Implementation Mobility in WiMAX Networks

Pedro Neves[1], Ricardo Matos, Susana Sargento

[1] Portugal Telecom Inovação

Abstract— The anticipated deployment of IEEE 802.16-based wireless metropolitan area networks (WMANs) will usher a new era in broadband wireless communications. The adoption of WiMAX technology for remote areas, for example, can address challenging scenarios in a cost-effective manner. While WiMAX Forum documents describe an architecture that inherently supports Quality of Service and mobility, several areas are left uncovered. We present an architecture which integrates WiMAX, Quality of Service and mobility management frameworks over heterogeneous networks, developing mechanisms for seamless handovers. Our approach takes into consideration the expected deployment of, on the one hand, the IEEE 802.21 (Media Independent Handover) proposed standard and, on the other, the IETF-standardized Next Steps in Signalling framework. The first contributions of this paper comprise a specification of the mechanisms for make-before-break vertical handovers taking Quality of Service signalling into account and integration in a heterogeneous environment. The latter contribution is an empirical evaluation of the proposed architecture using a testbed demonstrator. We quantify the processing delays of the main components in our prototype implementation when a terminal hands over between different access technologies, demonstrating the potential of our proposed architecture.

I. INTRODUCTION

Broadband wireless access (BWA) technologies are expected to play a central role in next generation networks (NGN) [1] [2]. WiMAX [3], based on the IEEE 802.16 family of standards [4] [5], is one such technology that can form the foundation upon which operators can deliver ubiquitous Internet access in the near future. Operators care about making the most out of existing and future infrastructure expenditures. Of central concern in the emerging telecommunications environment is delivering seamless mobility while taking advantage of the different access networks, some of them already deployed, other, such as WiMAX, soon to be available. There are several proposals for fast and seamless mobility management between different access networks. IEEE has been working on the 802.21 draft standard [6] which enables Media Independent Handovers (MIH). IEEE 802.21 defines an abstract framework which delivers link layer information to the higher layers, in an effort to optimize heterogeneous handovers. When IEEE 802.21 is deployed, mobility management processes will be harmonized, irrespective of the underlying technology, considering that proper communication and interfaces are presented to the link layers.

Although the work within IEEE 802.21 is already in an advanced stage, the framework needs to be integrated with specific technologies, since each one has its specific mobility control procedures. Moreover, seamless mobility requires the active support of QoS-related mechanisms in the handover process, guaranteeing that resources are reserved in the target access network before mobility management operations are completed. In other words, we cannot dissociate mobility management and QoS processes. We propose an architecture based on IEEE 802.21, which integrates the two mechanisms, and we empirically evaluate it using a real WiMAX testbed.

The aim of this paper is three-fold. First, we define a mobility architecture, based on IEEE 802.21, which supports seamless mobility in BWA networks, integrates different technologies, such as WiMAX and Wi-Fi [7], and is suitable for NGN environments. Second, we show how the proposed architecture supports mobility management and integrates QoS, specifying mechanisms to enable the complete combination of mobility and QoS, through Next Steps in Signaling (NSIS) protocols [8] [9] [10]. Finally, we present an empirical evaluation of the proposed architecture. Using a real demonstrator, we report processing time for each module involved in handovers where WiMAX backhauls data.

This paper is organized as follows. Section II presents related work on mobility, QoS architectures and experimental testbeds. Section III introduces our mobility-QoS integrated architecture, its elements and functionalities. Section IV briefly describes how this architecture was implemented and section V presents our testbed, the performed tests and the results obtained. Finally, section VI concludes the paper and lists items left for future study.

II. RELATED WORK & BACKGROUND

Up to now and to the best of our knowledge, there are very few implementations of the IEEE 802.21 framework in real testbed deployments. Nevertheless, the trends are changing and both manufacturers and standardization bodies are adopting uniform solutions to address inter-technology handovers. For example, Intel has recently demonstrated a seamless mobility solution between WiMAX and Wi-Fi using IEEE 802.21, as reported in [11], and both 3GPP and WiMAX Forum standardization bodies have also started to evaluate the impact of integrating IEEE 802.21 within their architectures.

One of the well-known IEEE 802.21 deployments has been made in the European funded DAIDALOS project [12], which is addressing seamless mobility in heterogeneous environments. In this case, the IEEE 802.21 platform is considered as the means to implement protocol operations for seamless handovers, and further extended to support QoS provisioning along heterogeneous access networks [13]. However, results are yet to be presented that assess the feasibility and efficiency of the approach.

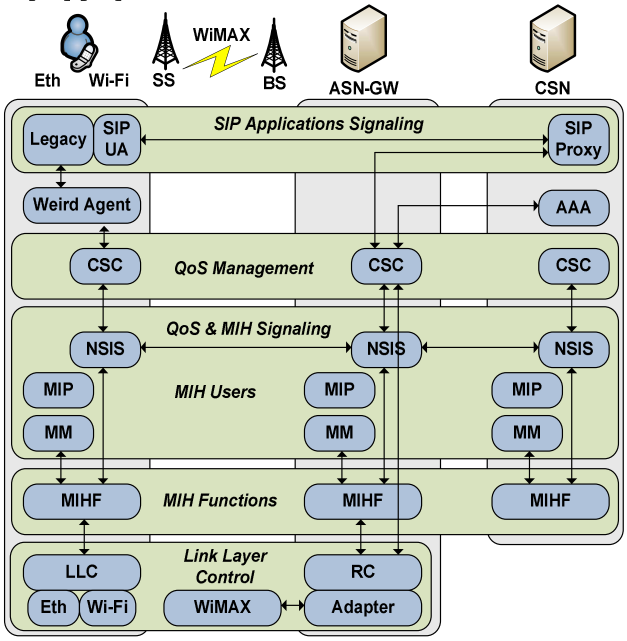
The mobility architecture presented in this paper has been implemented in the European funded WEIRD project [14]. WEIRD is focused on WiMAX and proposes an architecture compliant with the most relevant standardization bodies, such as IEEE 802.16, IETF 16ng [15] and WiMAX Forum. In order to guarantee full interoperability among different WiMAX vendors, the WiMAX Network Reference Model (NRM) is used as a foundation, and the NSIS framework is adopted for QoS reservations. IEEE 802.21 is also considered and integrated into the WEIRD architecture to optimize mobility procedures. This allows multiaccess nodes to take advantage of the WEIRD system and optimize seamless handovers between WiMAX and other access networks. Furthermore, in order to allow for independence from the particulars of WiMAX vendor equipment, an abstraction layer has been defined, which separates the lower layer specific functionalities from the upper layer ones [16]. In order to demonstrate the feasibility of the proposed solution, the project has also developed a joint prototype which is deployed on four testbeds distributed across Europe (Finland, Italy, Portugal and Romania) and interconnected via the GEANT network.

As in DAIDALOS, WEIRD also uses NSIS for network layer QoS signaling. Nonetheless, WEIRD has extended the generic NSIS signaling layer to include specific WiMAX related QoS parameters [17]. Furthermore, a Media Independent Handover (MIH) NSLP has been defined to transport the IEEE 802.21 MIH protocol messages across the network elements [18].

III. MOBILITY MANAGEMENT IN NGN WIMAX

The proposed mobility and QoS architecture, depicted in Fig. 1, is composed by the *Connectivity Service Network* (CSN), the *Access Service Network* (ASN) and the *Mobile Station* (MS), as defined by the WiMAX Forum NRM.

Regarding QoS management, the Connectivity Service Controller (CSC) modules, located in all entities of the NRM, hold the most important functions of the system. For SIP applications, the SIP Proxy extracts the QoS parameters received from the SIP User Agent (SIP UA), performs user authentication and authorization with the AAA, and forwards the gathered QoS information towards the CSC located at the ASN (CSC_ASN). For legacy applications, the CSC located at the MS (CSC_MS) communicates with the WEIRD Agent (WA) to obtain the required QoS parameters from the legacy application and forwards this information to the CSC_ASN using the NSIS framework. On the link layer level, the Resource Controller (RC) module hides all the WiMAX technology related functionalities from the higher layer entities of the architecture. Basically, it translates and adapts generic QoS parameters to WiMAX specific ones, and triggers the Adapter module to enforce QoS decisions on the WiMAX system [19]. Detailed information about standalone WEIRD QoS management procedures has been published in [16] [17].



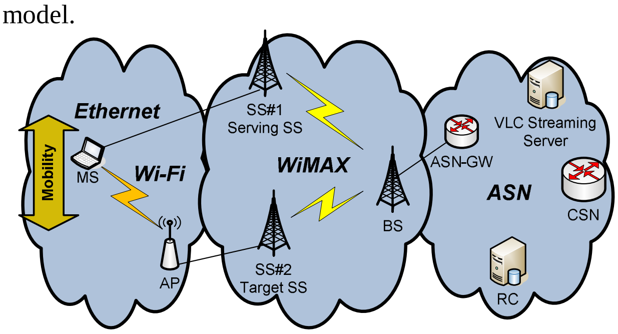
WEIRD Mobility and QoS Integrated Architecture

With respect to mobility procedures, the proposed architecture is based on the IEEE 802.21 [6] framework and on the standardized Mobile IP (MIP) [20] protocol. IEEE 802.21 is composed by the MIH Function (MIHF), which hides the specificities of different link layer technologies from the higher layer mobility entities, and by a set of well-known standardized interfaces: MIH_LINK_SAP, MIH_SAP and MIH_NET_SAP. Several higher layer entities, known as MIH Users (MIHUs) can take advantage of the MIH framework, including mobility management protocols and mobility decision algorithms. In order to detect, prepare and execute the handovers, the MIH platform provides three services: Media Independent Event Service (MIES), Media Independent Command Service (MICS) and Media Independent Information Service (MIIS).

Mobility Managers (MM), acting as MIHUs, are located in each functional entity of the architecture: MS, ASN-GW and CSN. The MMs are in charge of handover decisions and procedures, and they communicate with their peers using the MIH protocol. For transporting the MIH protocol signaling messages, the NSIS framework has been extended with the Media Independent Handover (MIH) NSLP, as defined in [18]. Finally, the Link Layer

Client (LLC) has been defined to control the lower layers, providing link layer information to the MIHF through the MIH_LINK_SAP interface.

Up to now we have described the mobility and QoS architecture modules and their operation. Now, we will present a practical use case of an inter-technology handover involving WiMAX as the backhaul access technology, demonstrating efficient management of control plane functionalities, such as data plane configuration and resource reservation for the traffic flows involved in the handover. Furthermore, we also demonstrate the transport of MIH messages using the NSIS framework, specifically the MIH NSLP. The example scenario is shown in Figure 2. It consists of a MS with two network interfaces (Ethernet and Wi-Fi), initially connected to an Ethernet cable, backhauled by a WiMAX fixed SS (serving SS). Later on, the user decides to move away from his desk and unplugs the Ethernet cable. Consequently, the MS connects to the Wi-Fi network, backhauled by another WiMAX fixed SS (target SS), located in the same ASN of the serving SS. This type of scenario includes inter-technology and intra-technology mobility procedures: the MS is connected via Ethernet and makes an inter-technology handover to a Wi-Fi network; at the same time, there is an intra-technology handover from the serving WiMAX SS to the target WiMAX SSs in the backhaul, following the intra-ASN WiMAX mobility model.

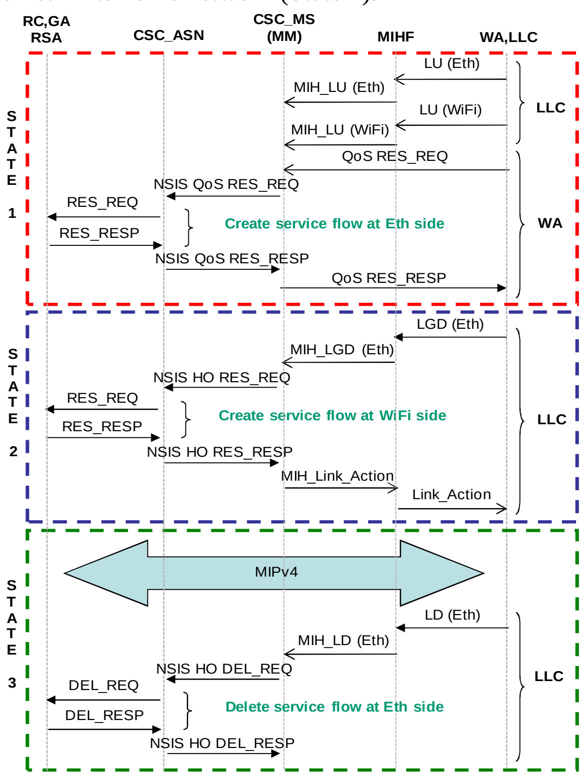


Deployed Scenario

The considered MS hosts some active applications that require specific levels of guaranteed QoS. Therefore the related sessions are initially associated to a particular set of Service Flows (SFs) allocated on the WiMAX channel between the serving SS and its BS. Each SF is characterized by a specific scheduling class and some parameters, like bandwidth and jitter that specify the QoS level for the data traffic.

Fig. 3 illustrates the seamless handover signaling diagram between Ethernet and Wi-Fi, backhauled by WiMAX. After connecting the terminal, two *Link_Up* events are sent by the LLC to notify the MIHF that Wi-Fi and Ethernet networks are available. The MIHF forwards these events to the registered MMs (local and remote). As a result, the MM updates its internal state machine with the new available access technologies. Simultaneously, a QoS reservation process is triggered by the WEIRD Agent to establish the required SFs in the composed WiMAX/Ethernet segment, providing the user with the required QoS parameters for the application (State 1).

Thereafter the user decides to unplug the Ethernet cable. Before unplugging the cable, the user interacts with the LLC to trigger a *Link_Going_Down* event, notifying the MIHF that the Ethernet link is going down within a certain period of time. The MIHF forwards this event to the registered MMs (local and remote). Thus, the MM updates its internal state machine with the received information (Ethernet link is going down). With this procedure, both terminal and network MMs have sufficient information about the Ethernet interface status in real time and can trigger the **HO Preparation phase** before the Ethernet cable is unplugged. In order to prepare the QoS resources in the composed target access network WiMAX/Wi-Fi, the MM located at the MS (MM@MS) triggers the NSIS QoS reservation process. After the QoS resources reservation in the composed target access network is complete, the MM@MS receives a response from NSIS. At this stage, the MS is still connected via Ethernet in its home network (State 2).



Seamless Handover Signaling Diagram

Since the composed target access network is already prepared to receive the MS, the MM sends a *Link_Action* command to the LLC in order to start the handover execution phase. During the **HO Execution phase**, the user unplugs the Ethernet cable from the MS, automatically triggering the Wi-Fi interface registration in the MIP Foreign Agent (FA). After the MIP registration in the FA, data starts flowing through the Wi-Fi link. To finalize, the LLC detects that the Ethernet cable is unplugged and sends a *Link_Down* event to the MIHF, which forwards it to the registered MMs (local and remote).

At this stage, the MS is connected to the WiMAX/Wi-Fi composed access network, but the resources in the previously WiMAX/Ethernet link are still active. Therefore, the MM@MS, after receiving the *Link_Down* event from the MIHF, triggers the deletion of the SFs in the WiMAX/Ethernet segment initiating the **HO Completion phase** (State 3).

IV. IMPLEMENTATION

This section briefly describes the implementation of the main mobility modules, such as NSIS, LLC, MIHF and MM.

A. NSIS

NSIS, as a framework for QoS signaling, decouples the transport layer from the signaling layer. In the NSIS framework, GIST provides the transport and association mechanisms necessary for QoS signaling. QoS NSLP instructs GIST on the NSIS nodes to signal in order to guarantee the QoS requirements of applications. MIH NSLP enables the transport of MIH messages between MIH peers. Both QoS NSLP and GIST are conformant to the specifications of the IETF NSIS working group [8] [9] [10], whilst the MIH NSLP was included in the WEIRD architecture to transport MIH messages between peer remote entities [18]. The MIH NSLP module has a northbound interface with MIHF, compliant with the MIH_NET_SAP specified in the IEEE 802.21 standard, and a southbound interface with GIST acting according to the specification of GIST. For MIH events/commands propagation, MIHF delivers the messages to the MIH NSLP. The MIH NSLP parses the received message and creates the necessary information to instruct GIST on the delivery process. Such information includes the MIH message and Message Routing Information (MRI) which includes, for instance, the type of transport required (e.g. TCP for reliable delivery). The NSIS framework related modules have been implemented in Java programming language.

B. LLC

The aim for Link Layer Client (LLC) was to implement a link information collector independent of the specific hardware, vendor, or GNU/Linux kernel. For this, Linux natively provides convenient ways for application layer software to gather link specific information from kernel and directly from network device drivers without modifications to both of them. LLC constantly monitors the network link states from the kernel and network drivers and provides events through an Event Trigger module to the registered MIHF based on this information. For simplicity, in the examined scenario, LLC provides only *Link_Up*, *Link_Down* and synthetically generated *Link_Going_Down* events. The monitored link types are Ethernet (IEEE 802.3) and Wi-Fi (IEEE 802.11).

Link states are identified in the Generic Link State Monitor (GLSM) by observing the operation status of access network interfaces. After each link is operationally up and its link type has been identified, GLSM initiates the Link-specific Information Monitor (LSIM) which acquires link-specific information. For instance, LSIM can obtain Access Point (AP) information for Wi-Fi accesses. This information is gathered using *ioctl* system calls.

C. MIHF

The MIHF is the core entity of the IEEE 802.21 framework. It provides communication with lower layers through MIH_LINK_SAP, with upper layers through MIH_SAP and with remote MIHFs via MIH_NET_SAP, using the MIH protocol [6]. During initialization, each MIHF must be configured and thereafter it automatically creates the communication sockets for each one of the standardized interfaces. Maps of events, commands and information services are associated with each one of the MIHFs. The MIH Users will also be associated to these sets of maps, after having subscribed to one (or more) of the MIH services (MIES, MICS and MIIS). The MIHF receives messages from the MIHU, LLC or remote MIHF, identify the incoming message and react accordingly. For example, after receiving a link event from the LLC though the MIH_LINK_SAP, the MIHF must look for the subscribed MIHUs to this event on the events list. For local MIHUs, the MIHF must generate the correspondent MIH event and send it through the MIH_SAP, whereas for remote MIHUs subscriptions, the MIHF must deliver the MIH event to the MIH NSLP through the MIH-NET-SAP.

D. CSC & MM

As mentioned above, each segment of the WiMAX network is managed by a Connectivity Service Controller (CSC), with its own Mobility Manager (MM). CSC has, as its main role, to manage sessions at the control plane, coordinating all relevant related signalling at different layers and the resource reservation in the WiMAX link, which is dynamically updated during the session setup and the handover phases. In particular, the CSC_MS is the main coordinator for sessions of applications based on host-initiated QoS signalling, while the CSC_ASN has the same role for IMS-like applications that adopt the network-initiated approach. Resource allocation on the WiMAX link follows the network-initiated model and is handled by the CSC_ASN at the ASN-GW.

The resource update for mobility follows the Make-Before-Break approach: when an imminent handover is detected, new SFs are allocated on the target segment, while at the end of the handover execution phase, resources on the old path are released. These procedures are completely transparent for the application layer and are managed by the entity that acts as the main coordinator for the sessions involved in the handover: the MM@MS for host-initiated sessions and the MM@ASN for IMS-like applications.

Link layer information about the wireless link status is monitored by LLC and sent to the MM module through a set of MIH Events carried by the MIH NSLP signalling (for remote events). The strong interaction between the CSC, which manages the sessions at the control plane, and the related MM, which manages the link layer MS status, allows the system to allocate new resources in the target link for the existing traffic flows whenever a new handover is detected through the *Link_Going_Down* event. Following the same approach, previously used resources are removed when the *Link_Down* message is received, as presented in Fig. 3.

V. TESTBED EVALUATION

This section describes the experimentation of the proposed mobility mechanism. The experimental scenario is depicted in Fig. 2. Particularly, the testbed is composed by the CSN, the ASN and the MS. Under the ASN, we have the WiMAX BS directly connected to the ASN-GW. Two WiMAX SSs are connected to the BS creating a Point-to-Multipoint (PMP) topology. The MS can be connected to SS1 by Ethernet and to SS2 by Wi-Fi.

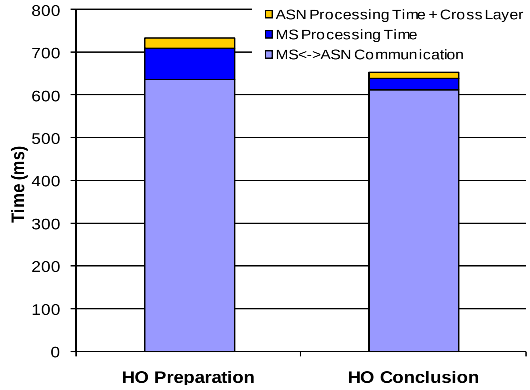
The goal of this scenario is to demonstrate a HO between Ethernet and Wi-Fi, backhauled by a fixed WiMAX link. Initially the MS is connected to Ethernet and therefore it is necessary to reserve in the BS-SS1 WiMAX link, two SFs (one uplink and one downlink) based on the MAC address of the MS with an allocated bandwidth of 512 Kb/s, to handle a video stream. While the user is watching a video received through the concatenated WiMAX/Ethernet link, he decides to unplug the Ethernet cable and connect to the Wi-Fi AP. This automatically triggers a vertical handover procedure between Ethernet and Wi-Fi, which will initiate the SFs reservation in the BS-SS2 WiMAX link. After this process, the user performs the HO and can continue to watch the video by the composed WiMAX/Wi-Fi link, experiencing the same video-quality.

The performance of the proposed mobility architecture is addressed in this section. The internal processing times of the several modules involved during the different phases of the scenario namely, HO Preparation, HO Execution and HO Conclusion, are analyzed. Additionally, the performance of the MIH transport mechanism for the communication between remote MIHFs is also evaluated. We repeated each experience 10 times and opted for the average value of the obtained times.

A. HO Preparation and Conclusion Phases

During the HO Preparation Phase, the resources on the WiMAX/WiFi link must be allocated to support the HO of the MS to the target network. During the HO Conclusion phase, the resources reserved in the WiMAX/Ethernet link will be released to be available for future connections.

Fig. 4 shows the processing time for HO Preparation and Conclusion phases in the case of mobile-initiated handovers. The required time for the HO Preparation phase is approximately 736 ms and for the HO Conclusion is nearly 655 ms.



HO processing and communication time for host-initiated sessions

The MS processing time (nearly 70 ms for the HO preparation and 25 ms for the HO conclusion) is due to the CSC_MS module, where the MM acts as the coordinator of the entire HO procedure. It computes the new resources that must be allocated for each existing session and translates them into a set of NSIS QSPEC to be sent to the CSC_ASN towards the WiMAX link. The processing time at the CSC_ASN and cross-layer modules is lower (approximately 25 ms for the HO preparation and 15 ms for the HO conclusion). These modules are only in charge of the WiMAX SFs reconfiguration on the WiMAX segment, as specified in the received QSPEC, without taking any active decision about the involved sessions. NSIS communication time between the MN and the ASN is the highest for both HO preparation and conclusion phases. This is due to the NSIS processing time, and also to each message exchange performed through the WiMAX link, which takes approximately 30 ms.

With respect to the MIHF, during the HO preparation phase, the processing time to forward the *Link_Going_Down* event received from the LLC to the CSC_MS is nearly 216 µs. After receiving the *Link_Action* from the CSC_MS, the MIHF processing and forwarding time, before sending the message to the LLC, is 146 µs. It is noticeable that the internal processing time of the MIHF is much smaller than the CSC_MS and CSC_ASN modules. This module, when properly configured and initialized, just has to forward events and commands to the MIHUs and LLCs. Finally, the communication time between the MIHF and the CSC is around 750 µs on each direction.

B. HO Execution

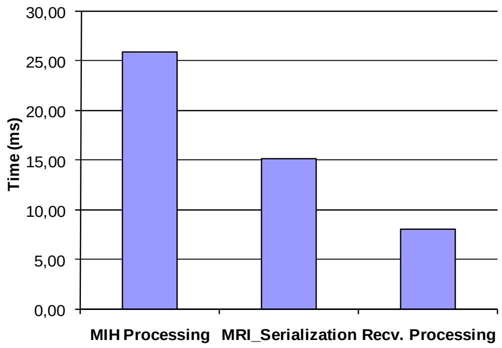
The HO execution time is the interval between the instant when the Ethernet interface stops receiving the video streaming and the moment when the Wi-Fi interface starts receiving it. The handover execution time is 4.199

seconds, being rather high. The use of the MIPv4 [20] mobility protocol is the source of this behaviour, due to the problems associated with the routing of the packets to the Care-of-Address of the MS. This problem is overcome by the Route Optimization in MIPv6 [21] [22] that provides a MS the opportunity to eliminate the inefficient triangle routing of MIPv4 and therefore, achieving lower HO times. Nevertheless, for simplicity reasons, MIPv4 was used in this demonstrator.

C. MIH Transport Mechanism

As stated before, the MIH transport mechanism relies on the NSIS communication facilities, namely GIST to assure the transport of messages and MIH NSLP to instruct GIST on the delivery process. The processing time of GIST includes the parsing of MIH messages received from the MIH NSLP, the forwarding to the next peer, and the refresh mechanisms to keep the associations. Since the MS acts as the initiator, GIST has a higher processing time than at the ASN (around 25 ms). This time is due to the decision process on the transport protocol (UDP or TCP), as well as on the message association mechanism required by GIST. On the ASN side, the GIST processing time is nearly 7.5 ms.

Fig. 5 depicts the processing time of MIH NSLP which includes different processes in the MS and the ASN. At the MS, the MIH NSLP processes the messages received by the MIHF (MIH messages to be transported to a remote MIHF), and due to the messages received, the MIH NSLP instructs GIST on the delivery process through the MRI serialization. The MIH Processing at the MS takes approximately 25 ms and includes the parsing of MIH messages in order to map the destination ID to an IP address (required by the forwarding process of GIST). The MRI Serialization at the MS side is nearly 15 ms. At the ASN side, the MIH NSLP processes the messages received from GIST and performs the necessary processing to deliver the MIH messages to the remote MIHF. This process takes around 7.5 ms. All these values are small and do not compromise the handover efficiency.



MIH NSLP Processing time

VI. CONCLUSIONS AND FUTURE WORK

This paper proposed an architecture to support integrated QoS and mobility in heterogeneous environments, using IEEE 802.16 access technology as backhaul. The integration of QoS and mobility was performed through an extension of IEEE.21 and NSIS frameworks, to transport the MIH information in the NSIS framework. This architecture was implemented and experimentally evaluated in a real testbed. The obtained quantitative results, through the processing delays of the main components in our prototype implementation when a terminal hands over between different access technologies, demonstrate the potential of the proposed architecture, since the processing times are mostly small, not compromising the handover efficiency. The main bottleneck of the presented handover time was the non-routing optimization process of MIPv4. However, MIPv4 was used just for simplicity purposes, not being a component of our architecture.

As future work, we plan to integrate the architecture with a fast mobility protocol, extend for other technologies, such as UMTS and DVB, and support inter-ASN handovers.

ACKNOWLEDGMENT

Part of this work was conducted within the framework of the IST Sixth Framework Programme Integrated Project WEIRD (IST-034622), which was partially funded by the Commission of the European Union. We thank our colleagues from all partners in WEIRD project for the fruitful discussions.

REFERENCES

[1] ITU-T, General Principles and General Reference Model for Next Generation Networks, Rec. Y2011, Oct. 2004.

[2] ITU-T, General Overview of NGN, Rec. Y.2001, December 2004.

[3] WiMAX Forum, WiMAX End-to-End Network Systems Architecture Stage 2-3: Architecture Tenets, Reference Model and Reference Points, Release 1, Version 1.2, Jan. 2008.

[4] IEEE 802.16 WG, IEEE Standard for Local and Metropolitan Area Networks. Part 16: Air Interface for Fixed Broadband Wireless Access Systems, IEEE Std. 802.16-2004, Oct. 2004.

[5] IEEE 802.16 WG, Amendment to IEEE Standard for Local and Metropolitan Area Networks. Part 16: Air Interface for Fixed Broadband Wireless Access Systems – Physical and Medium Access Control Layer for Combined Fixed and Mobile Operation in Licensed Bands, IEEE Std. 802.16e-2005, Dec. 2005.

[6] IEEE 802.21 WG, IEEE Draft Standard for Local and Metropolitan Area Networks: Media Independent Handover Services, IEEE P802.21/D10.0, April 2008.

[7] IEEE 802.11 WG, IEEE Standard for Local and Metropolitan Area networks; Part 11: Wireless LAN Medium Access Control and Physical Layer Specifications, IEEE Std. 802.11-2007, Feb. 2007.

[8] R. Hancock et al, Next Steps in Signaling (NSIS): Framework, IETF RFC 4080, June 2005.

[9] H. Schulzrinne, R. Hancock, GIST: General Internet Signalling Transport, IETF NSIS WG Internet-Draft, July 2008.

[10] J. Manner, G. Karagiannis, NSLP for Quality-of-Service Signaling, IETF NSIS WG Internet-Draft, Feb. 2008.

[11] Intel Wi-Fi to WiMAX seamless handover demonstration – http://blogs.intel.com/research/2008/02/wifi_wimax_handover.php

[12] The DAIDALOS project – http://www.ist-daidalos.org

[13] S. Sargento et al, Integration of Mobility and QoS in 4G Scenarios, in Proc. Third ACM Workshop on QoS and Security for Wireless and Mobile Networks, Chania, Crete Island, Greece, Oct. 2007, pp. 47-54.

[14] The WEIRD project – http://www.ist.weird.eu

[15] S. Madanapalli, Analysis of IPv6 Link Models for IEEE 802.16 Based Networks, IETF RFC 4968, Aug. 2007.

[16] P. Neves, T. Nissila, T. Pereira, J. Monteiro, K. Pentikousis, S. Sargento, F. Fontes, A Vendor-Independent Resource Control Framework for WiMAX, in Proc. 13th IEEE Symposium on Computers and Communications (ISCC), Marrakech, Morocco, July 2008, pp. 899-906.

[17] Bruno Sousa, P. Neves, D. Palma, J. S. Silva, S. Sargento, F. Fontes, M. Curado, F. Boavida, The Cost of Using IEEE 802.16 Dynamic Channel Configuration, in Proc. IEEE International Conference on Communications (ICC), Beijing, China, May 2008, pp. 383 - 390.

[18] L. Cordeiro, M. Curado, P. Neves, S. Sargento, G. Landi, X. Fu, Media Independent Handover Network Signalling Layer Protocol (MIH NSLP), IETF NSIS WG Internet-Draft, Feb. 2008.

[19] T. Nissilä, J. Huusko, I. Harjula, M. Katz, Adapter Implementation between WiMAX Specific Layers and Network/Application Layers, 1st BWA Workshop, Cardiff, Wales, Sep. 2007, pp. 328-333.

[20] C. Perkins, IP Mobility Support, IETF RFC 2002, Oct. 1996.

[21] D. Johnson, C. Perkins, Mobility Support in IPv6, IETF RFC 3775, June 2004.

[22] R. Koodly, Fast Handovers for Mobile IPv6, IETF RFC 4068, July 2005.