum level of signal that the receiver can detect. Real products specifications set this level of signal to -90 dBm[3]. This is the value that we have used in our simulations.

[2]Notice that usual VoIP codecs generate bit rates around 80 kbps and therefore their traffic pattern is very similar to the simulated one

[3]SMC Networks SMC2532W-B

The Active Scanning threshold defines the signal level at which the wireless card starts scanning for other APs in order to perform a WLAN to WLAN handover. When this level of signal is reached the Mobile Node detaches from the current AP. The IEEE 802.11b standard does not specify the value for this threshold, its value being design dependant. In the model presented, this value is set to -80 dBm. This value was selected after analyzing via simulations the maximum variability of the wireless LAN signal model. With this threshold, the Mobile Node will always handover to the 3G leg before reaching the sensitivity threshold.

5.2.2 3G channel Model

The 3G channel has been modelled as a PPP channel with a connection time of 3.5 seconds, disconnection time of 100 ms, bandwidth of 384 kbps(downlink) and variable delay of 100 to 150 ms per way.
The above PPP channel models the 3G channel when the PDP context is activated. These disconnection and connection times were obtained from measurements in different locations of an office building with a commercial UMTS data card. The round trip time is tuned to typical values of delay in this kind of channel under the same conditions. The connection time is measured as the time elapsed between bringing up the card and the moment when an IP address is assigned to the Mobile Node (activation of a PDP context).
Although the above model takes into account the connection time, in our simulations we have assumed that the PDP context is always active, so the value of the connection time does not have any impact. Indeed, our simulations are based on the following two assumptions i) full 3G coverage and ii) 3G link always on,which we argue that are realistic assumptions in typical scenarios.

5.3 Evaluation

In this section we present the handover performance study considering the following metrics:

- Wireless Utilization Time
- Number of Handovers
- Packet loss

In a first step, an analysis of the three metrics for different configurations of the thresholds is performed. Speed varies between 2m/s and 10m/s (Section 5.3.1). In a second step the study is extended by introducing the RTT in the 3G channel as additional variable (Section 5.3.2). The way which WLAN signal level is evaluated impacts the overall handover performance, for this reason, we have considered (and compared) several measurement techniques (Section 5.3.3).

5.3.1 *Effect of the speed in the thresholds configuration*

Figures 5.2 to 5.4 show how the algorithm behavior changes depending on the speed. Figures 5.2 and 5.3 respectively show the amount of time the Mobile Node is con-

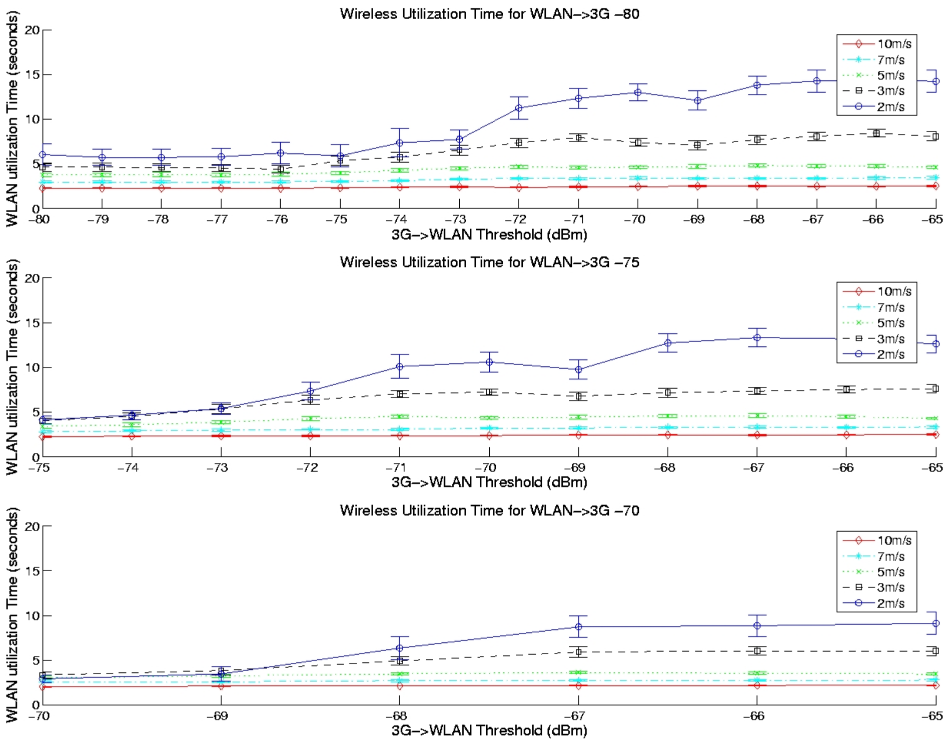


Figure 5.2. Wireless Utilization Time for several speeds (RTT 3G 300ms)

nected to the WLAN and the number of handovers performed by the Mobile Node. It can be observed that while the number of handovers decreases when more stringent thresholds are configured, the Wireless utilization time increases. This shows that the proposed algorithm (based on two thresholds), if properly configured, can optimize the wireless utilization time by reducing the number of useless handovers. Another interesting observation is that as the speed decreases, the difference in the wireless utilization time for different speed values increases.

Figure 5.4 shows the number of packet losses during the handover. All the curves of figure 5.4 show a common behavior. Note that losses can be either due to signal variation or due to handover failure. As the $WLAN \rightarrow 3G$ threshold increases,

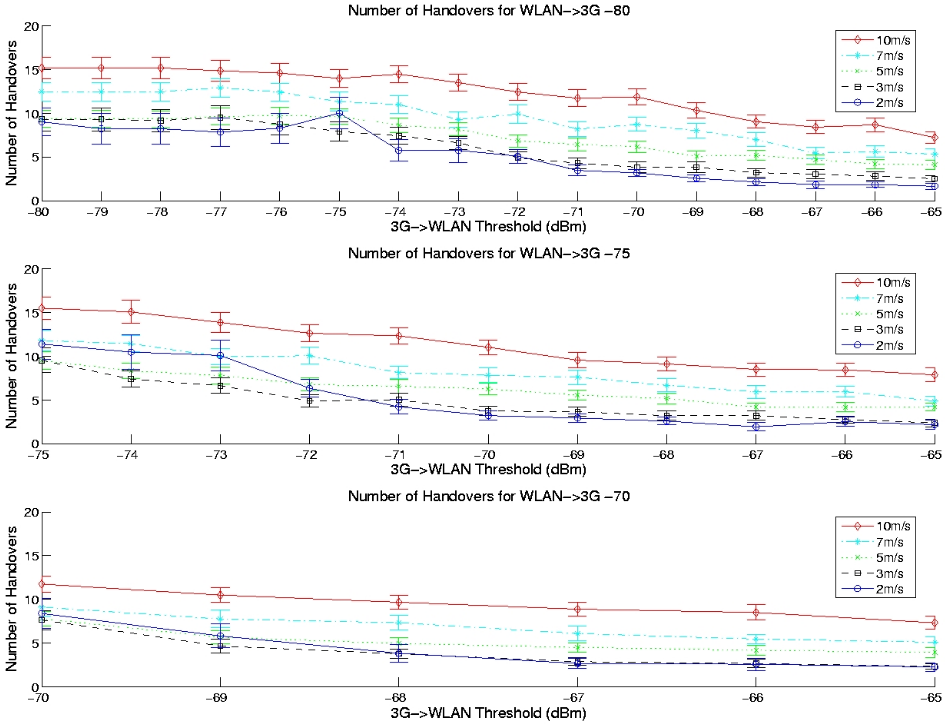


Figure 5.3. Number of Handovers for several speeds (RTT 3G 300ms)

losses (both due to signal varation and to a handover failure) are reduced. We define the threshold configuration for zero packet loss, as the configuration of both thresholds in the Mobile Node with which a seamless handover is possible. The threshold configuration for zero packet loss varies for the different speeds. For speed value of 2m/s a configuration of $WLAN \rightarrow 3G = -70dBm$ and $3G \rightarrow WLAN = -70dBm$ is enough to provide zero packet lost. However, for the same threshold configuration and speed about 10m/s, on average 20 packets are lost. These values give insightful information for optimal terminal configuration and handover performance.

5.3.2 *Effect of the 3G channel RTT in the threshold configuration*

To complete the study, an analysis on how the RTT of the 3G link affects the thresholds' configuration is provided. Figure 5.5 shows how the 3G channel RTT affects the Wireless utilization time, the number of handovers and the packet loss for a specific threshold configuration. Following typical values of RTT for an UMTS

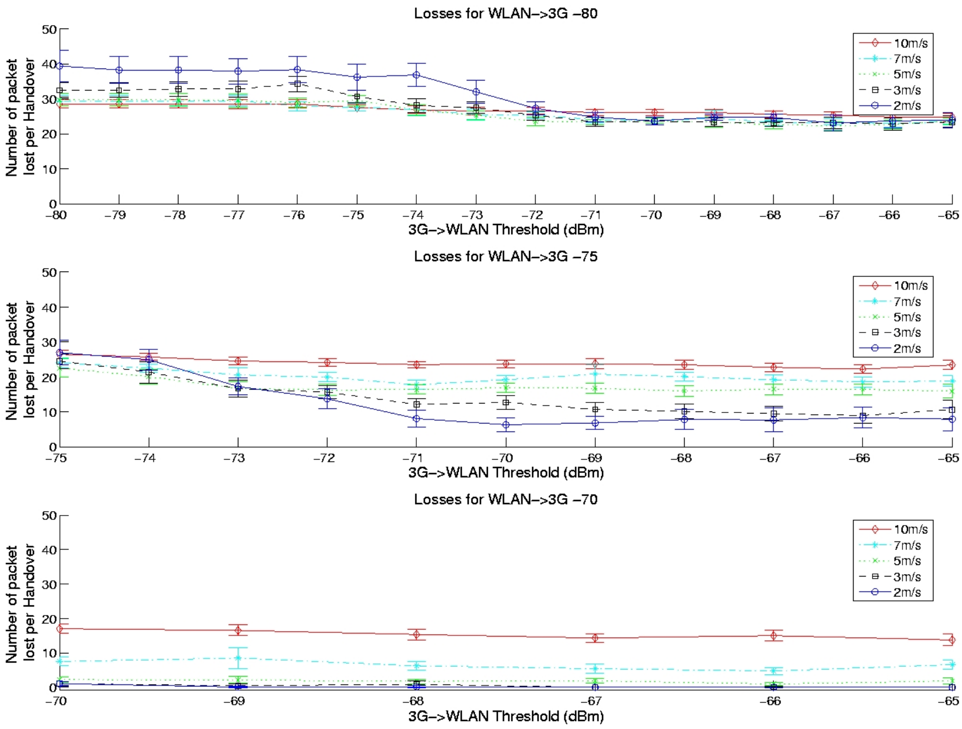


Figure 5.4. Number of Packet Lost for several speeds (RTT 3G 300ms)

channel, which range between 190ms and 220ms[4], we vary RTT between 200ms and 300ms (i.e. the values used in the study are a worse case estimation). Figure 5.5 shows that RTT affects neither the wireless utilization time nor the number of handovers performed. The major effect is in the number of packets lost. The reason is as follows. Since the RTT increases the time required to handoff to the 3G leg, the number of packets lost (due to WLAN signal level fading) increases accordingly. The effect is the same as if a less restrictive value for the $WLAN \rightarrow 3G$ threshold is used.

5.3.3 *Effect of the speed in the algorithm for measuring the signal level*

As our handover algorithm is based on signal power thresholds and the signal level can typically vary a lot in indoor environments, the information reaching the MIH layer (e.g. RSSI each beacon interval) can be different in a relative short amount of time. Therefore, taking into account last samples, or a series of samples is not

[4]Values measured with a commercial data card.

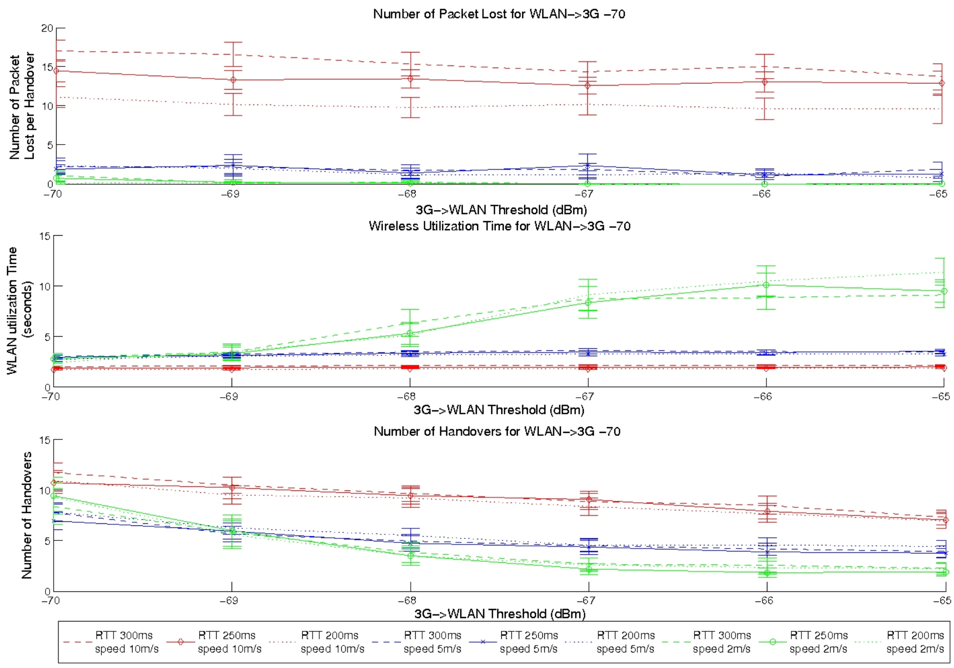


Figure 5.5. Wireless Utilization Time, Number of Handovers and Number of Packets Lost for several speeds and RTTs in the 3G Link

sufficient to derive the trend of the signal conditions. Thus, we propose several approaches to infer the real trend of the signal (based on beaconing interval) against different speed conditions. The different algorithms analyzed are:

- Single Sample (SS): The current value of the signal is the last beacon. $y[n] = x[n]$
- Weighted mean (WM): The current value of the signal is the value given by a weighted mean between the last beacon and the previous one. $y[n] = \alpha x[n-1] + \beta x[n]$
- Weighted mean with the previous mean (WMPM): The current value of the signal is the value given by the weighted mean between the last sample and the last mean. $y[n] = \alpha y[n-1] + \beta x[n]$
- Weighted mean of three samples (WM3S): The current value of the signal is the weighted mean between the last three samples.$y[n] = \alpha x[n-2] + \beta x[n-1] + \gamma x[n]$

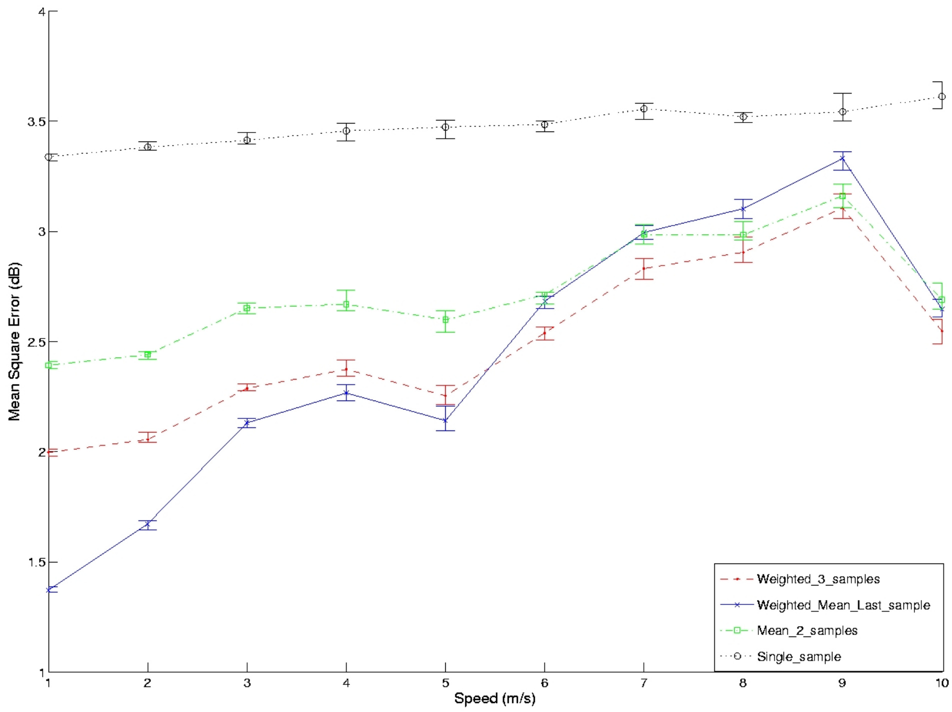


Figure 5.6. Mean Square Error of the signal behaviour prediction for different sampling algorithms

Speed	WMPM		WM3S		
	α	β	α	β	γ
1m/s	0.2	0.8			
2-3m/s	0.3	0.7			
4-5m/s	0.4	0.6			
6m/s			0.4	0.4	0.2
7-9m/s			0.5	0.3	0.2
10m/s			0.6	0.3	0.1

Table 5.1. Optimal parameters for the configuration of the *WMPM* and *WM3S* algorithms

Taking into account the four proposed algorithms, a simulation in Matlab has been performed. For each algorithm, the optimal parameters of the weighted mean have been computed (trying all the combinations) taking into account several speeds. Figure 5.6 shows the Mean Error square obtained while evaluating the signal level for [SS], [WM],[WMPM] and [WM3S] techniques. From the results, it can be seen

that for low speeds the algorithm *Weighted mean with the previous mean (WMPM)* outperforms the others, while for high speed the algorithm *Weighted mean of three samples (WM3S)* gives the best performance. Based on these results, we recommend a combined approach dependent on terminal speed. Table I presents the optimal configuration for the two recommended algorithms.
As an additional example, we could consider the case of a terminal moving at 2 m/s. The optimal sampling technique is the WMPM and the optimal threshold configuration values are -75 dBm for $WLAN \rightarrow 3G$ and -70 dBm for $3G \rightarrow WLAN$. These values (not affected by the RTT) optimize Wireless LAN utilization time while providing acceptable packet loss rate. In a similar way, results can be derived from the graphs for other speeds and RTT.

5.4 Conclusions

The work presented so far identifies the terminal design to efficiently support MIHO in an heterogeneous environment. The simulative study proves that the IEEE 802.21 upcoming standard meets the requirements identified in 3.7 and outperforms standard IP based mobility as identified in 5.1.2. We argue this is a necessary step before illustrating, in the next chapter –the core of this work–, the solutions to support NIHO in an IP-based heterogeneous environment where the terminal architecture above presented is accordingly extended for MN-to-network protocol exchange.

Chapter 6

Toward IP Converged Heterogeneous Mobility: A Network Controlled Approach

We now present the core of the work focusing on network control for IP converged heterogeneous mobility. Starting from the terminal device explored in the previous chapter we now extend terminal and network components for the support of NIHO. Conceptually the design is derived from the consideration given in section 3.4.

6.1 Framework Design

As mentioned above, our framework exploits the R3 IP based interface in IEEE 802.21, between the MN and the PoS (central entity), integrating the control signalling with Mobile IP signalling for data plane update. For simplicity (and due to its current industry relevance) we will discuss our proposal only applied across WLAN and cellular technologies.
In our scenario, global coverage from cellular technologies is always available, and enhanced coverage is available in multiple WLAN hotspots, a common situation currently. The mobile typically performs a soft-handover (meaning that the new link is established before releasing the old one) between different interfaces, although our framework could be adapted to hard-handovers (in which the connection is set up through the new interface after closing the previous one in use). Two network operational modes are defined, namely (i) Mobile Initiated and Network Controlled and (ii) Mobile Assisted and Network Controlled/Initiated handovers.

6.1.1 Mobile Initiated and Network Controlled

This operational mode places the handover initiation decision in the Mobile Node (MN). When the MN reaches a WLAN cell and estimates there are favorable conditions, it will inform the network (PoS) of the new link detected, waiting for a confirmation from the network which allows or denies the execution of the handover procedure. The PoS assumes that resources at the target PoA are always available, not considering network load for the handover decision. The analysis of Mobile Initiated and Network Controlled handovers will then assess the impact of the proposed IEEE 802.21 signalling compared to old scenarios where pure host driven mobility, which do not have the overhead of decision making signalling, is used.

6.1.2 Mobile Assisted and Network Controlled/Initiated

This operational mode places the handover decision mechanism in the PoS. The MN assists the handover decision mechanism by providing measurements of the environment where it is currently situated. This operational mode has been studied following two trends. First we analyzed the impact of signalling on handover performance (as in the previous operational mode). In a second stage a load balancing mechanism has been developed and tested, exploiting mobile node interface diversity for network optimization. The load balancing mechanism is explained in detail together with the signalling flow. The analysis of network controlled and initiated handovers will then show how network decisions can favourably impact terminal mobility, and which associated functionalities are required for these operations.

6.1.3 Signalling flows

Figure 6.1 presents the exploited IEEE 802.21 signalling flow to perform a handover. This signalling is explored in both network modes, with small differences. The detailed list of parameters included in each message is presented in subsection 6.1.5.

3G⇒WLAN Handover

The signalling flow for the 3G⇒WLAN handover supposes a MN that is connected to 3G and is approaching a WLAN cell. As soon as an access point (AP) is detected as result of the Active Scanning procedure, the MIH Function at the MN receives a corresponding indication from the link layer and sends message (1) to the PoS, encoding the MAC address of the AP in a UDP packet. This message is followed by message (2), where information related to the change in signal strength is supplied to the PoS. The PoS is then able to verify information related to that target, such as the load value. Upon load evaluation (3) at the PoS, message (4) is received in the MN, which replies with message (5), informing if the handover is possible or not.

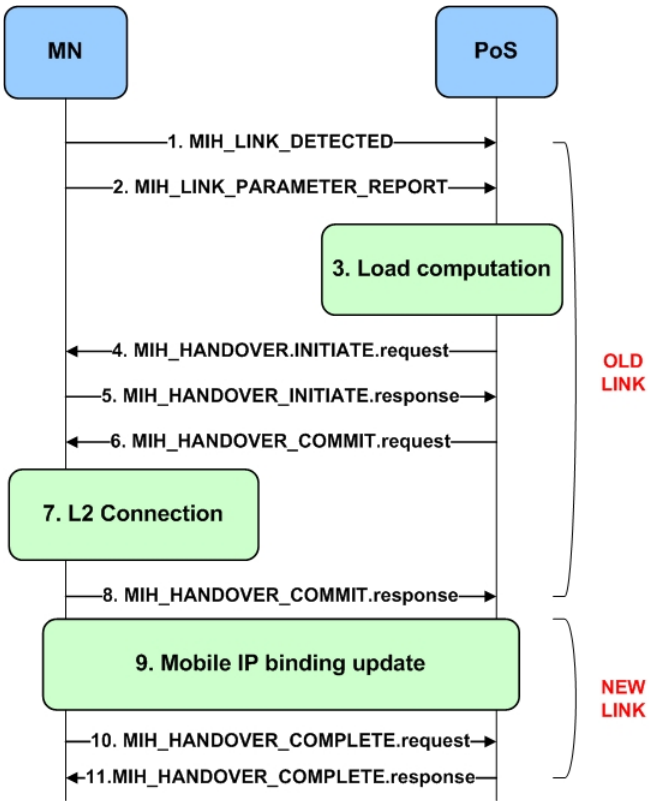


Figure 6.1. Handover Signaling for WLAN⇒3G and 3G⇒WLAN handovers

Note that e.g. the handover target in the handover request might not correspond to the one the MN is located at, in case of network handover initiation (e.g. because of terminal mobility). The PoS, upon reception of this message, sends message (6). The MN processes this datagram in the MIHF, sending a local link command to the wireless interface, in step (7). Upon successful L2 association[1], message (8) is sent to the PoS. If the signal strength conditions are still favorable, the MN can execute a L3 handover (9) (a MIP registration) through the new link. Upon successful MIP registration, message (10) is sent to the PoS, which replies with message (11). Finally the MN is able to receive L3 traffic as result of the MIP binding procedure. Note that the difference between a soft and hard handover is only related with the moment when data is not further received through the old link, and does not affect the signalling flow.

[1]Please note that in the simulator an active scanning procedure has been implemented to guarantee favorable radio conditions.

WLAN⇒3G Handover

This case supposes a MN associated to an AP, and the MIH Function continuously evaluating the signal level supplied by beacon messages. When the WLAN⇒3G threshold value is crossed, the MIH sends a Link_Parameters_Report (2) to the PoS, indicating deterioration of the received signal level. This will start a signalling exchange with the same messages and sequence as the 3G WLAN handover, except for (1) MIH_Link_Detected that is omitted, since the 3G leg is assumed always active (i.e. PDP context always active).

6.1.4 Load Balancing Mechanism

As stated before, a load mechanism has been implemented for the operational mode Mobile Assisted and Network Controlled/Initiated. The use of this mechanism entails several changes in behaviour and signalling, presented in the following paragraphs.
Upon receiving indication from the MN of favourable link conditions, the PoS takes into account the load value of the handover target. Message 2 sent by the MN might not produce a reaction from the PoS, due to the target PoA being at high capacity. Thus a timer (to retransmit the Link Parameter Reports) is specified in order to refresh the PoS that the necessary handover conditions are still valid. The time value chosen for the timer is related to the RTT of the link, as recommended in the 802.21 specification.
For the load balancing procedure, each AP has an associated load value. The MN is also accounted in this load, affecting the value of the AP identified in the Link ID parameter of the respective MIH messages. An additional feature introduced by load balancing capabilities is the ability of triggering handovers for a MN when the load reaches the maximum value in a specific region of the WLAN network. This possibility can emulate the scenario of preferring the 3G coverage to a WLAN hotspot with a large load. In the considered scenario, high load in the AP means that video feeds could reach the MN with increased delay, packet loss, etc. So, when the MN is in WLAN and the load at that PoA is greater or equal than the maximum allowed value, the PoS sends an unsolicited handover initiate message to the MN, forcing a WLAN⇒3G handover.
Note that the reverse case is the usual behaviour of the handover process described in section 6.1.3. Through the use of events received from the MN, the PoS is aware of the MN being inside a WLAN cell. Hence, when the PoS verifies that the MN is connected to the 3G leg and the load value of that AP presents itself good enough to admit a new entry (part of the operation in (3) 6.1), the PoS will initiate a 3G⇒WLAN handover, by sending message (4). Upon reception of this message, the MN will determine if the signal level is good enough for a handover.

In case a handover is both initiated by the MN and the PoS, to avoid concurrency problems, the event sent by the MN is ignored, and the handover initiated by the network continues normally.

6.1.5 Signalling Overhead

Given our reliance in the 802.21 signalling for the network operation, it is required to analyse the associated signalling overhead. IEEE 802.21 specifies a set of messages exchanged between the network and the terminal in order to perform a handover. The 802.21 frame is composed by header and payload. The header consists of two parts: a fixed header which carries information related to the type of message and entity which is addressed to, and a variable header which helps in parsing the content of the payload. The first part is always present in any 802.21 message and has a fixed length of 8 bytes, while the second part carries information such as Transaction ID, Session ID or synchronization information and has a variable length.
In our study we suppose that the variable header is always present in the messages (worst case assumption) and its size is 8 bytes. The 802.21 message is completely defined in the payload, which is situated after the variable header. Inside the payload block, TLV encoding is used and the size of the payload block could be variable depending on the message and the parameters used. For each parameter, 5 more bytes should be added in order to complete the TLV format. Alignment to 32 bits is achieved by means of padding.
Table 6.1 specifies the messages and all parameters used in this study, with the respective sizes of each parameter. Although there is not any transport protocol

MIHF Protocol Message	Parameter Name	Type	Size
MIH_LINK_DETECTED	Link ID	Network type	4
	MacNewPoA	MAC Address	6
MIH_LINK_PARAMETER_REPORT	LinkParameterType	Link Quality Parameter Type	1
MIH_HANDOVER_INITIATE.request	Handover Mode	Handover Mode	1
	SuggestedMacNewPoA ID	Mac Address	6
	CurrentLinkAction	Link Action	4
	SuggestedNewLink ID	Network Identifier	4
MIH_HANDOVER_INITIATE.response	Handover ACK	Handover Mode	1
	Preferred Link ID	Network Identifier	4
MIH_HANDOVER_COMMIT.request	NewLink ID	Network Identifier	4
	NewPoAMAC	Mac Address	6
	CurrentLinkAction	Link Action	4
MIH_HANDOVER_COMMIT.response	OldLinkAction	Link Action	4
MIH_HANDOVER_COMPLETE.request	Handover Status	Status	1
MIH_HANDOVER_COMPLETE.response	ResourceStatus	Resource Retention	1

Table 6.1. Messages and associated parameters (size in Bytes).

defined yet for 802.21 datagrams, there are proposals that use UDP [54] (general design considerations are given in [53] based on a common set or requirements [55]). In our framework all the signalling has been performed over UDP/IPv6. For each packet a calculation of the packet size has been performed in the following way:

$$Length{=}IPv6{+}UDP{+}FixedHeader{+}VariableHeader{+}TLV\ params \qquad (6.1)$$

The signalling messages per handover sum 672 bytes, which, in the case of 3G to WLAN, 528 bytes correspond to signalling deployed through the 3G and 144 bytes correspond to signalling through the WLAN. In the case WLAN to 3G the numbers are reversed.
To get an understanding of the cost in terms of signalling when using 802.21, several calculations of the bandwidth used for signalling have been performed, taking into account the handover probability of our model. Studies like [67], argue that the average number of users in a 3G cell varies up to 52 users. For different numbers of users, the bandwidth used for signaling can be calculated and is depicted in table 6.2.
In this table, it can be seen that the signalling load increases with the number of

	2m/s		5m/s		10m/s	
N° User	WLAN	3G	WLAN	3G	WLAN	3G
20	6.6±0.6	24.4±2.2	27.7±1	101±3	40.9±2	150±7.6
40	13.3±1.2	48.8±4.5	55.3±1.9	203±7	81.9±4.2	300±15

Table 6.2. Signalling Bandwidth cost in Bytes/sec in function of mobile node speed in m/sec

users and their speed of movement, but in all cases, signalling load remains very low. In the worst case (40 users and 10 m/s) the required signalling corresponds to 300 bytes/second in average, delivered through the 3G link; and 82 bytes/second, delivered through the WLAN. This result corresponds to handovers from 3G to WLAN. The inverse case (WLAN to 3G) has similarly corresponding values.
We argue that the signalling specified in IEEE 802.21 is loading the network very lightly and is enough to support a high number of users performing handovers between different technologies like WLAN and 3G. This supports our intention of exploiting 802.21 MIH functionalities to aid heterogeneity mobility.

6.2 Simulation Setup

In this section we present the simulation environment used to evaluate our framework, which also requires the detail of some of the entities involved in mobility management. Our study was conducted by simulating the movement of a MN attached to a 3G network and performing several handovers between 3G and WLAN hotspots, varying terminal speed and coverage threshold values.
The simulation scenario considers wide space with indoor characteristics (such as an airport) in which the user can move at different speeds and it closely follows the network scenario mentioned in section 6.1. It consists of an environment with a partial area of non-overlapping WLAN cells[2] and full coverage of 3G technology.

[2]The setup features four access points distributed in a square area of 500X500 meters.

The WLAN coverage is supplied by Access Points, each connected to an Access Router. The scenario also features a Home Agent for the MIP Registration process, an audio server which streams audio traffic to the MN[3], and the PoS which is the central network entity that exchanges MIH messages with the MN. This adds the network part of the IEEE 802.21, under standardization, to our model, thus creating a framework suited to model Network Initiated and Assisted handovers. Through the rest of this section several details of the model and the specification of the algorithm which conform the PoS and MN behavior, are provided.
This simulation scenario is similar to the one presented in [5] and [6] with the difference that in those contributions only Mobile Initiated Handovers, and without any network control, were considered. As a consequence there was neither the concept of central entity (the PoS) controlling mobility, nor IEEE 802.21 signalling over the air between the mobile node and the network.
The OMNeT++[4] simulator was selected as the primary tool for this study, with each simulation run for 60 random seeds. This number was chosen as a tradeoff between simulation time and confidence interval size.

Movement Pattern

The movement pattern selected is the Random Waypoint Mode. The MN moves between uniformly distributed waypoints, at speeds of 2m/s, 5m/s and 10m/s targeting to model speed scenarios that will be the usual worst case in WLAN environments, including the border between WLAN and 3G (the focus of our simulations). In section 6.4, the effect of higher speeds is also studied.

WLAN Model

The WLAN Model used is the one implemented in OMNeT++ based on free space losses with shadowing and a variable exponential coefficient. Each simulation was run with 3G⇒WLAN and WLAN⇒3G thresholds varying between -75dBm and -65dBm.

Load Factor

For the load balancing optimization, a birth-and-death Poisson process is used, caped at a maximum number of clients per AP. We have simulated different user inter-arrival rates varying network load from 50% up to 100% of the maximum system capacity.

The 3G Channel Model

[3] The traffic studied is a downstream audio, with a packet size of 160 bytes at application layer and interarrival packet time of 20 ms (83 kbps). Notice that usual VoIP codecs generate bit rates around 80 kbps and therefore their traffic pattern is very similar to the simulated one.

[4] http://www.omnet.org

The 3G channel has been modeled as a PPP channel with a connection time of 3.5 seconds, disconnection time of 100 ms, bandwidth of 384 kbps (downlink) and variable delay of 100 to 150 ms per way[5]. Although the above model takes into account the connection time, in our simulations we have assumed that the PDP context is always active, so the value of the connection time does not have any impact. Indeed, our simulations are based on the following two assumptions i) full 3G coverage and ii) 3G link always on,which we argue that are realistic assumptions in typical scenarios.

Metrics used in the study

The main focus of our simulation work in this paper is to verify that the introduction, in a threshold based handover algorithm, of the IEEE 802.21 signaling that enables network control, does not hinder the ability to achieve a good use of the wireless cells. For exploring this issue we used the following parameters:

- Mean percentage of L2 handover without MIP registration (failed handovers)
- Mean number of 3G⇒WLAN handovers
- Mean number of WLAN⇒3G handovers
- Mean wireless utilization time

Regarding the first metric, a failed handover is a situation in which the mobile node detects the WLAN cell and starts the signalling procedure in figure 6.1 but, after receiving message 6 the signal level never goes over the 3G⇒WLAN threshold, and the procedure is not completed, in particular a layer three registration to send the traffic to the WLAN interface does not take place. Notice that this situation does not imply any connectivity problem, as communication continues normally using the other interface. The second and third metric are related to the mean number of 3G⇒WLAN and WLAN⇒3G handovers, respectively. Lastly, we also account for the mean wireless utilization time.

Extended Terminal Architecture for NIHO support

The terminal's architecture includes a subset of the Media Independent Handover Protocol defined in [3]. In this paper we focus on the impact of the required signalling to perform handovers while mobile terminals move at different speeds, thus MIH capability discovery and remote registration are supposed to already have occurred.
The handover algorithm in [5] reacts to events resulting from the analysis of the

[5]Measurements have been taken with a commercial 3G data card.

signal strength in the WLAN interface. A MIH implemented in the MN supplies triggers to a local decision engine, based on 3G⇒WLAN and WLAN⇒3G thresholds, possibly resulting in a handover. In this paper we complement this algorithm with MIH signalling between the terminal and the PoS. Figure 6.2 depicts the mes-

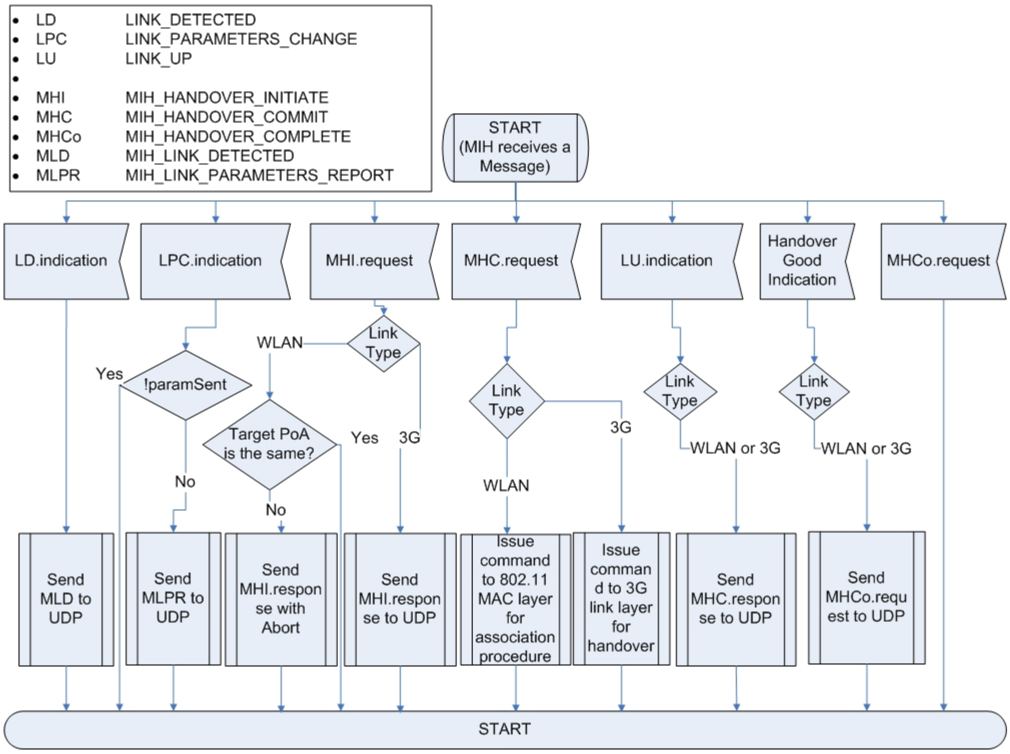


Figure 6.2. MIH Intelligence at the MN

sage exchange intelligence residing in the MIH layer at the MN. This message exchange allows the MN to supply fresh information about current link conditions to the PoS, as well as to receive remote commands for handover initiation. The message exchange is triggered upon signal level threshold crossing and generates local link events. These events are 1) LINK_DETECTED when the terminal detects a new WLAN cell, 2) LINK_PARAMETERS_CHANGE when the received signal level crosses a configured threshold, and 3) LINK_UP that indicates a successful L2 connection establishment. These events are collected in the MIHF of the MN and conveyed to the MIHF in the PoS.

The first two events supply to the PoS an indication that favorable handover conditions are available to the MN, and may result in signalling between the two entities for a handover initiation. When the necessary message for handover initiation is received from the PoS, the MN is able to perform the L2 handover. The terminal keeps analyzing the signal level and when a configured 3G⇒WLAN threshold is

crossed, a layer three handover can occur. In this phase, the MIP signalling takes place updating in the HA the new MN's CoA. Due to the configured 3G⇒WLAN threshold, and also to the movement of the node and the delay caused by the signalling, a layer two handover might not lead to a Mobile IP registration (this is one of the metrics of our simulation model, which is extensively studied in section 6.3). Since we analyse inter-technology make-before-break handovers, the MN will attempt to establish the new link before releasing the old one. When the MN is connected to the WLAN, and the MIH Function verifies that the received signal strength is not favorable anymore, a WLAN⇒3G is triggered. Thus, the MN starts the MIH signalling to the PoS, potentially initiating a handover to the 3G leg.
While evaluating the more suitable algorithm for the MN, we decided to perform the MIH signalling once the MN reaches the WLAN cell. Thus, when the signal level crosses the 3G⇒WLAN threshold, MIP signalling is sent to complete the layer 3 handover. The use of this model leads to higher MIH signalling load upon cell detection, but avoids possible delay for signalling completion between layer two link detection and the layer three handover processes.

PoS Design

The PoS is a network entity whose MIHF is registered to the MN's own MIHF, receiving subscribed events. Through the received messages, the PoS tracks down the terminal's position and the quality of its received signal strength. Then, the PoS can supply a remote command for handover initiation depending on the load value in that AP. The PoS intelligence depicted in figure 6.3. This is implemented as a network node with a full 802.21 MIHF stack, having the ability to send and receive MIH signalling encapsulated in UDP packets [19], and a decision engine for handover execution.
The PoS also has two operational modes depending on the active simulation scenario, where load processing can be active or not. In this last case it always supplies an affirmative handover command when called.

6.3 Results Evaluation

We first present the Mobile Initiated and Network Controlled scenario where no admission control mechanism is applied. Figure 6.4 depicts the percentage of failed handovers. Three speeds have been considered namely, 2, 5 and 10 m/s targeting indoor scenarios. From the graph we can see that by varying the threshold 3G⇒WLAN from -75 up to -65 dBm the percentage of failed handovers as defined above increases to almost 65% in case of 10 m/s. The curves follow a similar shape for 2 and 5 m/s. As can be noted, the curves show a trend to increase while the 3G⇒WLAN threshold value is increased.

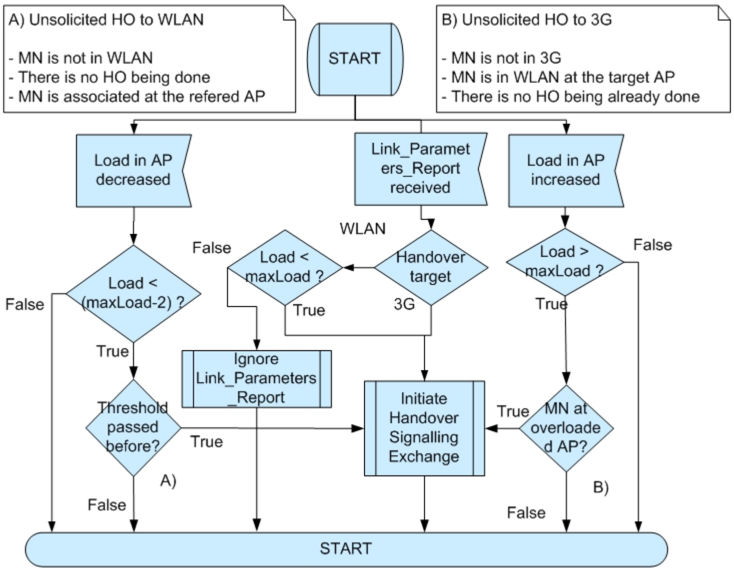


Figure 6.3. PoS Intelligence

When the mobile node detects the WLAN cell starts the signalling procedure of

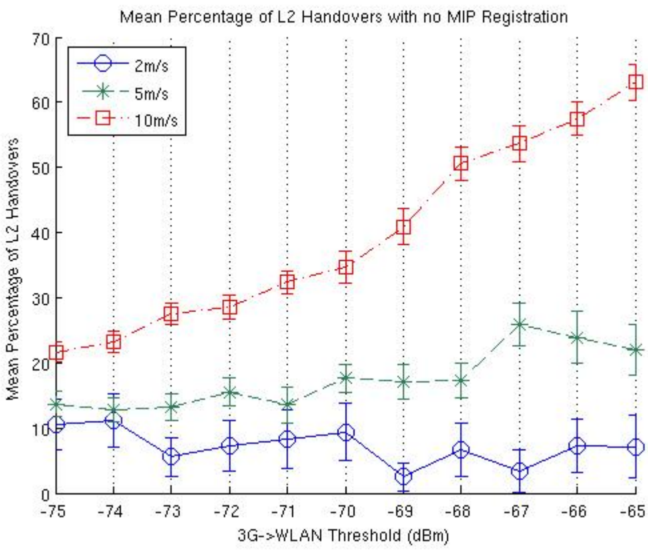


Figure 6.4. Mean percentage of layer two associations not followed by a layer three handover when WLAN⇒3G threshold configured at -75 dBm

figure 6.1. After receiving message 6, the mobile node checks the signal level received from the WLAN AP and waits for this level to be over the 3G⇒WLAN threshold for continuing with the signalling. If the signal level never reaches a value over the

3G⇒WLAN threshold, we have a failed handover. This can happen naturally because of the mobility pattern. The mobile approaches the WLAN cell, but because its movement direction, it never reaches the position in the cell where the signal level is above the threshold. Of course, as the 3G⇒WLAN threshold is higher, this happens more often, as can be observed in figure 6.4. Faster speeds also increase the number of failed handovers, because in more occasions the mobile is not enough time in the zone inside the threshold.
An important point for us is the impact of the delay introduced by our required signalling in this procedure. Without the signalling to enable network control (figure 6.1), the mobile node is ready to perform the handover immediately after detecting the WLAN cell. With the signalling, we introduce a delay (the time between message 2 in figure 6.1 and receiving message 6) in which, even if the signal level crosses the threshold, the mobile node cannot perform the handover because it has to wait to complete the signalling with the network. If the delay introduced by the signalling is larger than the time needed to cross the 3G⇒WLAN threshold, the handover is delayed or in the worst case could never happen. We explore this issue in table 6.3 in which the delay from sending message 2 to receiving message 6, and from sending message 2 to finishing step 7, is compared for different speeds and 3G⇒WLAN thresholds. The signalling delay is much lower than the time needed to cross the threshold and completing step 7, showing that the signalling does not interfere with the handover performance. So we argue that the mobile node to network communication is suitable both from a signalling overhead point of view (table 6.1) and from handover performance point of view (table 6.3).

Figure 6.5 depicts the mean number of layer three handovers obtained by varying

Speed \ Threshold	-75dBm	-72dBm	-69dBm	-66dBm	-65dBm
Time from sending message 2 to receiving message 6 (3G⇒WLAN)					
2m/s	0.43±0.0002	0.43±0.0002	0.43±0.0002	0.43±0.0005	0.43±0.0002
5m/s	$0.422\pm4.5\text{x}10^{-5}$	$0.422\pm4.8\text{x}10^{-5}$	$0.422\pm9.8\text{x}10^{-5}$	$0.422\pm5.5\text{x}10^{-5}$	$0.422\pm4.1\text{x}10^{-5}$
10m/s	$0.421\pm2.8\text{x}10^{-5}$	$0.421\pm2.8\text{x}10^{-5}$	$0.421\pm3.03\text{x}10^{-5}$	$0.421\pm3.4\text{x}10^{-5}$	$0.421\pm3.3\text{x}10^{-5}$
Time from sending message 2 to finishing step 7 3G⇒WLAN)					
2m/s	13.6±0.4	20.6±0.8	25.5±1.3	27.1±1.5	28.9±2.2
5m/s	4.4±0.07	6.1±0.1	7.6±0.2	8.5±0.2	9.0±0.3
10m/s	2.1±0.03	2.9±0.05	3.7±0.07	$4.1\pm0.1\text{x}10^{-5}$	4.3±0.08

Table 6.3. Time required in performing signaling depicted in figure 6.1 for selected 3G⇒WLAN thresholds.

the 3G⇒WLAN threshold. The impact of the speed affects the metric in different ways depending on the considered configuration. At the value -75 dBm the number of handovers is quite large especially considering high mobility level, while decreases and converges for greater values of the threshold. The decay in the slope of the different speeds is related with the failures of performing the layer three handover shown in figure 6.4. The graph shows how the values tend to converge, when the 3G⇒WLAN threshold is increased. The graph presenting the number of handovers from WLAN to 3G is symmetric due to the scenario symmetry. It is interesting to note that the closer the mobile node to the access point, the lower the chance of having complete handovers. This is complementary to the previous graph, as the metric is mostly affected by the mobility pattern and not from the signalling required for mobile to network comunication.

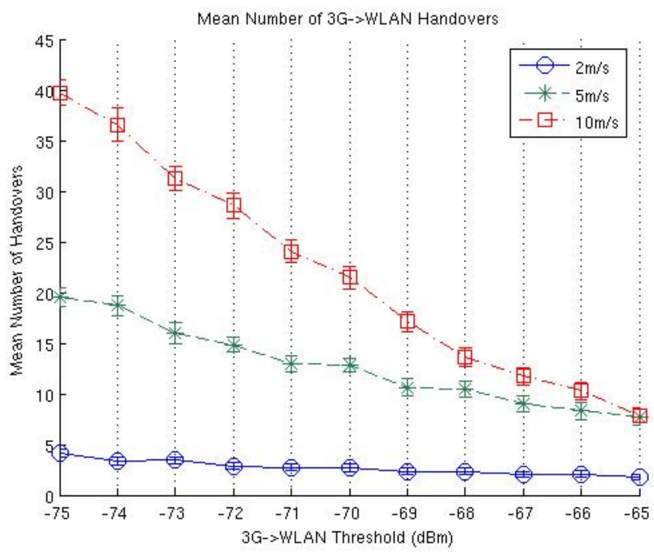


Figure 6.5. Mean number of 3G⇒WLAN handovers when the WLAN⇒3G threshold is configured at -75dBm

Figure 6.6 shows the mean wireless utilization time according to the three different speeds. The general observed behaviour is a flat response with the increase of the 3G⇒WLAN threshold. As the primary goal of this study is the maximization of the wireless utilization time, and thus to reduce the number of handovers which do not result in a long term stay inside the cell, figure 6.6 demonstrates that the signalling does not impact the mean wireless utilization metric. In fact, the relative magnitude between the different lines shows that the metric is mostly impacted by the time the user resides in the wireless cell, which result in a higher utilization time at lower terminal speed. This conclusion further supports the explanation of figure 6.4 where the mobility pattern represent the dominant effect on the system.
The results above presented demonstrated that if values in table 6.3 are verified the cost of mobile to network signalling for network controlled and initiated handovers is negligible. We argue this is an insightful result, especially considering environments (e.g. WLAN hotspots) where network controlled mobility is not yet considered as core technology to improve both user experience and network resource usage. We now further show the results obtained for the load balancing scenario defined in 6.1.4 taking as a reference figure 6.4, figure 6.5 and figure 6.6.

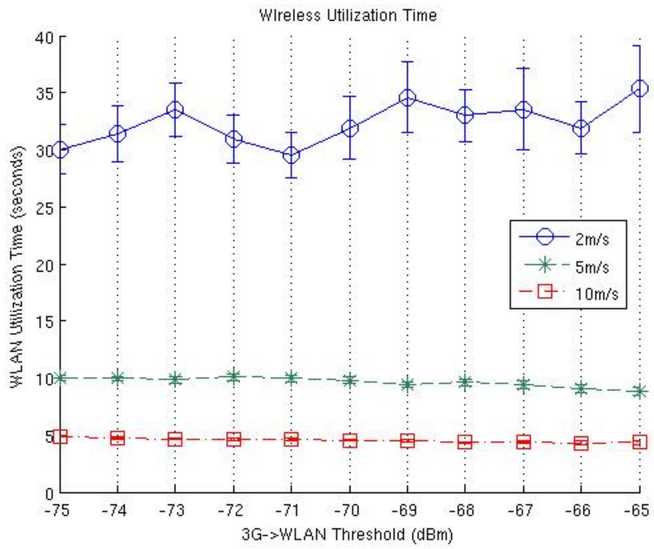


Figure 6.6. Mean wireless utilization time (units of time per handover)

Figure 6.7 represents the number of failed handovers as defined above, while load balancing is applied. The behavior is similar to the one in figure 6.4, since the

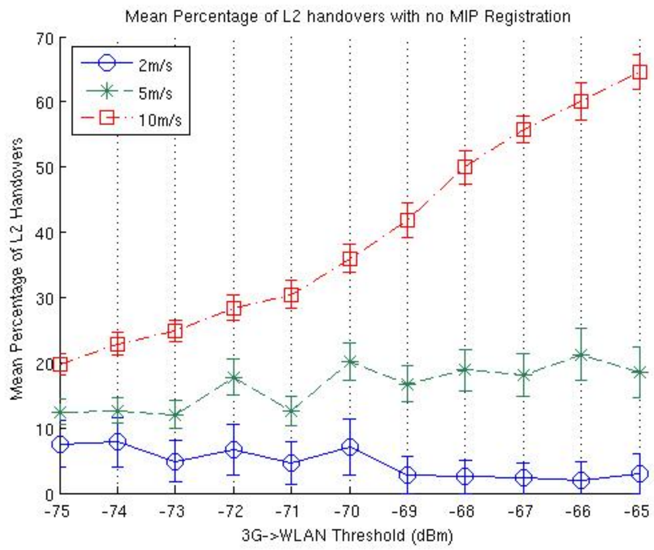


Figure 6.7. Mean percentage of layer two associations not followed by a layer three handover when WLAN⇒3G threshold is configured at -75 dBm. Load balancing scenario.

framework for network initiation accounts the terminal for the most up to date report information. The percentage of failed handovers due to wrong location report is around 3%, which seems an acceptable result. Figure 6.8 accounts for the number of

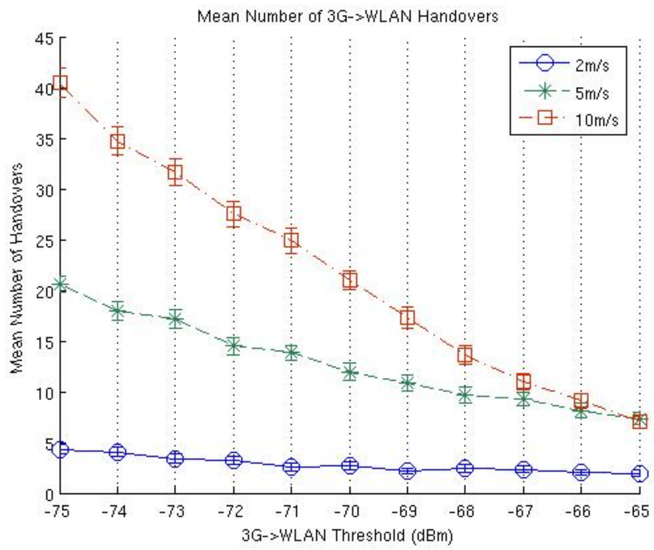


Figure 6.8. Mean number of 3G⇒WLAN handovers when the WLAN⇒3G threshold is configured at -75 dBm. Load balancing scenario.

handovers to the WLAN. The metric is directly impacted by the admission control mechanism and the load generated on the different access points, where a slightly smaller number of handovers can be verified between figure 6.8 and figure 6.5. It is worth noticing how the load balancing mechanism is not affecting as much lower speeds as 2m/s and 5 m/s as it is affecting 10 m/s. The values for these two lower speeds are not changing in a noticeable way between figure 6.8 and figure 6.5. We argue that the result (desired from the authors' perspective) proves the validity of the approach making load balancing scenarios attractive from an operator point of view.

Table 6.4 compares the wireless utilization time with and without load balancing, considering capacity usage of 50% and 100%. By comparing these results, we would expect that the wireless utilization time decreased, but as can be noted, the utilization time is not decreasing equally for all speeds, and the 10 m/s speed is the most affected one. This behaviour can be explained with the fact that the help of network initiated handovers reduces the overall number of performed handovers and at the same time increases the overall wireless utilization time. This is a desirable feature in next generation networks where minimizing the network overhead is a must, especially in last hop wireless channels.

Finally and for completeness, evaluation of RTT was considered, taking into consideration its effect on the 3G link. Simulations where RTT values varied between

200ms and 300ms showed only quantitative differences, maintaining the general behaviour of the previous graphs.

Speed (m/s)	No Load Balancing	Load Balancing 50% capacity	Load Balancing 100% capacity
2	32,4s	30,9s	25,9s
5	9,65s	9,46s	9,05s
10	4,53s	4,55s	4,45s

Table 6.4. Wireless usage with and without load balancing

6.4 Impact on 4G design

The results presented in the previous section validate the framework design showing the feasibility of a new approach for mobility and handover management. Specifically the IEEE 802.21 signalling, while introducing minimized network overhead, leads to optimal network control of terminal mobility. The comparison of simulation results with and without network load knowledge shows a negligible impact on the chosen metrics. However, when considering future 4G networks and wide scale deployments there are some further issues that should be accounted. That is, the configuration of optimal thresholds for WLAN⇒3G handovers is critical to avoid signalling packet loss and should be complemented with accurate methods for the out of cell detection. These issues are briefly described in the following.

6.4.1 Optimal configuration for WLAN⇒3G Handover

The case analyzed is the worst case condition when the terminal performs handover from the wireless LAN to the 3G leg. Since the 802.21 signalling is always performed through the current link there might be conditions in which the signalling could not be completed, and added mechanisms are required as fall back solutions. We present a detailed analysis of the problem deriving an optimal configuration to avoid such conditions. Although a transport protocol will introduce ACKs and retransmission of the lost packets, the effects shown in this section must be taken into account or the transport reliability will introduce undesired delays. Figure 6.9 shows the effect of the WLAN⇒3G threshold on the signalling between the MN and the PoS. The picture shows, for each simulated speed, the number of signalling failures to perform handover from the WLAN leg to the 3G leg fails. The results indicate that at high speeds (10m/s) we obtain a high mean number of interrupted/failed signalling flows with the PoS.

This number increases with decreasing the WLAN⇒3G threshold. This behaviour can be explained as the result of the MN going out of the cell before the signalling

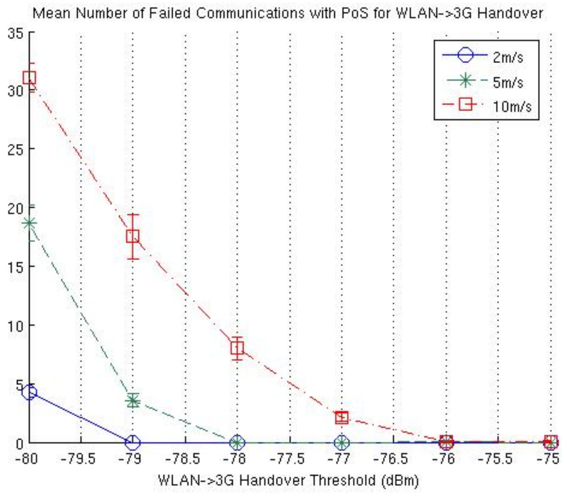


Figure 6.9. Effect of the -80 dBm threshold on handover signalling

flow ends. As the WLAN⇒3G threshold increases (in dBm) the signalling between the PoS and the MN starts before and the probability of going out of the cell decreases. Regarding the MIH functioning on interrupted signalling, this occurrence falls back on transport issues, which incorporate delay and loss of messages (as stated in [5]).
MIH Functions existing at the MN and PoS can optionally implement the optional Acknowledgement mechanism. In the case of interrupted signalling, this event would be dealt as if messages where lost. Also, the behaviour from the terminal in case a LINK_DOWN is received in the MIH is implementation dependent. For example, upon connection to a new available link, the MIH at the terminal can send a MIH message to the PoS requesting a handover rollback for freeing resources previously reserved for the handover that failed. This behaviour can free the resources faster than waiting, for example, for a timeout.

6.4.2 Out of cell mechanism detection

The load balancing mechanism studied previously is based on the assumption the PoS has available the current location of the terminal. We propose to exploit 802.21 capabilities to update the PoS with the information on the current location. The mechanism bases on the fact that the terminal via internal state machine can determine with the help of the MIH function whether he is approaching a WLAN cell or he is leaving a cell previously visited. Since the terminal can determine with acceptable accuracy the RSSI from the visited cell, we propose to convey this information to the PoS to enable better target choice while performing load balancing.

The rational behind is as follow. In order to successfully move terminals form one cell to another to optimize network load the network has to determine the current location of the terminal. Indeed, the selected cell should also be visible from the terminal point of view. Nevertheless the freshness of that information is crucial in the decision process although a trade off between freshness of the information and signalling overhead in the network must be considered.

6.4.3 Speedy handovers: an upper bound

The approach described in this paper is based on the assumption the IP layer is the common convergence layer across heterogeneous technologies. In case the signalling is applied to devices integrating broadband wireless access technologies such as WLAN and WiMax it would be desirable to identify what are the upper bounds in terms of stability and reliability not affecting performance of the handover procedures. To achieve this we analyze a specific scenario featuring one single WLAN cell that the mobile node crosses following a straight line. This movement pattern is similar to automotive/train scenarios where vehicles/trains can move only along predefined paths. The experiments have been performed for selected thresholds letting the mobile node moving with increasing speeds, up to 35 m/s. We argue this setup is sufficient to investigate how the threshold based algorithm and 802.21 signalling perform in such speedy scenarios.
The graph in figure 6.10 presents the result of the study. In this graph we represent the highest speed at which handovers finish successfully for different 3G⇒WLAN thresholds. As can bee seen, it shows that the performance of the system rapidly decreases crossing the -65 dBm threshold. This is the expected behavior, as the failures are function of the speed. It should also be noted that the study in figure 6.10 considers the results shown in figure 6.9 where the optimal threshold configuration guaranteeing no packet loss due to WLAN signal fading is configured at -75dBm. This study completes the results presented in the previous section giving insights on the applicability of the technology in speedy scenarios providing wireless broadband access.

6.5 Impact on terminal design

Figure 6.1 describes the signaling exchange between the network and the terminal, for our target case of 3G and WLAN technologies. In the following section, based on [8], we focus on the terminal design (including L2 functionalities) and its integration with the L3 signaling.

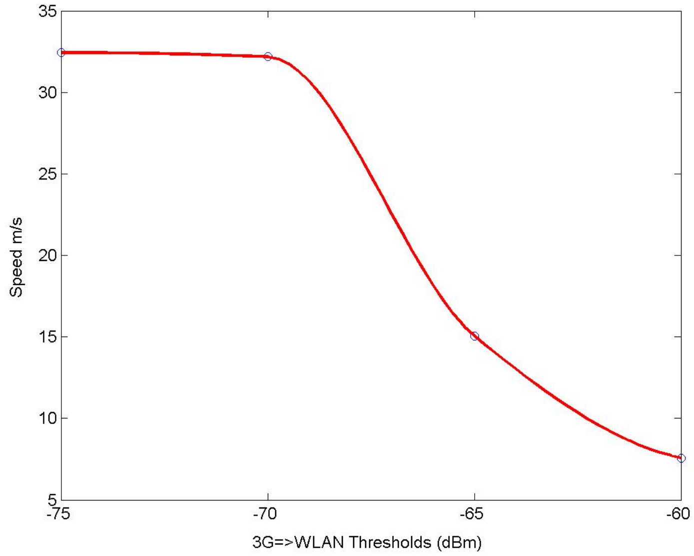


Figure 6.10. Interpolation of values showing system breakdown based on the speed.

6.5.1 Thresholds

The terminal's intelligence relies on several thresholds across the signal strength evaluation, as can be seen in figure 6.11. While connected to the 3G leg, the terminal is able to collect probe responses and beacons from the access points, evaluating the received signal strength indication (RSSI). Two thresholds are defined, namely the association threshold and the 3G⇒WLAN threshold. The first one refers to the mean signal strength required for the terminal's intelligence to decide to connect to an access point. The second one refers to the mean signal strength required for the terminal to decide that a successful 3G⇒WLAN handover is possible. Furthermore, when connected to the network through the WLAN leg, a WLAN⇒3G handover threshold is defined to determine when the signal strength conditions require a handover to the 3G leg. It is worth noting in figure 6.11 that the 3G⇒WLAN threshold is defined as being greater (in dBm) than the WLAN⇒3G threshold for zero-packet loss, as analyzed in the configuration of [5] and [6]. Also, the association threshold is defined as being lower (in dBm) than the WLAN⇒3G threshold.

6.5.2 Operational Modes

Depending on when (time-wise) the L3 signaling is triggered, two different operational modes have been implemented, hereinafter referred as Operational Mode A

(OM.A) and Operational Mode B (OM.B). These two modes execute the signaling model presented in section III, but differ in the timing of occurrence of certain messages, more specifically in the point at which the IEEE 802.21 remote signaling related to L2 connection execution is started. In OM.A the signaling to the PoS is triggered at the configured 3G⇒WLAN threshold, and in OM.B the signaling to the PoS is started at a fixed value of -80dBm, the association threshold. Both Operational Modes have been implemented to compare the effect of how the timing of the signaling messages affects handover procedures. Figure 2 visualizes the correlation between events (WLAN cell connection) and signaling triggers to the network. It is important to note the splitting of the signaling between cell detection, and associated RSSI report, and the signaling for effective L3 handover, including Mobile IP binding update. In fact, as can be seen later, one of the metrics evaluated for the performance study is the number of L2 connections not followed by a successful L3 handover.

In OM.A, after cell detection, the terminal only triggers IEEE 802.21 signaling

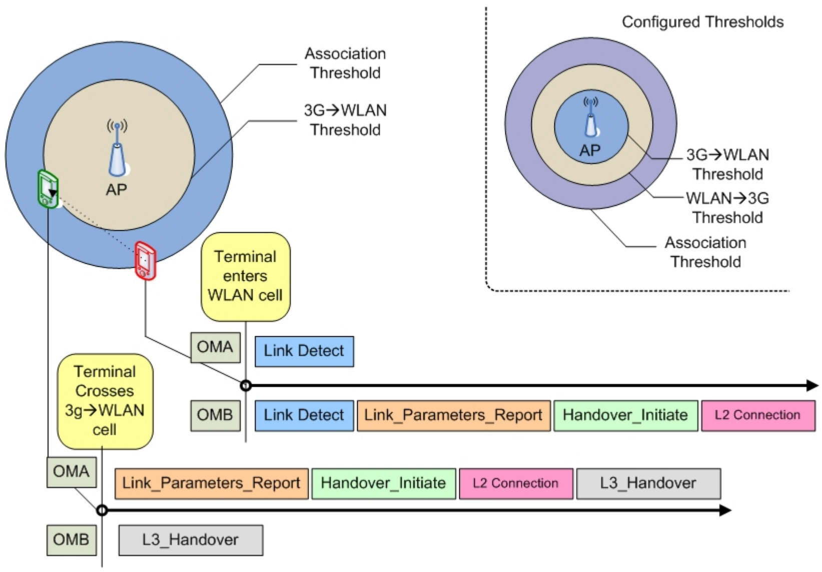


Figure 6.11. Different signalling stages for both operational modes

related to the L2 connection, i.e. message (2), at the 3G⇒WLAN threshold. So, in this mode, the terminal has to move within reach of a WLAN cell and the signal has to cross a certain configured threshold in order to execute a L2 connection, which is followed by the MIP binding update process. The nature of these operations ensures that good signal level conditions are met before the handover is executed, avoiding unnecessary handovers.

In OM.B the L2 connection related signaling is promptly sent when the association threshold is crossed, resulting in an earlier L2 connection. So, in this mode, when

the signal strength crosses the 3G'WLAN threshold, the L2 connection has already been executed and the MIP binding update process can start right away. Note that the traffic flows through the old leg until the L3 handover is completed.
For both modes, in order to maintain the handover's feasibility, upon receiving indication from the network to commit to the handover, the terminal's intelligence executes an active scan of the wireless environment. This procedure, executed in message (7) of figure 6.1, guarantees the signal strength hasn't deteriorated while waiting for the network handover command.

6.5.3 Simulation setup

The simulated scenario consists of an environment with a partial area of non-overlapping WLAN cells and full coverage of 3G technology. The WLAN coverage is supplied by Access Points, each connected to an Access Router. The scenario also features a Home Agent for the MIP binding update process, a video server which streams video traffic to the MN, and the PoS which is the network entity that exchanges MIH messages with the MN.
The OMNeT++ simulator has been used as the primary tool for this study, with each simulation run for 60 random seeds. The WLAN Model used is the default in OMNeT++, based on free space losses with shadowing and a variable exponential coefficient. Each simulation was run with 3G⇒WLAN and WLAN⇒3G thresholds varying between -75dBm and -65dBm. The 3G channel is modelled as a Point to Point Protocol (PPP) channel sharing the same characteristics and assuming that the PDP context is always active.
As the scope of our work is the analysis of the impact of signalling (the framework considers the upcoming IEEE 802.21) for network controlled mobility and its integration with L2 technology we propose the following metrics:

- Mean percentage of L2 connections without MIP registration.
- Mean number of 3G⇒WLAN handovers.
- Mean number of WLAN⇒3G handovers. Mean wireless utilization time.

The first metric indicates the percentage of handovers where a L2 connection was executed but the L3 handover was non-existing, due to signal deterioration or terminal's movement out of the wireless cell. The selected operational mode has a significant impact on this metric. The second and third metrics indicate the number of 3G⇒WLAN and WLAN⇒3G handovers per simulation run. Due scenario design the two metrics are symmetric (i.e. a 3G⇒WLAN handover is always followed by a WLAN⇒3G handover). The last metric refers to the time the terminal was connected to the WLAN leg, per handover. Packet loss is not considered, since zero-packet loss threshold configuration (taken from chapter 5) is always used.

6.5.4 Results evaluation

In this section we compare OM.A and OM.B against the above mentioned metrics. Figure 6.12 represents the percentage of L2 connections not followed by a L3 Mobile IP registration (thus failed handovers), for both operational modes. The 3G-⇒WLAN threshold variation from -75 up to -65 dBm shows us that, for 10m/s, the percentage of L2 associations not followed by a successful L3 handover increases up to almost 80% and 60%, for OM.A and OM.B respectively. The curves follow a similar increasing behavior for 2 and 5 m/s, although not so accentuated. As can be noted, the curves show a trend to increase while the 3G⇒WLAN threshold value is increased.

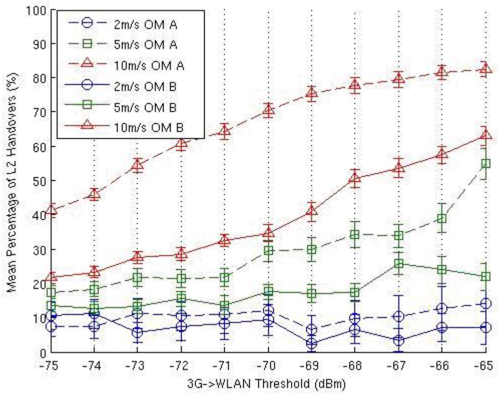


Figure 6.12. Mean percentage of L2 connections not followed by a L3 handover when WLAN⇒3G threshold is configured at -75 dBm

This is a direct consequence of the implemented signaling. As the 3G⇒WLAN threshold is increased (in dBm) the MN needs to be nearer to the AP to connect to the WLAN. Since the signaling handshakes that must occur are also impacted by the Round Trip Time (RTT) of the links, this interchange of information increases the probability of moving out of the cell prior to the reception of the MIH_Handover_-Commit.request command. Depending on the speed of the terminal, this behavior can be dominant, as in the 10 m/s case. The different results obtained for the two operational modes shows us that starting the 802.21 handover related signaling as soon as a WLAN cell is detected (i.e. OM.B) decreases the number of failed L3 handovers in 20%, for 10m/s. This decrease is also verified for the 2m/s and 5m/s speeds, although not as accentuated. This behavior is particularly evident at lower threshold configurations, where the percentage of failures is almost reduced by half. Figure 6.13 depicts the mean number of L3 handovers obtained by varying the 3G⇒WLAN threshold. The impact of the speed affects the metric in different ways depending on the considered configuration. At the value -75 dBm the number

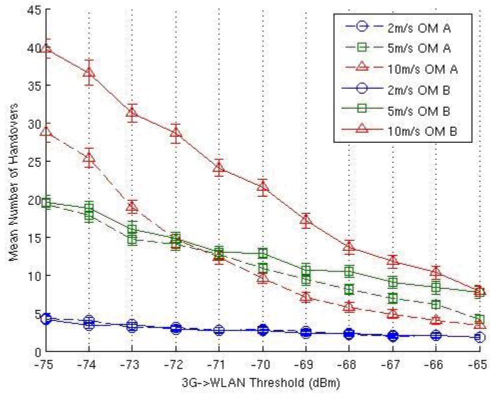


Figure 6.13. Mean number of 3G⇒WLAN handovers when the WLAN⇒3G threshold is configured at -75 dBm

of handovers is quite large especially considering high mobility level, while decreases and converges for greater values of the threshold. The decay in the slope of the different speeds is related with the failures of performing the L3 handover shown in the previous metric. The graph shows how the values tend to converge, when the 3G⇒WLAN threshold is increased.
It is interesting to note that the closer the mobile node to the access point, the lower the chance of having complete handovers. This is complementary to the previous graph in the sense that even starting the signaling at -80 dBm, thresholds close to the -65 value affect the feasibility of the handover procedure.
Comparing both operational modes, it is visible that the number of handovers in OM.B is greater than in OM.A, especially at higher speeds. It is also visible that at higher speeds the number of handovers decreases greatly, where the 10m/s curve becomes lower than the respective 5m/s curve, for OM.A. This shows how terminal speed impacts network response time making handovers not possible. In OM.B the 10m/s curve always resides above the 5m/s curve indicating that, by executing the signaling upon cell detection, there is a greater chance that the terminal is still inside the cell when the answer arrives from the network. Simulation results confirm therefore that, for a better and cleaner protocol design, splitting of the signaling for L2 and L3 events is required, where the L2 connection is performed at the association threshold and the L3 handover at the 3G⇒WLAN threshold. As a final remark on the tendency of the 5m/s slope and 10m/s slope we see how OM B outperforms OM A (when crossing the -72 dBm 3G⇒WLAN threshold) , reducing therefore the number of handover opportunities.
Table 6.5 shows the mean wireless utilization time for the different speeds, according to both operational modes. Variations on the 3G⇒WLAN threshold showed a flat behavior for all speeds, and the average value is represented here. As we can see,

although OM.B has a slightly higher wireless utilization time on all three speeds, the point of start for the IEEE 802.21 handover related signaling has no significant impact on this metric.

	Operational Mode	
Speed	OM.A	OM.B
2m/s	32.25s	32.35s
5m/s	9.11s	9.65s
10m/s	4.33s	4.53s

Table 6.5. Wireless utilization time per handover.

The fact that within the same speed, the results for both operational modes are of the same order of magnitude also confirms that, when the handover is executed, performance of the configured system is maintained.

6.5.5 Access Point transmission power impact

When considering threshold configuration and time sensitive operations, it would be desirable to implement a model able to adapt to different environments such as operator dependent network deployments (e.g. network planning). In this section we analyze the impact of transmission power on the threshold based model. A reference WLAN coverage area was chosen from the previous simulations, and new threshold values where calculated with new transmission values, maintaining the same WLAN coverage area for event triggering. Our goal is to verify the model adaptation to transmission power changes, and to analyze handover behavior differences while maintaining the same signaling triggering points. Transmission power values were taken from commercial products data sheets, complying with UMA [66] and [68]. From figures 6.14, 6.15, 6.16 we can derive that the previous metrics present similar values, within their respective confidence intervals, when comparing different transmission powers in the same model and at the same speed. Figure 5 shows how the first metric, incomplete handovers, maintains a relative linear behavior in which is visible the differentiation between OM.A and OM.B, particularly at higher speeds. The same linear behavior can be noticed in figure 6.15, for the number of handovers. Figure 6.16, for the wireless utilization time, shows us that there is no different behavior in handover related issues caused by transmission power or speed change. These results lead us to the conclusion that changing the APs transmission power, at the same time than the thresholds, and thus maintaining the wireless coverage area, produces no changes in the results obtained.
Having this data in consideration, we can argue that the only factor that contributes

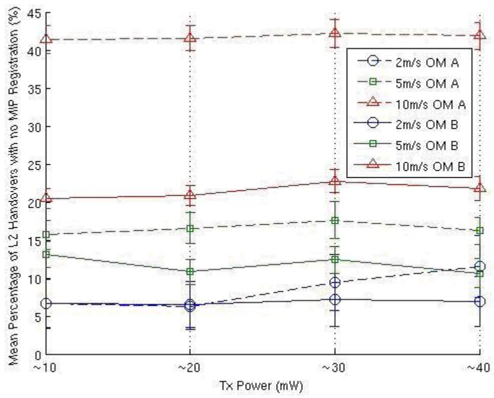


Figure 6.14. Mean percentage of L2 connections not followed by a L3 handover with different Tx and threshold values

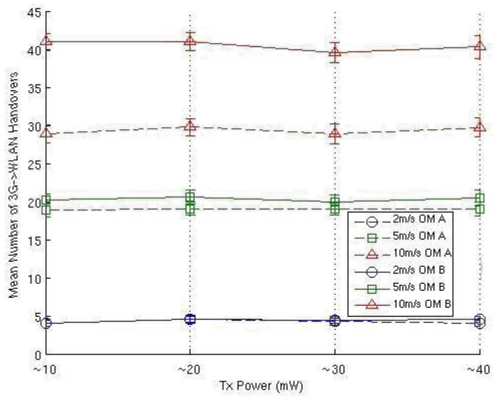


Figure 6.15. Mean number of 3G⇒WLAN handovers with different Tx and threshold values

for result differentiation is the amount of time the terminal logically resides in the WLAN cell, which is affected by threshold configuration. It is desirable that this configuration can be dynamically adapted in the MN, through information received from the AP concerning its transmission value: this may allow an operator to dynamically adjust the coverage area of WLAN hotspots according to the density of users, but still retaining a uniform behavior in terms of handovers. This will allow operators to better configure their networks and terminals to improve handover procedures.

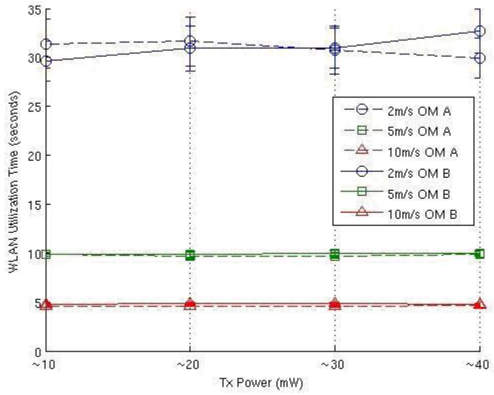


Figure 6.16. Wireless utilization time with different Tx and threshold values

6.6 Conclusions

This chapter presented the major contribution of this thesis showing that network driven mobility is achievable and that performance is acceptable even with real time applications such as Voice over IP applications. The simulative study, starting from the IEEE 802.21 standard, specifies the design for both mobile terminal side and network side where the intelligence for enhanced handover decision making is implemented. That is, while the terminal is able to trigger MIHO for poor radio conditions the network can perform admission control as well as load balancing by moving the mobile device from/to the WLAN/3G leg. The approach is an IP based approach here evaluated in an mixed 3G/WLAN scenario but, without loss of generality, also applicable to any other 802 family of technology such as WiMAX. We initially demonstrate the validity of the solution for indoor scenarios and further analyze how the system behaves in scenarios with high degree of mobility. That is, the simulation proves that the signaling supports mobile users up to 30m/s, targeting scenarios such as WiMAX mobile scenarios. We argue such considerations are relevant for the design of future 4G networks. In section 6.1.5 it is also demonstrated that the required bandwidth for handover signalling is at the most 300Bytes/sec when the MN moves at the speed of 10m/s. We argue this is a negligible amount of traffic worth to be supported for network controlled mobility.
Finally, in section 6.5 we show how the model designed is radio signal level agnostic and the handover performance is only impacted from the time the terminal resides in the wireless cell. In fact, by adapting the thresholds configuration to the transmission power of the access points the wireless utilization time is not affected.

Chapter 7

Conclusions

The thesis presented possibilities and challenges of IP-based heterogeneous network controlled handovers. Starting from mechanisms implemented in nowadays networks chapter 2 and from trends analyzed in beyond 3G networks (4G) chapter 3, we present a novel study for network driven handovers in a multi wireless access. In a first stage we show the benefit of applying network controlled handovers in scenarios where, traditionally, mobility decisions are host centric (e.g. in IETF). Results are presented in section 3.5.4 and conclusions in section 3.7 showing that the NIHO technology is not only suitable but also desirable in next generation 4G networks. A specific example is also illustrated in section 3.6. To author's best knowledge this is one of the first studies combining resource allocation schemes traditionally implemented in CS networks with the IP-based mobility management mechanisms. Upon investigation presented in 3.4 we select a centralized approach (in opposition to distributed approaches), choice essentially due to scalability and performance reasons. In fact a distributed approach in an environments accounting for millions of mobile subscribers would suffer of synchronization problems (events carried out to multiple decisions engines), especially in mobile operator wide networks.

We further proceed with the design of terminal and network components for NIHO support based on the IEEE 802.21 standard briefly summarized in chapter 4. The IEEE 802.21 has been selected for several reasons. First of all the upcoming standard is at an early stage of development, thus it is still open for contributions likely to be accepted, if provided with solid analysis and experimental results. Second, the scenarios and procedures the standard is considering nicely match the considerations on 4G networks presented at the beginning of this section. It should be noted that the design of an alternative protocol is possible. However, since we wanted to focus on the feasibility study of IP-based network control mobility for multi wireless access, we preferred to adopt undergoing standardization efforts and contribute to the working group proposing enhancements aiming at better performance as shown in [12].

Chapter 5 describes the terminal design showing the benefit of the 802.21 cross layer design evaluated via the simulation study. The setup considers 3G cellular coverage area complemented with isolated wireless LAN cells, a common scenario available in several environments such as airports, shopping malls, universities. The design is further extended in chapter 6 to support the NIHO technology and associated protocol operations. The algorithm of the mobile node is revised as in 6.2 and a new network entity is introduced for centralized support of the signalling depicted in figure 6.1. The simulation experiments show that the approach is feasible in IP based networks allowing optimal control of the network while requiring low bandwidth consumption for the signalling to convey to the central entity fresh information for handover decision making.
We argue this approach, similar in the concept to the mechanisms running in current 2G/3G networks but different in the realization primarily because of the wireless heterogeneous support, is an useful tool for next generation mobile operator networks requiring new methods for better support of mobile subscribers across heterogeneous networks. Some of the shortcomings in current solutions are analyzed in [1] where the authors highlight new possibilities for the optimal delivery of IP based services. The NIHO technology is considered as one of those solutions.
Currently, upon acceptance of [12] and [13], new work started on the analysis of network-to-network communication for mobility support and the impact of such requirement on the transport protocol. A design team has been recently formed in the IETF Mipshop WG aiming at specifying the new transport for Mobility Independent Services (NIHO is considered as one of such services). It is worth to mention that the the author of this work is part of the design team as a result of the thorough research work.

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Appendix A

Contributions to standards

A.1 IEEE 802.21

[12] extensively describes the contribution on centralized NIHO presented and accepted for inclusion in the draft [3] from the IEEE 802.21 WG. The proposed amendments were as follow:

1. In order to allow a central network entity to poll a PoA to inquire their available throughput we propose to modify the MIH_Get_Status command as follows: ***Define this command in page 45 not only as a Network ' Client primitive, but also as Network ' Network and Client ' Network, in order to allow communication between two network entities (namely, the centralized entity and a PoA in our scenario)***

2. In order to allow the central network entity to detect when a PoA becomes overloaded by setting thresholds that will trigger an event, we propose to modify the MIH_Configure command as follows: ***Define this command in page 45 as Network ' Network and Client ' Network in addition to Network ' Client***

3. Both primitives MIH_Get_Status and MIH_Configure make use of the Link_QoS_Parameter_List. This list (defined in Table 21 in page 108) contains the parameter 'Throughput' described as "the maximum information transfer rate achievable. This value is determined by the physical characteristics of the link . It is measured in kbps." The current definition of 'Throughput' seems to be defined without taking into account the already in use bandwidth by other users. Therefore, we would suggest to add another parameter called 'CoS Available Throughput' which refers to the maximum data throughput that a user can use, given the data throughput already used by other users and the data throughput the PoA reserves for other potential users, according to its

own policies. We also consider this available throughput needs to be specified for every class of service as PoA policies may be class of service dependent.

Figure A.1 summarizes the approach as follow:

1-6 The Mobility Management Entity (MME) is the centralized entity that controls and optimizes the connections of a region. This entity issues a MIH_Configure request to configure all the PoA with thresholds for the 'CoS Available Throughput' of their links and it also issues MIH_Configure requests to all interfaces of the mobile terminal to configure its QoS parameters thresholds (signal strength, error rate, etc). In messages 1 to 6 it configures the thresholds for load in PoA2. Based on this threshold, if PoA2 becomes overloaded it will send an event indicator to the MME.

7-12 In messages 7 to 12 the MME configures the thresholds for 'CoS Available Throughput' in PoA1.

13-24 In messages 13 to 24 the MME configures the QoS parameters thresholds in all interfaces of every mobile terminal. Based on this information, the MME is aware of all potential candidate PoAs for each mobile terminal. Note that this information is required in order to take appropriate handover decisions.

25-27 In messages 25 to 27 PoA1 becomes overloaded and based on the previous threshold configuration it notifies of this event to the MME.

28-33 In messages 28 to 33 the MME retrieves the information on the 'CoS Available Throughput' of the other PoAs for a certain Class of Service by using the MIH_Get_Status command . The 'CoS Available Throughput' indicates the maximum data throughput that a user can use, given the data throughput already used by other users and the data throughput the PoA reserves for other potential users, according to its own policies. With this information, the MME can ensure that a new terminal connecting to that PoA will have the available resources demanded by its Class of Service. Based on this information and the QoS information from the terminals, the MME has enough information in order to take optimal handover decisions to optimize the overall network performance of its region. The execution of the handover is therefore triggered by the MME. The execution part has been omitted here for convenience.

A.2 IETF Mipshop WG

As mentioned already in the various section of this thesis, the IEEE 802.21 WG is undergoing the standardization of the MIH protocol. MIH messages can be transported over layer two transport, for instance encapsulated in MAC frames in 802

technologies, or can be encapsulated in layer three packets and transported on top of the IP stack. The definition of such transport protocol has to be defined in the appropriate standardization body, namely IETF. For this purpose IEEE 802.21 WG and IETF Mipshop WG have in place a liaison to standardize the protocol IEEE 802.21 is currently demanding.
The results presented in this thesis have been input to both working groups resulting in accepted extension for the IEEE 802.21 WG and a new document on "Mobility Independent Services" in the IETF Mipshop WG. This document [13] (derived from [55]) has been adopted as working group document with the intention to become informational RFC. This problem statement document is also the basis for the development of the transport layer currently under specification in the working group.

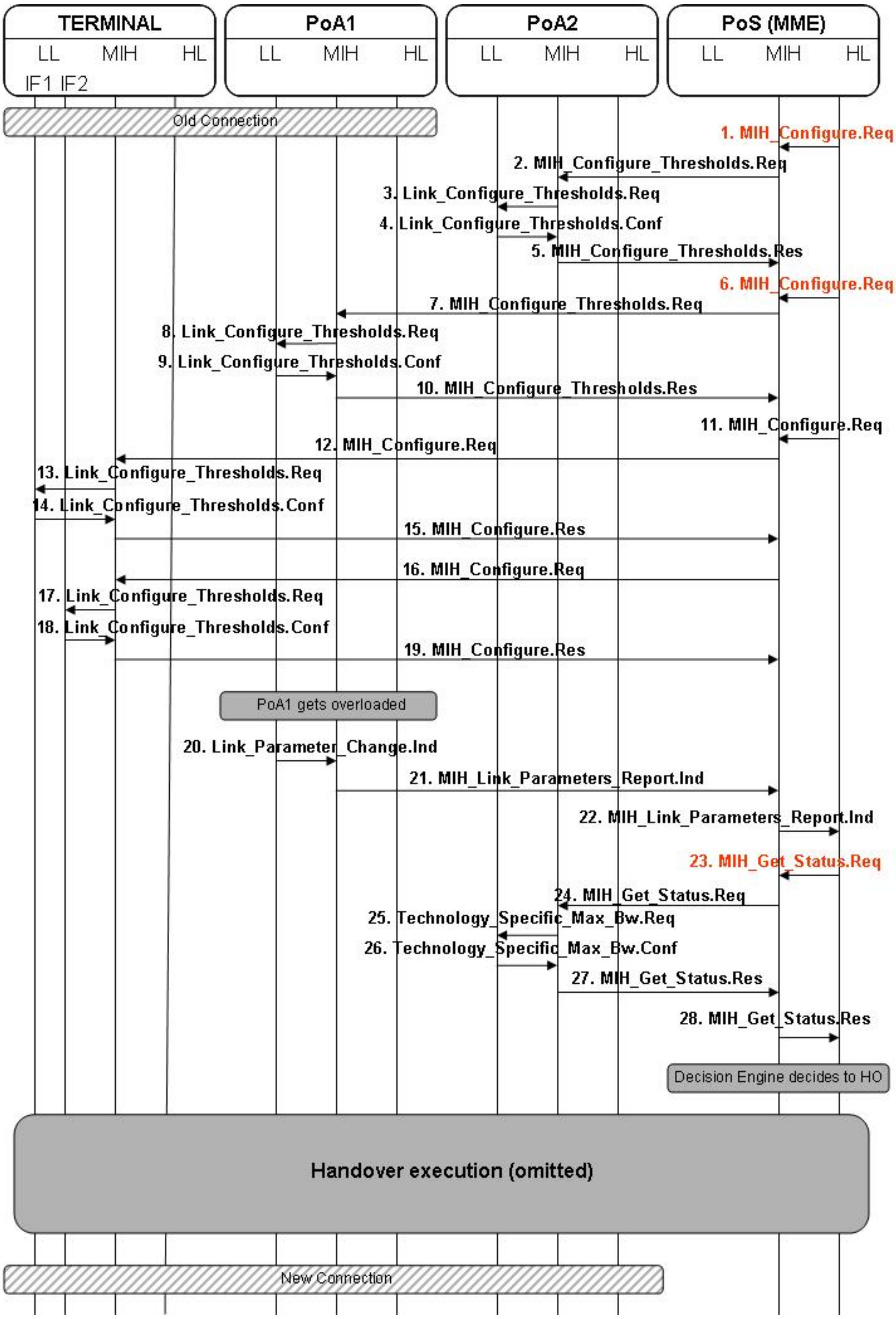

Figure A.1. Proposed signalling example

Appendix B

Implementation Experience

The focus of this section is on one of the functions implemented [10] in the Daidalos architecture - the Network Initiated Handover (NIHO) function and extensively explained in [4].

B.0.1 NIHO decision function

The NIHO operation is depicted in figure B.1 NIHO may be triggered either by the degradation of the quality of the signal received from the MT (Mobile Terminal) by the AP or when the load of an AP exceeds a predefined threshold. NIHO decisions are taken with the goal of optimizing global performance in a region. These decisions are taken by the PM (Performance Management) module in conjunction with the QoSB (QoS Broker) engine module. To this end, AP load data as well as data related to signal strength are sent to the PM module according to the process described in the following.

Signal strength measurements are taken by MM (Measurement Modules) at the

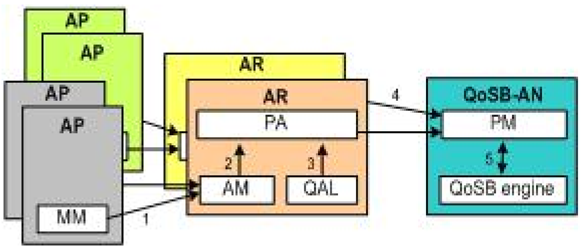

Figure B.1. NIHO decision function

APs and from there they are transferred to the AM (Aggregation Modules) at the ARs (message 1), which aggregate all the information received and provide it to the PA (Performance Attendant) (message 2). By measuring the strength of the signal

received from a given MT at all the APs of a region, it is possible to estimate all the candidate APs that provide good signal quality to this MT. In addition to signal strength data, the PA also collects load-related information from the QAL (QoS Abstraction Layer) modules (message 3). The data of all the PAs of a region is sent to their corresponding PM module (message 4).
With all the above information, the PM is aware (through the QoS related data) of the load of the various APs of the region, and is also aware (from the measurements taken) of the possible candidate APs that each MT may be handed over to while preserving a good signal quality. Based on these data, the PM can then decide the AP to which each MT should be attached to such that 1) load is optimally distributed among all the APs of a region, and 2) the signal strength of all connections is good. These decisions are checked against the QoSB engine in order to make sure that end-to-end QoS requirements are kept for the connections (message 5). At this point the handover execution process starts (see next section).

B.0.2 NIHO execution function

The handover execution procedure is time critical, since it needs to be performed without users' awareness. The sessions need to be transferred from the old to the new network without noticeable disruptions. Our procedure is an extension and enhancement of the Fast Handovers for MIPv6 [15]. It includes Duplication and Merging (D&M) to minimize the data packet losses and delays during handover, Context Transfer (CT) to transfer mobility and security information to the new network, and integration with QoS modules to assure that the QoS requested by the MT is preserved after the handover.

Figure B.2 presents an overview of the integrated FHO operation. The protocol operation involves the MT, the old and new ARs (oAR and nAR) and QoSB. When the PM initiates a NIHO, the QoSB informs both the nAR (message 1) of the QoS requirements and the oAR about the handover decision (message 2a and 2b).
After the oAR processes message 2, it triggers the CT, instructs the D&M to start duplication, and informs the MT that it SHOULD move to the network provided in the message ProxyRouterAdvertisement (messages 3a, 3b, 3c). When duplication is activated, the oAR forwards any data directed to the MT to the nAR for its delivery to the MT, in order to minimize data loss during the handover process. The context information to be transferred includes security related information; note that QoS-related context does not need to be transferred by CT since it was previously transferred directly through the QoSB.
As soon as the MT receives a ProxyRouterAdvertisement, it starts the merging process (messages 4a, 4b, 4c and 4d), whose function is to filter out the duplicated packets received from the oAR and the nAR and deliver only one copy of each packet

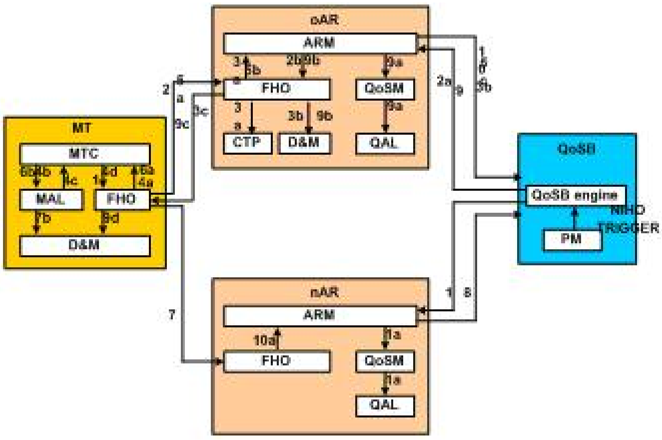

Figure B.2. FHO operation

to the applications. Then, the MT sends a FastBindingUpdate (FBU) message (message 5a) to the oAR, which informs the QoSB of the MT's decision (message 5b and 5c). This is followed by disconnection from the current link and attachment to the new one. Specifically, the FHO (Fast Handover) module in the MT notifies the MTC (Mobile Terminal Controller) of the decision to perform disconnection from the previous interface (message 6a), and the MTC notifies the MAL (Mobility Abstraction Layer) about the target AP the terminal should attach to (message 6b). Upon connection to the nAR interface [69] the MT sends a FastNeighbourAdvertisement (FNA) message (message 7). By means of this message, the IPv6 neighbor cache is updated and packets are forwarded to the terminal. The nAR informs the QoSB that the MT is attached on the new link (message 8), and therefore this indication is then forwarded to the oAR (message 9) in order to delete reservations (messages 9a), and stop D&M (messages 9b, 9c and 9d). If this message is not received at the oAR within a time period, the oAR will nevertheless terminate the D&M process and release the QoS reservation. After this process, the oAR informs the QoSB (message 10) that the reservation release actions have been successfully performed.

B.0.3 Demo Setup

The proposed demonstration is based on a prototype implemented on Linux 2.6.8.1 with MIPL basic Mobile IPv6 support for Wireless LAN technology [15]. In order to optimize the WLAN to WLAN handover latency we introduced modifications to the behaviour of the HostAP WLAN driver in the MTs and in the APs. A normal WLAN driver decides about handover and executes it only based on signal strength. The handover decision and execution can be done at firmware or driver level because all the information required is available in both places. In our architecture, the handover decision is influenced by other factors and therefore the decision cannot be taken at the firmware/driver level. Besides, in our architecture the decision must be separated from the execution. For this reason, the first modification we implemented was to disable automatic handovers and use a function to force handover execution when it is required. In NIHO [4] APs are required to measure the signal strengths of the MTs connected (using different channels) to other APs. In order to make these measurements, we have installed a second WLAN card at the APs whose function is to scan all channels periodically and perform passive measurements on the signal strength detected from the MTs. QoS functions, required for NIHOs, have been developed based on the algorithm of [70] for admission control in WLAN.

The demo setup is illustrated in figure B.3 and described in the following. Initially,

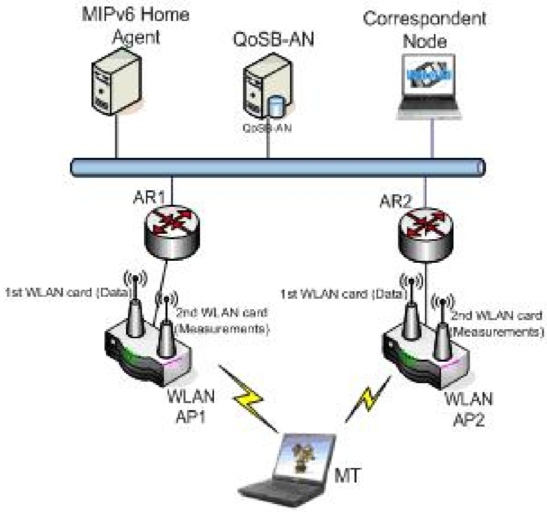

Figure B.3. Demo setup

the MT has requested 500 Kbps bandwidth and is connected to AR1. This bandwidth suffices for an audio application but not for a video one, as will be shown by running the respective applications. If the MT wants to run a good quality video it will have to request for more bandwidth (2 Mbps). The problem is that AR1 is already loaded with other terminals (not shown in the figure) and therefore when increasing the bandwidth of the MT, AR1 becomes heavily loaded. This is why, upon detecting AR1 high load after the MT's request, the QoSB decides to trigger a NIHO. The execution of the NIHO will be shown by some graphical application in addition to some real captures of the signaling messages. Once connected to AR2, which is not loaded by other terminals, the MT experiences a larger bandwidth and can run video and audio applications.

Appendix C

The SS7 Protocol

The SS7 protocol stack borrows partially from the OSI Model of a packetized digital protocol stack. The SS7 protocol has only four levels, matching the OSI layers 1 (physical), 2 (data link), and 3 (network), with level 4 corresponding to OSI layers 4 through 7. The levels are identified as Message Transfer Part (MTP) 1, MTP 2, and MTP 3 with Level 4 consisting of the Signaling Connection and Control Part (SCCP) and a number of different user parts, of which Telephone User Part (TUP), ISDN User Part (ISUP), Transaction Capabilities Application Part (TCAP) with Intelligent Network Application Part (INAP), and Mobile Application Part (MAP) are examples.
The MTP covers the transport protocols including network interface, information transfer, message handling and routing to the higher levels. SCCP is a sub-part of other L4 protocols, together with MTP 3 it can be called the Network Service Part (NSP), it provides end-to-end addressing and routing, connectionless messages (UDTs), and management services for the other L4 user parts. TUP is a link-by-link signaling system used to connect calls. ISUP is the key user part, providing a circuit-based protocol to establish, maintain, and end the connections for calls. TCAP is used to create database queries and invoke advanced network functionality, or links to intelligent networks (INAP), mobile services (MAP), etc.

SS7 provides a universal structure for telephony network signaling, messaging, interfacing, and network maintenance. It deals with establishment of a call, exchanging user information, call routing, different billing structures, and supports Intelligent network (IN) services. In order to move some non-time critical functionality out of the main signaling path, and for future flexibility, the concept of a separate "service plane" was introduced by the IN technology. The initial, and still the most important use of IN technology has been for number translation services, e.g. when translating toll free numbers to regular PSTN numbers. But much more complex services have since been built on IN, such as CLASS and prepaid telephone calls.

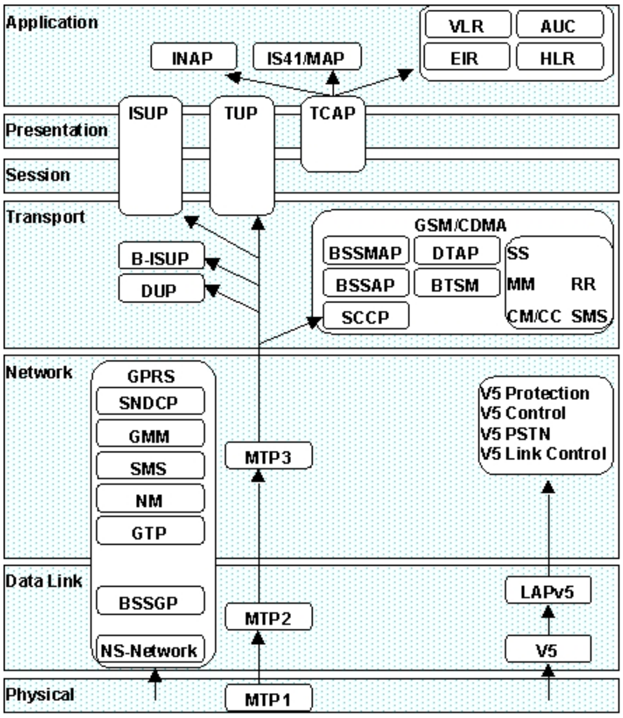

Figure C.1. SS7stack

SS7 is also important in linking VoIP traffic to the PSTN network. SS7 is also used in the mobile cellular telephony networks like GSM and UMTS for voice (Circuit Switched) and data (Packet Switched) applications.

Appendix D

3G Network Interfaces summary

D.1 Interfaces between Mobile Station and the Fixed Infrastructure

- Interface between Mobile Station and Base Station System (Uminterface) The interface between the MS and the BSS is specified in the 44- and 45-series of Technical Specifications.

- Interface between User Equipment and Radio Netwok System (Uuinterface) The interface between the UE and the RNS is specified in the 24- and 25-series of Technical Specifications.

D.2 Interface between the Core Network and the Access Network – CS domain

- Interface between the MSC and Base Station System (Iu_CS interface) The interface between the MSC and its BSS is specified in the 25.41x-series of Technical Specifications. The BSS-MSC interface is used to carry information concerning:

  1. BSS management;
  2. call handling;
  3. mobility management;

D.3 Interface between the Core Network and the Access Network – PS domain

- Interface between SGSN and BSS (Gb-interface) The BSS-SGSN interface is used to carry information concerning packet data transmission and mobility management. The Gb interface is defined in TS 48.014 [71] and TS 48.016 [72].
- Interface between SGSN and BSS (Iu_PS-interface) The BSS-SGSN interface is used to carry information concerning packet data transmission and mobility management. The Iu_PS interface is defined in the 25.41x-series of 3GPP Technical Specifications.
- Interface between SGSN and RNS (Iu_PS-interface) The RNS-SGSN interface is used to carry information concerning packet data transmission and mobility management. The Iu_PS interface is defined in the 25.41x-series of Technical Specifications.

D.4 Interfaces internal to the access network

- Interface between RNC and Node B (Iub-interface) When the RNS consists of a Radio Network Controller (RNC) and one or more Node B, this interface is used between the RNC and Node B to support the services offered to the UMTS users and subscribers. The interface also allows control of the radio equipment and radio frequency allocation in the Node B. The interface is specified in the 28.5x-series of Technical Specifications.
- Interface between two RNCs (Iur-interface) This interface is defined in the 25.42x series of Technical Specifications.

D.5 Interfaces internal to the Core Network –PS domain

- Interface between SGSN and HLR (Gr-interface) This interface is used to exchange the data related to the location of the mobile station and to the management of the subscriber. The main service provided to the mobile subscriber is the capability to transfer packet data within the whole service area. The SGSN informs the HLR of the location of a mobile station managed by the latter. The HLR sends to the SGSN all the data needed to support the service to the mobile subscriber. Exchanges of data may occur when the mobile subscriber requires a particular service, when he wants to change some data attached to his subscription or when some parameters of the subscription are modified by administrative means. Signalling on this interface uses the Mobile Application Part (MAP), which in turn uses the services of Transaction Capabilities (TCAP) (see TS 29.002 [73]).

- Interface between SGSN and GGSN (Gn- and Gp-interface) These interfaces are used to support mobility between the SGSN and GGSN. The Gn interface is used when GGSN and SGSN are located inside one PLMN. The Gp-interface is used if GGSN and SGSN are located in different PLMNs. The Gn/Gp interface also includes a part which allows SGSNs to communicate subscriber and user data, when changing SGSN. Signalling on this interface uses the User Datagram Protocol, UDP/IP. The Gn/Gp interface is defined in TS 29.060 [74].

- Signalling Path between GGSN and HLR (Gc-interface) This optional signalling path may be used by the GGSN to retrieve information about the location and supported services for the mobile subscriber, to be able to activate a packet data network address. There are two alternative ways to implement this signalling path:

  1. if an SS7 interface is implemented in the GGSN, signalling between the GGSN and the HLR uses the Mobile Application Part (MAP), which in turn uses the services of Transaction Capabilities (TCAP) (see TS 29.002 [73]);
  2. if there is no SS7 interface in the GGSN, any GSN in the same PLMN and which has an SS7 interface installed can be used as a GTP to MAP protocol converter, thus forming a signalling path between the GGSN and the HLR.

- Interface between SGSN and EIR (Gf-interface) This interface is used between SGSN and EIR to exchange data, in order that the EIR can verify the status of the IMEI retrieved from the Mobile Station. Signalling on this interface uses the Mobile Application Part (MAP), which in turn uses the services of Transaction Capabilities (TCAP) (see TS 29.002 [73]).

D.6 Interfaces used by CS and PS domains

- Interface between MSC/VLR and SGSN (Gs-interface) The SGSN may send location information to the MSC/VLR via the optional Gs interface. The SGSN may receive paging requests from the MSC/VLR via the Gs interface.

The MSC/VLR may indicate to an SGSN, via the Gs interface, that an MS is engaged in a service handled by the MSC. Signalling on this interface uses connectionless SCCP (without TCAP). SCCP Global Title (GT) is used for addressing. The Gs-interface is defined in TS 29.016 [75].

- Interface between HLR and AuC (H-Interface) When an HLR receives a request for authentication and ciphering data for a Mobile Subscriber and it does not hold the requested data, the HLR requests the data from the AuC. The protocol used to transfer the data over this interface is not standardized.

- Interface between SGSN and SMS-GMSC/SMS-IWMSC (Gd-Interface) This interface is used to transfer short messages between SGSN and SMS-GMSC or SMS-IWMSC over GPRS. Signalling on this interface uses the Mobile Application Part (MAP) (see TS 29.002 [73]).

D.7 Reference Points for 3GPP/WLAN

- Reference point 3GPP AAA Server - HLR (D'/Gr' Reference Point) This is the reference point between the 3GPP AAA server and the HLR up to and including Rel-4 and the HSS in Rel-5. The functionality of this reference point is similar to that of the Wx reference point. For more information see TS 23.234 [76].

- Reference point WLAN access network - 3GPP AAA Proxy/Server (Wa Reference Point) This is the reference point between the WLAN access network and 3GPP AAA Proxy or Server. The AAA protocol on this reference point is used to transport authentication, authorization and charging data.

- Reference point 3GPP AAA Server-3GPP AAA Proxy (Wd Reference Point) This is the reference point between the 3GPP AAA Server and Proxy. the purpose of the protocols crossing this reference point is to transport authentication, authorization and related information. For more information see TS 23.234 [76].

- Reference point 3GPP AAA Server/Proxy-WAG (Wg Reference Point) This is the reference point between the 3GPP AAA server/proxy and WAG. It is used to provide information needed by the WAG to perform policy enforcement functions for authorised users and to transport per-tunnel based charging information from the WAG to the AAA Proxy in roaming scenarios.

- Reference point PDG - packet data networks (Wi Reference Point) This is the reference point between the PDG and a packet data network. It may be an operator external public or private packet data network or an intra operator packet data network, e.g. for provision of IMS services.

- Reference Point 3GPP AAA Server/Proxy - PDG (Wm Reference Point) This is the reference point between the 3GPP AAA server/proxy and PDG. The functionality of this reference point is to enable:
    1. The 3GPP AAA Server/Proxy to retrieve tunneling attributes and wireless LAN UE's IP configuration parameters from/via Packet Data Gateway
    2. Carrying messages for service authentication and authorization
    3. Carrying authentication data for the purpose of tunnel establishment, tunnel data authentication and encryption. For more information see TS 23.234 [76].
- Reference Point WAG - WLAN access network (Wn Reference Point) This is the reference point between the WAG and the WLAN access network. It is used to force traffic between a WLAN UE and PDG to go through the WAG.
- Reference Point WAG - PDG (Wp Reference Point) This is the reference point between WAG and PDG. It is used to transport the Wu reference point protocol data packets.
- Reference point WLAN UE - PDG (Wu Reference Point) This is the reference point between the 3GPP WLAN UE and PDG. The functionality of this reference point is to establish a tunnel between WLAN UE and PDG and to exchange data packets between WLAN UE and PDG.
- Reference point WLAN UE - WLAN access network (Ww Reference Point) This is the reference point between the 3GPP WLAN UE and WLAN access network. The functionality of this reference point is specified by IEEE and outside the scope of 3GPP.
- Reference point 3GPP AAA Server - HSS (Wx Reference Point) This is the reference point between the 3GPP AAA server and HSS. The functionality of this reference point is to enable:
    1. Retrieval of authentication vectors
    2. Retrieval of WLAN access-related subscriber information (profile)
    3. Registration of the 3GPP AAA Server of an authorised WLAN user in the HSS
    4. Indication of change of subscriber profile

5. Retrieval of online charging / offline charging function addresses from HSS.
6. Retrieval of service related information

For more information see TS 23.234 [76].

- Reference point 3GPP AAA Server - SLF (Dw reference point) This reference point is between the 3GPP AAA Server and the SLF. The prime purpose of the protocol(s) crossing this reference point is to enable the 3GPP AAA Server to find the address of the HSS which holds the subscriber data for a given user identity in a configuration with multiple separately addressable HSSs.

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Allokationen von Ressourcen, QoS Aspekte und das IP Multimedia Subsystem

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o Seit Januar 2006, die leitende Funktion bei dem Device Mobility Track (in etwa zehn Partner) bei dem Daidalos Projekt, 2nd Phase. Die Aufgabe besteht sowohl aus Management Aspekte als auch aus der Entwicklung von der Mobility Platform und ihre Relation mit QoS, Sicherheit und Broadcast Aspekte.
o März 2005, März 2006, Business Unit verwandtes Projekt in Zusammenarbeit mit NEC Japan.
o Januar 2004, Dezember 2005, Specifikation and Implementation der Daidalos (1st Phase) Mobility Platform. Demonstrationen fanden statt sowohl während das letzte Projektsprüfung als auch während der Infocom '06 Demo Session (Siehe bei den Publikationen).
o Juli 2002, Dezember 2003 Implementation und Auswertung der IPv6 Mobility Stack für das MobyDick Projekt. Ein Video der Mobility Demo ist hier verfügbar. Resultate sind hier verfügbar.

FÄHIGKEITEN

o Teamarbeit (genieße internationale Atmosphären und HEAD UP mit neuen Teammitgliedern)
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