Media Independent Handover Management in Heterogeneous Access Networks - An Empirical Evaluation

Tiago Cardoso*†, Pedro Neves*, Manuel Ricardo†, Susana Sargento‡

*Portugal Telecom Inovação
Rua Eng. José Ferreira Pinto Basto, 3810-193, Aveiro, Portugal
Email: {tiago-miguel-cardoso,pedro-m-neves}@ptinovacao.pt

†Faculdade de Engenharia da Universidade do Porto
Rua Dr. Roberto Frias, 378, 4200-465, Porto, Portugal
Email: mricardo@inescporto.pt

‡Instituto de Telecomunicações
Universidade de Aveiro, 3810-193 Aveiro, Portugal
Email: susana@ua.pt

***Abstract*—The growth of available broadband access technologies has brought an enormous challenge for operators wanting to ensure seamless mobility to its customers in heterogeneous environments. In this paper we present an enhanced Mobility Management entity focused on a real heterogeneous environments and based on IEEE802.21 standard. This entity is capable to perform terminal and handover management regardless the access technology used. This entity was deployed in a real heterogeneous environment with Wi-Fi, WiMAX and HSPA using an Android smartphone. In order to provide Layer 3 mobility support it was integrated with a modified version of MIPv6. The results show not only the impact of a centralized entity to manage vertical handovers, but also the performance of IEEE802.21 protocol in a real scenario with a real implementation.**

***Index Terms*—IEEE802.21 - Media Independent Handover Services, Vertical Mobility, Heterogeneous Networks, Mobility Management**

I. Introduction

THE constant evolution on the telecommunications sector particularly with the increasing development of wireless technologies has led to the diversification of access networks solutions. Nowadays technologies like Wi-Fi, WiMAX, UMTS and LTE are a set of heterogeneous networks that provide mobile broadband access to multiple devices, from smartphones to laptops or tablets. This diversification alongside with the appearance of multi-technology terminals and user ubiquitous access requirements, brought enormous challenges to mobility management in heterogeneous network environments. To address this issue the IEEE group has been working on a standard in order to optimize mobility procedures through different access technologies, the IEEE802.21 Media Independent Handover (MIH) Services. The goal of this standard is to support and improve handovers regardless the access technology used by defining an abstraction layer called Media Independent Handover Function (MIHF) between Layer 3 and Layer 2 and below (MAC and PHY). This paper focuses on the performance of this framework by presenting an Enhanced Mobility Manager (EMM) entity capable of performing terminal and handover management using this framework. The EMM was deployed and tested in a real heterogeneous network environment providing Wi-Fi, WiMAX and HSPA networks access with IPv6 and MIPv6 support. To evaluate a real usage scenario a Android mobile device was used. The results show that IEEE 802.21 framework meets the proposed objectives by enabling both seamless handover between different Radio Access Technologies and QoS provisioning.
This paper is organized as follows: Section II presents related work regarding the IEEE802.21 and mobility management developments, Section III briefly introduces the IEEE802.21 framework and its main goals. Section IV describes the proposed mobility management entity and how it can be integrated with the IEEE802.21 framework in order to control and execute handover procedures. Section V describes how the EMM was developed, how it works and presents the implemented testbed details. In Section VI the methodology used to perform the performance evaluation is presented and results are presented and discussed. Finally, Section VII presents the conclusions and future work possibilities.

II. Related Work

The need to provide a ubiquitous access for users has sparked interest in both academia and industry to develop solutions that ensure mobility in heterogeneous networks. The most relevant effort of these works is the development of IEEE802.21 [1] standard which is evaluated in [2] and is described how it can be used to provide seamless mobility. Regarding QoS provisioning in vertical mobility, [3] proposes an enhanced MIH framework and simulation results are presented in a heterogeneous environment with WiMAX and Wi-Fi networks. For a broader handover support in Wi-Fi, WiMAX and UMTS networks, [4] describes and evaluates a detailed seamless handover procedure using the IEEE802.21 standard and the NS-2 tool. This tool is also used in [5] to evaluate an approach based on IEEE 802.21 MIH and Mobile

IPv6 to optimize vertical handover management. In [6] a mechanism for seamless handover through L2 and IEEE802.21 based API is proposed where the decision making process is in the Terminal side. In [7] an enhanced UMTS/WLAN handover mechanism is proposed by modifying the IEEE802.21 standard and handover decision algorithms and some tests in NS2 are performed. In [8] the QualNet simulator is used to implement a proposed solution for mobility management in heterogeneous network based on MIH framework. A Mobility Management entity is proposed in [9] by presenting an optimized handoff decision procedure between WLAN and WiMAX networks using IEEE 802.21. Nevertheless, these last two works lack of performance results.

III. IEEE802.21 – MIH Services

The IEEE802.21 - Media Independent Handover Services standard specifies a set of services that provide a framework to optimize mobile devices handover procedure between different broadband access technologies like UMTS, HSPA, IEEE802.11 or IEEE802.16. Its main goal is to make the specificity of Radio Access Technologies (RATs) transparent for both users and applications every time a mobility situation occurs while providing several other features: Service Continuity, QoS Provisioning, Power Management and handover intelligence in the decision-making process. This is achieved by introducing an abstraction layer - Media Independent Handover Function (MIHF), also known as Layer 2.5, that provides abstracted services to upper layers in order to assist the dissemination of handover-related information between network entities involved in the handover procedure. This information is provided by three main services: Media Independent Event Services (MIES), Media Independent Command Services (MICS) and Media Independent Information Services (MIIS). The MIES purpose is to provide information to local and remote MIHU entities regarding Link Layer events like link state or transmission changes. The MICS provide control services for the upper layers (MIHU's) in order to manage lower layers parameters, configure MIH entities and can also be used to execute mobility-based decisions in order to initiate handover procedures in these entities. Finally, MIIS are pointed as one of the main advantages of this standard as it can provide the key information to assist handover preparation mechanisms which rely on intelligent decision algorithms to make the fast and best target network choice for both terminal and network interests. This information is provided by Information Elements (IE) and can provide specific information about available neighbor networks within a geographical area.

IV. Enhanced Mobility Manager

A mobility management entity should not only be able to control mobility procedures but also must be able to gather context information and use it in order to feed internal and external mechanisms such as: information databases, handover decision algorithms or resource management entities. The proposed mobility management entity, Enhanced Mobility Manager (EMM), gathers device-related information in the EMM network in order to perform a comprehensive mapping of existing devices and provide that information to other network entities (Terminal Management module). This information is used by an Handover Management module to make the most appropriate handover decisions. These decisions can be based on many factors such as network availability, user profiles, application requirements or available resources. Figure 1 shows the EMM high level architecture.

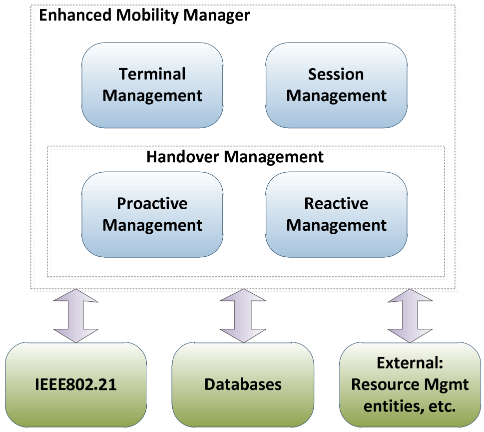

Figure 1. Enhanced Mobility Manager - Architecture.

A. *Terminal Management*

The Terminal Management allows the EMM to obtain an overview of what is happening on the network and to configure the terminal so that it can operate in accordance with the network settings. The purpose of this module is to gather information from terminals either by quering it directly or through events generated by their link layer. In Table I it is shown the type of information that can be obtained from a mobile device.

All this information gives the EMM the possibility of becoming an information provider or context provider for other entities, where the IEEE802.21 protocol can be one of the means used to feed the Terminal Management module. Through the MIH framework is possible to define a procedure for managing mobile devices through four steps:

- Terminal Discovery: Through the reception of MIH_Register the EMM can start the process of registering the terminal with the local database.
- Device information: Through the messages MIH_Capability_Discover, MIH_Get_Information and MIH_Link_Get_Parameters it is possible to gather much of the information referenced in Table I.
- Event subscription: subscribe for all events supported by each interface on terminals MIHF so EMM is alerted whenever one of these specific events occur.
- Terminal Configuration: in this phase the configuration of active network interfaces is done. Through MIH_Configure_Threshold primitve a threshold is defined and when it is exceeded the mobility process is

Table I
INFORMATION AVAILABLE IN MOBILE DEVICES.

	Static	**Dynamic**
Terminal	**Hardware** • Type: PC, Notebook or Smartphone • Brand/Model • CPU, Memory, Storage **Software** • Operative System • Software versions	**Hardware** • Current CPU, Memory, Storage or battery level • Sensors: Location(GPS), Temperature, Velocity, Movement, Luminosity **Software** • Running Services • Current QoS needs
Network	**General** • Routing tables **Interfaces** • Type: Ethernet / Wi-Fi / LTE / WiMAX / HSPA • MAC Address, Max Data Rate • Supported protocols: addressing, mobility, security • Settings: IP Address	**General** • TCP connections **Interfaces** • Status: Connected / Disconnected • Stats: Bandwidth, Packetloss, RSSI, SINR • NetworkID • Cells: Current / Neighbours

initiated. At this stage several configuration settings may also be made through MIH_Link_Actions.

B. Handover Management

The Handover Management module is responsible for controlling the handover process in a centralized network architecture, this means that the process is controlled by the network using a Network Controlled Handover (NCHO) approach. This module has two operation modes that implement the handover procedure based on four phases: Initiation, Preparation, Execution and Completion. The difference between these two modes reside on the way they operate in the Initiation Phase.

The Reactive Management has the ability to control handover procedures that are initiated by the terminal using a Mobile Initiated HandOver (MIHO). This process is initiated when the terminal is in the imminence of losing the connection, ie: when a configured threshold is exceeded and a MIH_Parameters_Report is received, or when a change in a network interface state occurs and MIH_Link_Going_Down is received.

The Proactive Management is responsible for continuously monitoring the mobile terminal obtaining detailed context information to detect in advance a mobility situation/opportunity. This is achieved using the primitives MIH_Link_Up, MIH_Link_Detected, MIH_Link_Get_Paramenters or MIH_Link_Actions(LINK_SCAN), this means that it is possible to initiate a handover procedure if a new connection with better conditions (Signal strength or QoS) is detected and proactively taking a decision improving the user experience and avoiding service degradation or interruption. These constant updates allows the EMM to keep its local databases updated making this information very useful and likely to be shared with other entities.

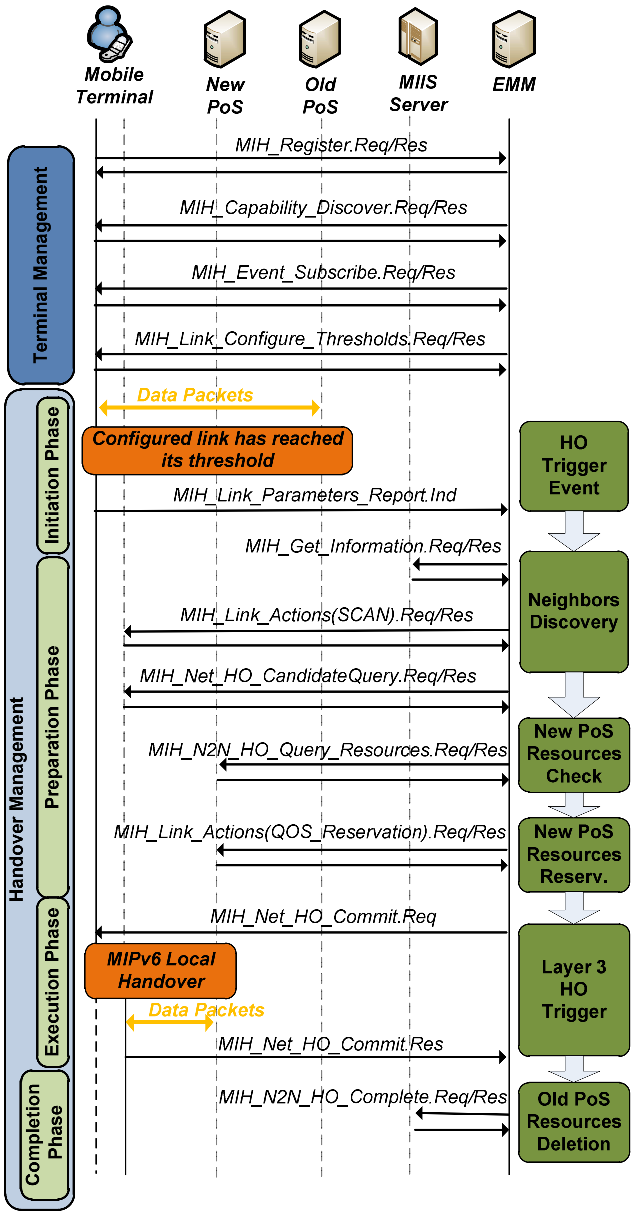

Figure 2. Enhanced Mobility Manager Work Flow. Reactive HO Management.

In the Preparation Phase a search for networks near the terminal is performed in order to gather the maximum candidate solutions to the user/terminal this is done by consulting the MIIS Server through MIH_Get_Information primitive. This list is then compared to the one obtained through a link scan made in the involved network interfaces by using the primitive MIH_Link_Actions(LINK_SCAN) in order to obtain a updated list of the candidate networks that really are in the vicinity of the mobile terminal since the static information of MIIS may be outdated. The final list of candidate networks is obtained by querying the terminal for its preferences using the MIH_MN_HO_Candidate_Query. This final list is used to query each candidate network to find which one has enough resources to receive the terminal, by using MIH_N2N_HO_Query_Resources messages. The first to verify that condition will be chosen to receive the mobile terminal. The resources reservation in the selected network is performed by using MIH_Link_Actions(QOS_Reservations) and if this process is successfully completed the EMM can initiate the Execution Phase. In the Execution Phase the EMM remotely triggers the handover at Layer 3 through MIH_NET_HO_Commit message. Once this process is completed successfully and the terminal is connected to the new network the EMM starts the last phase (Completion Phase) by releasing the network resources from the previous network using the MIH_N2N_HO_Complete primitive.

V. Implementation

The EMM was developed in C/C++ using MySQL to implement the databases. It is an entity that supports multiple users/terminals simultaneously in order to be easily integrated in an mobile operator environment with several terminals connected. Three modules: Session Management, Terminal Management and Reactive Handover Management were implemented. The Terminal Management and the Reactive Handover Management are two state machines that run independently: the first starts when new terminal arrives to the network and the second when a preconfigured terminal measures signal degradation (RSSI). To be able to operate regardless the network access technology used by the mobile terminal the EMM used a proprietary implementation of the IEEE802.21. The Figure 2 represents the different states of the two state machines during the Terminal Management and Reactive Handover Management procedures as specified in the previous section.

The EMM was deployed on a testbed that provides a real heterogeneous environment with three broadband access technologies: IEEE 802.11 (Wi-Fi), IEEE802.16 (WiMAX) and UMTS / HSPA. The WiMAX network was used as backhaul to testbed infrastructure allowing the use of resource reservation properties, this feature was implemented via SNMP commands. The 3G environment was a commercial and shared 3G network with IPv4 support only. The testbed has full support for MIPv6 by using a modified version of UMIP [10] which include: support to multiple active connections on the same terminal, allows outside parties to control handover and support to IPv6 over IPv4 tunnels. The terminal used was a HTC Nexus One with Android operating system running MIPv6 and the IEEE802.21. This particular device supports HSPA and Wi-Fi access technologies which allowed it to migrate between HSPA and Wi-Fi domains as shown in Figure 3. Since the testbed location was inside a limited access network (with firewall) a 3G bundle was used in order to provide full outside access.

VI. Results

In order to evaluate the EMM performance in a real world service scenarios four traffic types were tested: conversation (VoIP - UDP), network games (Quake3 - UDP), video streaming and large (UDP) file transfers (FTP - TCP). The traffic was generated by D-ITG tool from a PC outside of both domains in

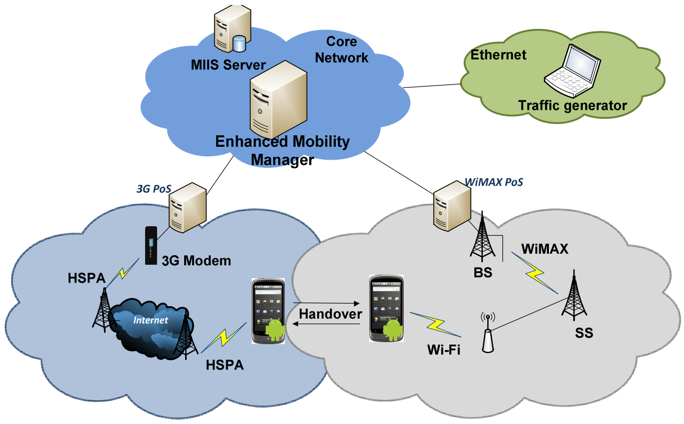

Figure 3. Testbed architecture.

order to easily test MIPv6 proper operation in heterogeneous scenarios. Twenty handovers were tested for each traffic type: 10 towards Wi-Fi → 3G and 10 towards 3G → Wi-Fi to make the sample more consistent.

The Terminal Management procedure lasted 500ms over Wi-Fi and 800ms over 3G networks. The average time is far superior on 3G network, this is due to a combination of several factors such as the conditions provided by the shared (commercial) 3G network which means that packets may have suffered a delay due to network equipment congestion situations. This result may also have been influenced by the quality of 3G signal received by the terminal and by the number of extra network equipments where packets passed through on the 3G network. The fact that there was a 6to4 tunnel adds some additional processing to the network equipment where each packet is transported. The signalling packets impact is mainly characterized by the transport protocol used by IEEE802.21 implementation which ran over TCP. As TCP is a reliable transport protocol it uses more packets than UDP. In this procedure an average of 9 TCP packets were exchanged in the network with a total size set of 1990 bytes, almost 2Kb.

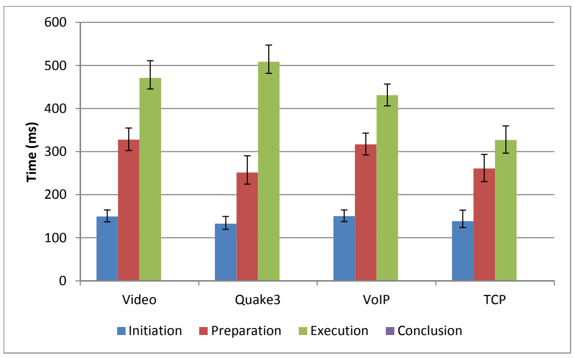

Figure 4. Handover Phases Delay, 3G → Wi-Fi.

The Handover Management is the main feature of EMM and therefore a more comprehensive analysis has to be made. The EMM performance results are presented in Figure 4 and Figure 5 with a confidence interval of 95%. Analysing these figures we can state that Initiation times are slightly

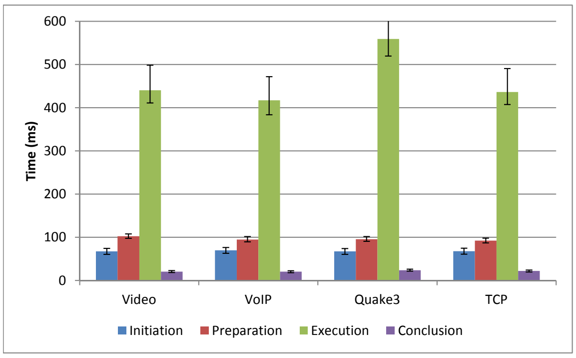

Figure 5. Handover Phases Delay, Wi-Fi → 3G.

higher in the handover from 3G to Wi-Fi as in this case the terminal was still reachable in the 3G interface and therefore all packets had the additional delay as explained before. In the Preparation Phase the difference is much higher due to the increased number of MIH messages exchanged and thus increasing the weight of the delay caused by the 3G network. This difference is not observed in the Execution Phase since only two messages are exchanged between the terminal and EMM where one is transmitted through the old network and the response is sent through the new network. As can be seen this is the most critical phase since it takes about 500ms. Note that this time is measured since the EMM remotely triggers the handover in the terminal until it sends the response after receiving the Binding Update from its HA which means that the handover was performed successfully. The results of Completion Phase are quite different because the resource deletion is only possible in the WiMAX network, in WiFi to 3G handovers, since we do not have such control over the commercial 3G network. Analysing the different traffic classes we can state that the EMM performance is not much affected by the traffic type. However in the Execution Phase we can see some discrepancies since traffic behaviour affects the MIP operation.

Table II
AVERAGE PACKETLOSS

	Video	Quake3	VoIP	FTP
Wi-Fi → 3G	0	0	0	0
3G → Wi-Fi	9	7.5	3.5	0

Analyzing Table II we state that the packet loss was minimal and the mobility procedure was very close to seamless handover this is due to the previous referred changes made in MIPv6. During the four handover phases an average of 21 TCP packets were transmitted making a total of 3568 bytes, about 3.5 Kb per handover.

VII. CONCLUSIONS

The diversification of access technologies solutions has brought many challenges to Service Providers especially in how to ensure mobility across heterogeneous environments and at the same time ensuring Quality of Service. In this paper we proposed and demonstrated an Enhanced Mobility Management (EMM) with support for heterogeneous environments using the IEEE802.21 framework. The EMM proved that this framework can be used to optimize the handover procedures by facilitating the exchange of messages between multi-technology devices and specific network entities. The different types of tests allowed to verify the operation of the EMM in different scenarios and especially to evaluate the impact of a mobility manager entity in a real heterogenous handover scenario. This work presents empirical results obtained by measuring the handover performance with a real device using this framework in a real testbed implementation. The testbed has also an important and innovative aspect with the use of an Android device, the use of MIPv6 protocol and integration with a WiMAX network providing QoS support. We stated that EMM operation is hardly affected by traffic type however the network conditions does affects its performance. The MIPv6 operation on the terminal side represents a major impact on the Execution Phase and depends on the traffic type that is used. For future work the improvement of the Information Server with dynamic information should be done, in order to boost the network performance in the handover Preparation Phase. New versions of Mobile IP, FMIPv6 or PMIPv6, should be tested to decrease the Execution Phase times and improve the user experience.

REFERENCES

[1] IEEE, *IEEE802.21 Media Independent Handover Services*, IEEE Std., 2009.

[2] G. Lampropoulos, A. K. Salkintzis, and N. Passas, “Media independent handover for seamless service provision in heterogeneous networks,” *IEEE Communications Magazine*, pp. 64–71, Jan 2008.

[3] P. Neves, F. Fontes, S. Sargento, M. Melo, and K. Pentikousis, “Enhanced media independent handover framework,” *69th IEEE Vehicular Technology Conference (VTC-Spring)*, April 2009.

[4] P. Neves, J. Soares, and S. Sargento, “Media independent handovers: Lan, man and wan scenarios,” *GLOBECOM Workshops, 2009 IEEE*, Nov 2009.

[5] S. Benoubira, M. Frikha, S. Tabbane, and K. Ayadi, “Vertical handover based on ieee802.21 and mobile ipv6 in umts/wlan networks,” *The First International Conference on Communications and Networking*, Nov 2009.

[6] J. Song, S. S. Lee, and Y. S. Kim, “Integrated mobility control mechanism in next generation network,” *Asia-Pacific Conference on Communications*, Oct 2007.

[7] H. Yu, Z. Gao, and L. Huang, “A cross-layer umts/wlan handover algorithm using optimized mih,” *3rd International Conference on Anti-counterfeiting, Security and Identification in Communication*, Aug 2009.

[8] Şerban Georgică Obreja, O. Fratu, and A. Vulpe, “A simulation testbed for a mih enabled system,” *8th International Conference on Communications*, June 2010.

[9] S. Mansor and T.-C. Wan, “Mobility management in heterogeneous wireless access network with ieee 802.21 services,” *Second International Conference on Computer and Network Technology*, April 2010.

[10] U. P. for IPv6 (USAGI) Project. Usagi-patched mobile ipv6 for linux (umip) 0.4. [Online]. Available: http://www.linux-ipv6.org/