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WiMAX Cross-Layer System for Next Generation Heterogeneous Environments

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1. Introduction

The Access Network (AN), which is the important path between the operator Core Network (CN) and the Customer Premises Network (CPN), often has high requirements with respect to available bandwidth, and must be thoroughly planned. Current wired solutions, such as coaxial cable, Digital Subscriber Line (DSL) and fiber, are the main access technologies used for “last mile” connectivity. Nevertheless, due to the associated costs and difficult terrestrial conditions, important geographical areas are left without broadband connectivity. Often, lack of broadband access is the main reason for unequal access to Information and Communication Technologies (ICTs), a gap known as the Digital Divide. Previously, a significant amount of effort and resources have been invested in broadband wireless access technologies (e.g. Motorola Canopy) in order to fill this gap. Yet, since these were proprietary solutions, their adoption has been very low.

IEEE 802.16, a Broadband Wireless Access (BWA) solution for Wireless Metropolitan Area Networks (WMANs), covering large distances with very high throughputs, is an attractive BWA technology that can be used to overcome the previously mentioned limited access to the ICTs, for both fixed and mobile environments (IEEE 802.16, 2004; IEEE 802.16 a, 2005). However, the IEEE 802.16 standards do not define an end-to-end (E2E) system or architecture. They only define the PHY and MAC layers in the protocol stack. The Worldwide Interoperability for Microwave Access (WiMAX) Forum is currently defining a high-performance “All-IP” end-to-end (E2E) network architecture to support fixed and mobile users (WiMAX Forum a, 2008; WiMAX Forum b, 2008). The WiMAX Forum is also committed to perform an interoperability effort across different vendors. This opens a different set of business opportunities for telecom operators, turning WiMAX into a viable technology for the Next Generation Network (NGN) environments (ITU-T a, 2004; ITU-T b, 2004). In these environments, users wish for having ubiquitous Internet access with a wide range of possible services (e.g. “triple play”) and assured QoS guarantees, even while moving. These characteristics will lead NGNs to the “Always Best Connected” (ABC)

paradigm, and as a consequence, operators have to cope with a whole new set of challenging requirements. Therefore, all the network design, including the WiMAX access network, should be able to address these aspects.

In this chapter we present a NGN architecture for WiMAX, able to support and differentiate real-time services. Special attention is given to the integration of QoS and mobility management functionalities, such as the IEEE 802.21 (IEEE 802.21, 2008) Media Independent Handover (MIH) framework, between the WiMAX technology and the higher layer entities of the designed architecture, through the specification and development of the WiMAX Cross-Layer (WXL) system. The WXL system comprises a middleware layer between the WiMAX technology and the network layer, hiding the WiMAX equipment specific functionalities from the network control plane, thus providing robustness, scalability and vendor independency. Following the recent trends in the WiMAX standardization field, the WXL interaction with the WiMAX system is established through standardized IEEE 802.16g (IEEE 802.16, 2007) primitives. In order to validate and evaluate the WXL system, a set of performance measurements were made, focusing on the resource management mechanisms. This evaluation was made in the EU IST WEIRD project (WEIRD, 2008). The results obtained from the development and experimental setup of this architecture show that the processing times for the resource reservations, both in the resource control modules and WiMAX equipments are small, even for a large number of simultaneous reservation requests, which enable the use of WiMAX in real-time environments with high mobility scenarios.

The chapter is organized as follows. Section 2 briefly describes both the IEEE 802.16 and the WiMAX Forum reference models and Section 3 presents the main characteristics of the IEEE 802.21 Media Independent Handover framework. Section 4 introduces the proposed WiMAX Cross-Layer system, including its interfaces and services. Section 5 describes a practical use case of the WXL system, developed in the WEIRD project, whereas Section 6 discusses the experimental results obtained, as well as our test methodology. Finally, Section 7 concludes this chapter.

2. WiMAX Overview

This section starts by briefly introducing the IEEE 802.16 reference model, including the data, control and management planes. Thereafter we present the network architecture defined by the WiMAX Forum standardization body to integrate the WiMAX access technology in a real network deployment.

2.1 IEEE 802.16 Reference Model

WiMAX standardization efforts are currently being made by the IEEE 802.16 working group and by the WiMAX Forum. The IEEE 802.16 defines the air interface specifications, namely the Physical (PHY) layer and the Medium Access Control (MAC) layer, for both fixed (IEEE 802.16, 2004) and mobile (IEEE 802.16 a, 2005) terminals. The MAC layer provides the interface with the higher layers through the Service Specific Convergence Sublayer (CS). Below the Service Specific Convergence Sublayer is the Common Part Sublayer (CPS), which is responsible for the core MAC functions. Finally, under the Common Part Sublayer, there is the Security Sublayer. Figure 1 illustrates the IEEE 802.16 reference model, comprising the data, management and control planes.

Fig. 1. IEEE 802.16 Reference Model

As presented in Figure 1, the CS is the first sublayer from the MAC layer. The sending CS accepts higher layer MAC Service Data Units (SDU) coming through the CS Service Access Point (SAP) and classifying them to the appropriate connection. The classifier is based on a set of packet matching criteria applied to each packet. It consists of some protocol-specific fields, such as IP and Ethernet addresses, a classifier priority and a reference to a specific connection. Each connection has a specific service flow associated providing the necessary QoS requirements for that packet. If no classifier is found for a specific packet, the packet can be discarded, sent on a default connection or a new dedicated connection can be established. Finally, the CS Protocol Data Unit (PDU) is delivered to the MAC CPS through the MAC SAP and delivered to the peer MAC CPS. Downlink classifiers are applied by the WiMAX Base Station (BS) and uplink classifiers are applied by the WiMAX Subscriber Station (SS) or Mobile Station (MS).

The CPS is the second sublayer from the MAC layer. It receives packets arriving from the CS and is responsible for the most important MAC functions, such as system access, construction and transmission of MAC PDUs, scheduling services management, bandwidth allocation and contention resolution. The 802.16 system is connection oriented since all services are mapped to a connection. Associated with each connection is a Service Flow (SF) and a scheduling service. Five scheduling services are supported by IEEE 802.16: Unsolicited Grant Service (UGS), real time Polling Service (rtPS), extended real time Polling Service (ertPS), non real time Polling Service (nrtPS) and Best Effort (BE).

Finally, the Security Sublayer is the last sublayer from the MAC layer, providing authentication and security mechanisms.

Since the IEEE 802.16 entities are part of a larger network environment, it is necessary to define control and management communication mechanisms between the WiMAX system and the higher layers. The IEEE 802.16g-2007 (802.16, 2007) standard has been defined to efficiently integrate the IEEE 802.16 entities with the higher layer control and management functionalities. In particular, 802.16g defines two Service Access Points (SAPs) – the Management Service Access Point (M-SAP) and the Control Service Access Point (C-SAP) –

to establish communication between an IEEE 802.16-based system and the control and management entities on the higher layers, respectively. The C-SAP and the M-SAP are depicted in Figure 1. The Control SAP (C-SAP) is oriented for more time sensitive control plane primitives, including:

- Handovers security management;
- Subscriber mode (idle, sleep, normal) management;
- Handover context management;
- Media Independent Handover management;
- Radio resources management;
- Network entry and exit management;
- Service flow management.

The Management SAP (M-SAP) is used for less time-sensitive management plane primitives, such as:

- Connections and subscribers accounting management;
- Subscriber / Mobile Station interface management;
- System configuration;
- Statistics monitoring;
- Notifications and triggers management.

Detailed information about each one of the aforementioned primitives can be found in the IEEE 802.16g standard (IEEE 802.16, 2007).

2.2 WiMAX Network Reference Model

Based on the PHY and MAC layer specifications provided by the IEEE 802.16 working group standards, the WiMAX Forum standardization body is designing an all-IP end-to-end network architecture for WiMAX environments. As a result, the WiMAX Forum has defined the WiMAX Network Reference Model (NRM), illustrated in Figure 2.

Fig. 2. WiMAX Network Reference Model

The WiMAX NRM is a logical representation of the WiMAX architecture, based on a set of functional entities and eight standardized interfaces, also known as Reference Points (RPs).

Using this model, multiple implementation options for each functional entity are allowed, while maintaining interoperability using the RPs. Three functional entities are defined: Connectivity Service Network (CSN), Access Service Network (ASN) and the Customer Premise Network (CPN). The CPN is the terminal equipment, responsible for establishing radio connectivity with the BS. For fixed WiMAX (IEEE 802.16, 2004), the CPE might be composed by single-user SSs or multi-users SSs (MSS) when a LAN/WLAN is connected to the SS. For mobile WiMAX (IEEE 802.16 a, 2005), a single-user Mobile Station (MS) is the envisioned scenario (see Figure 2). The ASN is composed by several BSs connected to several gateways (ASN-GWs), which establish connectivity with the CSN. The ASN includes a set of functionalities in order to provide radio connectivity to the WiMAX subscribers, including service flow and micro/macro mobility management. Additionally, it also performs relay functions to the CSN in order to establish IP connectivity and Authentication, Authorization and Accounting (AAA) mechanisms. Finally, the CSN holds the DHCP, DNS, MIP and AAA servers, as well the SIP Proxy. Moreover, the CSN is responsible for establishing connectivity with the IP backbone.

3. IEEE 802.21 – Media Independent Handover Services

The main goal of IEEE 802.21 (802.21, 2008) is to optimize mobility mechanisms in heterogeneous access environments. Towards this aim, it defines a Media Independent Handover (MIH) framework, which provides standardized interfaces between the access technologies and the mobility protocols from the higher layers in the protocol stack. IEEE 802.21 introduces a new entity called MIH Function (MIHF), which hides the specificities of different link layer technologies from the higher layers mobility entities. Several higher layer entities, known as MIH Users (MIHUs) can take advantage of the MIH framework, including mobility management protocols, such as Mobile IPv4 (MIPv4) (Perkins, 2002), Mobile IPv6 (MIPv6) (Johnson et al, 2004), Fast Mobile IPv6 (FMIPv6) (Koodli, 2005), Proxy Mobile IPv6 (PMIPv6) (Gundavelli et al, 2008) and Session Initiation Protocol (SIP) (Rosenborg & Camarillo, 2002), as well as the other 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). MIES provides event reporting such as dynamic changes in link conditions, link status and link quality. Multiple higher layer entities may be interested in these events at the same time, so these events may need to be sent to multiple destinations. MICS enables MIHUs to control the physical, data link and logical link layer. The higher layers may utilize MICS to determine the status of links and/or control the access to different networks. Furthermore, MICS may also enable MIHUs to facilitate optional handover policies. Events and/or Commands can be sent to MIHUs within the same protocol stack (local) or to MIHUs located in a peer entity (remote). Finally, MIIS provides a framework by which a MIHF located at the MS or at the network side may discover and obtain network information within a geographical area to facilitate handovers. The objective is to acquire a global view of all heterogeneous networks in the area in order to optimize seamless handovers when roaming across these networks.

Figure 3 presents the 802.21 MIH framework, including the three aforementioned services – MIES, MICS and MIIS.

Fig. 3. IEEE 802.21 MIH Framework (Neves et al, 2009)

4. WiMAX Cross-Layer System Design

Nowadays, standardized mechanisms for both network layer and link layer are already in place. For example, on the network layer side, QoS signaling protocols such as NSIS (Hancock et al, 2005; Schulzrinne & Hancock, 2007) or Diffserv (Blake et al, 1998), as well mobility management protocols such as Mobile IP and Host Identity Protocol (HIP) (Moskowitz & Nikander, 2006) are well established. However, one of the major gaps is the inter-layer connectivity, also known as cross-layer, between the network and the link layer functions. One particular example is the WiMAX access technology, which requires an efficient communication with the network layer to exploit all its functionalities. To establish an efficient communication between the network and the WiMAX MAC layers, we propose the WiMAX Cross-Layer (WXL) system. The WXL is responsible for providing all the required cross-layer services between the WiMAX MAC layer and the network layers, such as QoS, mobility, AAA, security, multicast and broadcast. The WXL system comprises a middleware layer between the WiMAX technology and the network layer, hiding the WiMAX technology specific functionalities from the network control plane. To interact with the network layer, the WXL provides a set of dedicated interfaces, known as *WXL Upper Interfaces*, comprising, among others, support for QoS, mobility, accounting and security. Likewise, the *WXL Lower Interfaces* also encompass several interfaces to interact with the link layer technologies. The preferred and most appropriated interface between the WXL system and the WiMAX BS is established using the IEEE 802.16g (802.16, 2007) standardized service primitives. As described in Section 2, 802.16g provides a set of primitives to address each one of the specific WiMAX services, and therefore it is the ideal solution to satisfy all the requirements for this type of interface. Nevertheless, we cannot assume beforehand that all WiMAX systems support the 802.16g standardized interface. For example, current

commercial WiMAX equipments available on the market, though already certified by the WiMAX Forum, only supports Simple Network Management Protocol (SNMP), Hypertext Transfer Protocol (HTTP) or a simple Command Line Interface (CLI) to manage the equipments. Hence, the WiMAX Cross-Layer system must be flexible to support any type of interface with the link layer as alternatives to the preferred IEEE 802.16g interface. Figure 4 illustrates the WiMAX Cross-Layer (WXL) system architecture.

Fig. 4. WXL System Architecture

The functionalities provided by the WXL system are grouped on different management services. As illustrated in Figure 4 and described in Table 1, six services are exposed by the WXL to the upper layers, namely QoS, Mobility, Mobile Station, AAA & Security, Multicast & Broadcast and Vendor Independency Management Services.

Management Service	Function
QoS	Service flows and admission control management for the WiMAX link.
Mobility	Control of the handover context between the serving and the target BSs, as well as translation of the 802.21 Media Independent Handover primitives to the WiMAX system.
Mobile Station	Management of the MS states (normal, sleep and idle modes), MS status (on, off) and the MS network entry, re-entry and exit procedures.
AAA & Security	Subscribers and connections accounting, initiated by the end of the subscribers registration procedure and by the service flow allocation, respectively.
Multicast & Broadcast	Management of multicast and broadcast related functionalities.
Vendor Independency	Management of WiMAX equipments from different vendors.

Table 1. WXL Management Services

In this chapter we will focus on the WXL QoS and Vendor Independency Management Services from the WXL system.

4.1 WXL QoS Management Service

The **QoS Management Service (QMS)** controls the QoS operation of the WiMAX network, handling the creation, modification and deletion of service flows (Service Flow Manager), as well as providing full control of all the service classes (Service Class Manager) and the related convergence sublayer classifiers (Convergence Sublayer Manager). As defined in the IEEE 802.16d/e standard (802.16, 2004; 802.16 a, 2005), three different sets of QoS parameters might be associated with a particular SF such as:

- *ProvisionedQoSParamSet*: indicates a QoS parameter set provisioned via means outside of the scope of 802.16d/e standard, such as the operator network management system.
- *AdmittedQoSParamSet*: defines a set of QoS parameters for which the BS and the SS/MS are reserving resources. This QoS parameter set is the preparation to subsequently activate the flow.
- *ActiveQoSParamSet*: specifies the set of QoS parameters that are actually being provided to the SF.

Depending on the QoS parameters set, a specific service flow will have a status associated. The following service flow statuses are defined and supported in the WXL system:

- *Provisioned Service Flow*: created via provisioning by, for example, the network management system. Its *AdmittedQoSParamSet* and *ActiveQoSParamSet* are both null.

- *Admitted Service Flow*: indicates that the service flow has resources reserved by the BS for its *AdmittedQoSParamSet*, but these parameters are not yet active.
- *Active Service Flow*: resources are committed by the BS for its *ActiveQoSParamSet*, and as a result the BS is able to forward data packets through this service flow for the subscribers.

With respect to the supported convergence sublayers, the WXL system supports Ethernet, VLAN tags, IPv4 and IPv6 CSs for packet classification. To manage the service flows and their status, both static and dynamic models are defined. The static model is used for medium- and long-term QoS reservations, triggered by the Network Management System (NMS). In this case, the service flow must pass through all the existing status (Provisioned and Admitted) until it reaches the Active one. In the dynamic model, the service flow can be directly activated without traversing the remaining status. This model is suitable for real-time services that require instantaneous allocations of service flows on the WiMAX path. Figure 5 illustrates the WXL QoS Management Service (QMS) framework.

Fig. 5. WXL QoS Management Services Framework

Moreover, the QMS is also responsible for deciding on new QoS requests through the Admission Control Manager. The Admission Control Manager verifies if the available resources in the WiMAX link are enough to satisfy the requirements of the new QoS request. If enough resources are available, the service reservation is accepted. On the other hand, if

resources are not available to satisfy the requested QoS parameters, the Admission Control Manager will have to analyze the Service Class and the Priority parameters from the new service flow and compare it with the already existent service flows in the WiMAX link. Based on this evaluation, a lower priority service flow can be downgraded and hence the new QoS request is accepted, or the new QoS request is rejected.

Figure 5 also illustrates the QoS Parameters Manager, which is responsible for performing the translation of generic network QoS parameters (e.g. DiffServ) to WiMAX specific QoS parameters, described in IEEE 802.16d/e standard.

4.2 WXL Vendor Independency Management Service

To cope with the complexity that the increasing heterogeneity brings into future communication networks, we propose the **Vendor Independency Management Service (VIMS)**, a common solution that applies to different WiMAX vendor equipments. This service provides architecture independence, as much as possible, from the WiMAX equipments manufacturers. To achieve this level of independency permits that different WiMAX equipments can be seamlessly integrated and supported without requiring modifications over the remaining architecture modules and interfaces. Figure 6 presents the Vendor Independency Management Service (VIMS).

Fig. 6. Vendor Independency Management Services (VIMS) Framework

Internally, this service is composed by a Generic Adapter (GA) module and one or more Vendor Specific Adapter (VSA). The Generic Adapter (GA) allows the convergence between different Vendor Specific Adapters (VSAs) for the adaptive applications and processes. The Generic Adapter provides an abstraction of the hardware management functions. All details are hidden from the upper modules, allowing the use of common primitives. To allow this, the Generic Adapter converts the common primitives to more specific primitives, serving

the needs of the Specific Adapters. GA is able to communicate with local and remote VSAs modules using inter-process communication.

The Vendor Specific Adapter deals with the WiMAX equipment specificities. For each vendor specific equipment, a library is implemented providing a differentiated request processing, according to the supported protocol by the WiMAX system (802.16g, SNMP, HTTP, CLI, XML, ...). Each VSA is responsible to fetch information from the WiMAX network elements (allowing important control functions, such as admission control and effective resources control) and to enforce the control decisions triggered by upper layer entities in the WiMAX segment. Hence, its functionalities assume considerable relevance in the global architecture.

Summarizing, in order to support an additional WiMAX vendor equipment in the WXL system, minor modifications are required. More precisely, it is only necessary to design and implement a new VSA, as well as the associated interface without modifying any other module or interface.

5. The WEIRD System: A Practical Use Case of the WXL System

This section presents a practical use case to show the implementation of the WXL for QoS Management (QSM) and Vendor Independency Management Services (VIMS). We consider and describe the proposed architecture in the WEIRD Project (WEIRD, 2008).

Following NGN trends (Knightson, 2005), the WEIRD system (Guainella, 2007) follows a multi-plane structure. Vertically it is composed by two stratum - the Applications and Service Stratum responsible for the management and control of the applications, and the Transport Stratum responsible for the resources management, as well as the data transport. Horizontally, the WEIRD architecture is split into three well-known parallel planes - Management, Control and Data Plane.

Figure 7 depicts the WEIRD Control Plane modules and interfaces. Although the WiMAX NRM is used as the basis of the architecture, new modules have been defined on the Control Plane to efficiently support real time services with QoS differentiation. Both SIP (Rosenberg, 2002) and legacy applications are supported. For SIP-based applications, the SIP User Agent (SIP UA) in the MS communicates directly with the SIP Proxy at the CSN. For legacy applications, a specific module is specified for the MS - the WEIRD Agent - which adapts and configures the QoS parameters as required by legacy applications.

The Connectivity Service Controller (CSC) modules, located at all NRM entities, include the most important functions of the system. Since WEIRD is focused on the ASN segment, the CSC at the ASN (CSC_ASN) is the main coordination point for QoS functions, such as resource allocation and admission control in the ASN and the WiMAX segments. For SIP applications, the SIP Proxy extracts the QoS parameters from the SIP/SDP messages, performs user authentication and authorization with the AAA server, and forwards the collected QoS information to the CSC_ASN using a Diameter (Gq/Gq') (Calhoun, 2003) interface.

Fig. 7. WEIRD architecture – Control Plane

CSC_MS communicates with the WEIRD Agent to obtain the QoS parameters required by the legacy applications and provides this information to the main QoS coordination point (CSC_ASN). When the CSC_CSN receives the QoS reservations requests from the CSC_ASN, it establishes the QoS paths on the core network. Moreover, the CSC_ASN has an interface with the Network Management System (NMS) for medium- and long-term functions, such as QoS provisioning.

The communication between the several CSCs (MS, ASN and CSN) is performed through the usage of the Next Steps in Signaling (NSIS) QoS signaling protocol (Hancock, 2005). NSIS decomposes the overall signaling protocol suite into a generic (lower) layer and specific upper layers for each specific signaling application. At the lower layer, General Internet Signaling Transport (GIST) (Schulzrinne, 2007) offers transport services to higher layer signaling applications. Above this layer, the NSIS Signaling Layer Protocol (NSLP) (Manner, 2007) supports any protocol within the signaling application layer.

All functions related with the WiMAX system are managed and controlled by the WXL system described in Section 4. It contains the Resource Controller (RC) module for QoS Management Services (QSM), including service classes, service flows and convergence sublayer classifiers control (e.g. Ethernet, IPv4 and IPv6 classification), as well as for admission control tasks on the WiMAX link. Furthermore, the RC acts as an abstraction layer for QoS between the upper parts of the architecture and the lower level modules. It

hides all QoS WiMAX technology related functionalities from the upper layers, keeping them independent and oblivious of WiMAX-specific QoS characteristics. To enforce the QoS decisions on the WiMAX BS, the RC triggers the Vendor Independency Management Service (VIMS) through the Adapter module that will communicate the decisions to the WiMAX BS through an SNMP interface. The initial proposed model of the WiMAX Adapter is presented in (Nissilä, 2007). As previously described in Section 4, it is split into a Generic Adapter (GA) component and one or more Vendor-Specific Adapter (VSA) modules. From all modules defined on the WEIRD architecture, VSAs are the only dependent on the specific WiMAX equipment used. As an example, Figure 8 illustrates the signaling between the different entities involved in the QoS reservation process. The signaling for QoS modifications and deletions is similar.

Fig. 8. QoS reservation signalling diagram

6. Performance Evaluation

We tested the proposed resource control framework, encompassing the WXL system for both QoS Management (QSM) and Vendor Independency Services (VIMS), in the Portuguese (for the Redline Communications WiMAX equipment) and Finnish (for the Airspan WiMAX equipment) testbeds, based on the WiMAX NRM, as illustrated in Figure 9. Particularly, the testbed is composed by the CSN, the ASN and the CPN. Under the ASN we have the BS directly connected to the ASN-GW. Two SSs are connected to the BS creating a Point-to-Multipoint (PMP) topology for the Radio Access Network (RAN). Our tests focus on evaluating our system with respect to efficiently managing the WiMAX system and integrating it with a NGN IP architecture. Specifically, we evaluate the performance of the WXL system regarding QoS integration in a vendor independent WiMAX RAN. Each module in the chain has been evaluated, as well as the overall path towards the WiMAX system.

Fig. 9. WEIRD testbed

The Redline Communications certified WiMAX equipment has been used since it fully supports the evaluated QoS actions: reservations, modifications and/or deletions. The results obtained for every specific QoS action that has been evaluated for a specific number of service flows (2, 8, 32, 64, 128 and 256) in both uplink and downlink directions, comprise the mean of three runs.

6.1 Overall QoS Tests

This section presents the results of QoS sessions establishments, modifications and deletions. Figure 10 illustrates a stacked column graphic, where each column represents a specific module of the ASN-GW (CSC, RC, GA and the Redline Communications Specific Adatper - RSA).

Fig. 10. QoS reservation, modification and deletion measurements

Each stack column is further split in three parts, each one corresponding to a specific action, namely, QoS session establishment (blue), modification (purple) and deletion (white). For each action, the vertical axis represents the cumulative average time (in milliseconds - ms) to enforce a specific action on the WiMAX system. As an example, the blue part of the CSC column represents the cumulative average time, composed by the CSC, RC, GA, RSA and WiMAX BS modules, to establish the SF reservations in the WiMAX system. The blue part of the RC column describes the QoS reservation cumulative average time, composed by the RC, GA, RSA and WiMAX BS, whereas the blue section of the GA column provides the cumulative average time, given by the GA, RSA and WiMAX BS modules. Finally, the RSA column represents the internal module processing time, as well as the SNMP management messages exchange with the WiMAX BS. On the horizontal axis is represented the number of SFs (2, 8, 32, 64, 128, 256) that have been used for each test. Therefore, each group of four columns represents a specific performance test.

Comparing the obtained results with respect to the type of actions that are being requested to the WiMAX system, we show that the required time to establish a QoS reservation (blue) is approximately 53 % of the total time consumed. The rationale for this behavior is due to the fact that the amount of operations required by the WiMAX system for a QoS reservation is higher when compared to the modification and deletion processes. Figure 10 also shows that the most time consuming module is the RSA, mainly because it includes the negotiation of the QoS parameters between the BS and the SS through the usage of the DSA/C/D (Dynamic Service Addition / Change / Deletion) messages, as defined in the IEEE 802.16 standard, which is the major time consuming process in the chain. The average time taken by the RSA to perform the three actions has a minimum of 17,9 ms for 2 SFs up to a

maximum of 20,9 ms for 256 SFs, with small impact on the increase of SFs. The time spent by the remaining modules is due to the message flow and internal processing. The average time measured on the CSC to reserve 256 SFs is 15 ms; moreover, 6 ms are required to modify the previously established SFs and then, finally, 6 ms are required to delete the 256 SF reservations at the end of the flow lifetime. In this case, the entire management of the 256 flows required approximately 27 ms.

In short, an increasing number of SFs slightly raises the time spent to establish, modify and delete the QoS sessions. This behavior occurs because the number of entries in the hash tables increases, as well as the interaction with the SNMP Management Information Base (MIB) (Case, 2002; McCloghrie, 1999) tables in the WiMAX BS. The overall elapsed time is very good for real-time applications and fast mobility environments, ensuring a desirable quick resource reallocation, from 21 ms for 2 SFs up to 27 ms for 256 SFs.

6.2 Redline Specific Adapter Tests

This section is devoted to the discussion and analysis of the RSA performance results. A considerable set of times was collected in order to analyze the time distribution along the different tasks accomplished by RSA. The RSA is the Vendor-Specific Adapter module from the WXL VIMS that interacts with the Redline WiMAX equipment. Thus, the total time spent from the reception of a request (SF Reservation / SF Modification / SF Deletion) to the sending of the correspondent answer to the GA was obtained; the partial times were also gathered, in order to distinguish between the internal processing time of the RSA module and the time it takes to set each SNMP MIB table. Figure 11 illustrates the RSA performance times. The RSA Resv/Mod/Del Total Path blocks show the total time used up by RSA to process each request, that is, the entire path since it receives a request from the GA, until it sends back the response to the latter. The RSA Resv/Mod/Del Total SNMPSET blocks represent the sum of all SNMPSET times needed, respectively, for a SF reservation, modification, or deletion. Finally, the RSA Resv/Mod/Del Internal Processing blocks represent the internal processing time of RA routines.

As can be observed in Figure 11, the RSA internal processing time is so small that the total path time is almost not affected, and therefore unseen on the graphic bars. In the worst case, the internal processing time is less than 55 μ s. This case occurs when 256 SFs are deleted, which causes the module to deal with considerable processing work when looking for the associated indexes to set the SNMP MIB tables (IEEE 802.16 b, 2005).

Another conclusion taken from the graphic is that QoS session's establishment takes more time than the deletion ones, and these, in turn, are more time consuming than the modification requests. Furthermore, we can also perceive that there is a slight increase of time when the number of SFs increases. Nevertheless, these values are kept stable, showing that the RSA and the WiMAX equipment are prepared to deal efficiently with a large number of sequential requests. Finally, the differences between the RSA Resv/Mod/Del Total SNMPSET processing times are due to the different amount of Object IDs (OIDs) that have to be set on the WiMAX MIB, which is larger for the reservation requests when compared to modifications or deletion ones.

Fig. 11. RSA performance times

Table 2 details all the SNMP MIB Tables, and the correspondent OIDs number that are assigned when performing a SF Reservation, Modification and Deletion.

SF Request: MIB Tables	Function	OIDS
DEL : <i>ServiceClassTable</i>	Contains the SF QoS parameters	1
MOD : <i>ServiceClassTable</i>		5
RESV : <i>ServiceClassTable</i>		12
DEL : <i>ProvisionedSfTable</i>	Contains the SF profiles provisioned by NMS	1
RESV : <i>ProvisionedSfTable</i>		5
RESV : <i>ProvisionedForSfTable</i>	Maps the MAC addresses of SSs to the provisioned SFs	1
RESV : <i>ClassifierRuleTable</i>	Contains packet classifier rules associated with SFs	14

Table 2. WiMAX QoS MIB Tables

Figure 12 shows the time spent by every single SNMP MIB table set. Once again, the inherent processing time is coupled with the increased number of SFs requests, increasing as we increase the number of sequential requests. Furthermore, the time taken to process each SNMPSET is also strictly related with the number of OIDs that must be set in each operation – the larger the number of OIDs to assign, the larger the time spent on performing this task by the equipment. The differences that occur when setting distinct SNMP MIB tables with the same OIDs number are due to the inherent processing time of WiMAX equipment for

those tasks. For instance, erasing an existing SF by the WiMAX equipment is more time consuming than just performing an amendment to the QoS parameters of an existing one. Moreover, as an example, when deleting a *ProvisionedSfTable* row entry, we are in fact deleting, at the same time, all the associated entries in *ProvisionedForSfTable* and *ClassifierRuleTable*. For that reason, the deletion process when erasing elements of *ServiceClassTable* is smaller than when deleting elements from *ProvisionedSfTable*.

Fig. 12. Single SNMPSET performance times

7. Conclusions

This chapter presented a NGN architecture integrating WiMAX, able to support and differentiate real-time services in mobile environments. To provide several services in the network (such as mobility, QoS, network management, AAA and multicast/broadcast services) independently from the equipment specific functionalities, between the WiMAX technology and the higher layer entities of the designed architecture, a WiMAX Cross-Layer (WXL) system was specified and implemented. This system provides independency between the network control plane and the WiMAX system through standardized IEEE 802.16g functionalities. The presented system architecture, developed as a practical use case in the WEIRD project, comprised, integrated in the WXL, a Resource Controller and WiMAX Adapter modules for the support of QoS reservations, modifications and deletions.

In order to validate the WXL system, and the consequent support of QoS resource management of both Resource Controller and Adapters, QoS measurements have been performed in a WiMAX certified testbed. The results obtained from the real deployment of this architecture in the testbed have shown that the processing times for the QoS reservations, modifications and deletions are very small, even for a large number of simultaneous reservation requests, which enable the use of the WiMAX based architecture in NGN real-time and mobile environments without traffic disruptions.

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WIMAX New Developments

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WiMAX (Worldwide Interoperability for Microwave Access) is a wireless broadband access network named by industry group called the WiMAX forum formed in June 2001. It is Wireless MAN with IEEE 802.16 family standards. Loosely, WiMAX is a standardized wireless version of Ethernet that enables the last mile, intended primarily as an alternative to wire technologies (such as Cable Modems, DSL and T1/E1 links) to provide broadband access to customer premises. Mission of the WiMAX forum is to promote and certify compatibility and interoperability of broadband wireless products. This book touches most of the above issues in form of 22 individuals' papers containing research work in WiMAX domain in particular. WiMAX has two important standards/usage models: a fixed usage model IEEE 802.16-2004 for Fixed Wireless Broadband Access (FWBA) and a portable usage model IEEE 802.16e-2005, which is mainly concentrated on Mobile Wireless Broadband Access (MWBA). Both are released as standards and amendments are available in form of drafts. Higher data rate transmissions (@ 100 Mbps) are achieved in IEEE 802.16-2004 WiMAX through LOS communications which incorporate a stationary transmitter and receiver but IEEE 802.16e supporting NLOS communication is much complicated and little less bit rate is achieved. 2-11 GHz licensed band is the range of frequencies with TDD and FDD supports. The book will provide a wide horizon to visualize the WiMAX technology and its developments leading towards 4G systems. It will provide a good platform to the researchers with clues to the innovative ideas in WiMAX domain. I wish all the best to the authors and readers of this book in their successful research of WiMAX technology.

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