Quality of Service and Mobility Support in WiMAX Networks

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Abstract **- This paper presents the enhancement of the IEEE 802.16 Broadband Wireless Access (BWA) technology with automate Quality of Service (QoS) and resources management integration attending to the inherent requirements of Next Generation Networks. A novel IEEE 802.16 based architecture is presented, focused on a new designed and implemented model named 802.16 System Manager. The later is responsible to fetch information from the WiMAX network elements in order to accomplish important control functions, such as admission control, effective resources control, load balancing, and enforcing the control decisions in the hardware. It is also depicted in this document how the 802.16 System Manager can be integrated in heterogeneous environments regarding QoS and mobility support. The work was developed concerning the needs to efficiently utilize the resources at the data link level. Hence, performance tests were performed for the two distinct modes of operation, point-to-point and point-to-multipoint, proving at the same time the stability and efficiency of the management application.**

I. INTRODUCTION

Worldwide Interoperability for Microwave Access (WiMAX) [1] is a standard-based wireless broadband solution that has emerged as one of the major candidates for next generation wireless networks. It is a technology that offers high-speed wireless internet and data network access over a wide area, offering users unique benefits and convenience, since it brings the broadband experience to a wireless context. As defined in [2], there are two different types of broadband wireless services: Fixed Wireless Broadband (FWB) defined in IEEE 802.16-2004 [3] and Mobile Wireless Broadband (MWB) presented in IEEE 802.16e-2005 [4]. The FWB provides a set of services similar to the ones offered by the traditional fixed-line broadband but using wireless as the medium of transmission. On the other hand, the MWB provides the additional functionality of portability, nomadicity and mobility.

WiMAX continues to gain tremendous momentum in the market, enabling advanced multimedia applications with its high-data rates, catching the attention with its low-cost infrastructure and addressing several different types of potential customers and situations, especially where alternative DSL solutions [5] are either not available or not economically viable. As the standard evolves from nomadicity to mobility support [4], WiMAX is assumed as the major candidate to lead the standardized BWA technology.

WEIRD [6] project, in which the developed work is contextualized, specifies an architecture to achieve end-to-end QoS and mobility support in WiMAX networks. With this scenery as background, the focus of this work was the specification and development of an 802.16 System Manager to interface with an WiMAX Forum compliant equipment, supplied by Redline Communications [7], using the SNMP protocol. The interface with the WiMAX network, either triggering service flows requests or retrieving resources data or other important information, assumes a remarkable importance in the specified architecture in order to accomplish service flow management, resources management and other functions like admission control, network load balancing or fault detection.

The 802.16 System Manager, called Adapter, intervenes at the level of the service flow management and resources management of the WiMAX network and performs automatically the 802.16 network discovery. It makes use of an SNMP interface to perform the service flow management but uses a combined SNMP/CLI interface to accomplish the resources management and the WiMAX network discovery, showing a way to overcome equipment limitations when a SNMP interface does not exist. The work has been developed with a FWB equipment (802.16-2004 compliant), but this does not invalidate the possibility to reuse some of the developed modules with MWB, 802.16e-2005.

This paper is organized as follows. In section II we summarize the main aspects of the accomplished work relating some background pointers about the 802.16 technology. Section III details the developed architecture for the support and integration of full QoS. Afterwards, section IV presents and discusses the performance results. Finally, section V states some conclusions.

II. BACKGROUND

The IEEE 802.16f standard document [8], which amends IEEE 802.16-2004 by defining a Management Information Base (MIB) [9] [10] for the MAC and PHY layers, has been the basis of the developed work. Alternative ways to overcome the limitations associated with the equipments that are not yet 802.16f compliant, but use other viable interface with the 802.16 hardware are also mentioned in this section. Since the work presented in this paper brings together concepts like QoS, management and mobility, following two sub-sections describe the inherent QoS and mobility features of the 802.16 technology. The remaining sub-sections depict the main requirements of heterogeneous environments, and the features envisioned for the 802.16 system manager.

A. Quality of Service in IEEE 802.16 technology

WiMAX inherently supports QoS as a fundamental part of its MAC layer design. QoS control is achieved by using a connection-oriented MAC architecture, where all downlink and uplink connections are controlled by the serving Base Station (BS). Only after the establishment of a transport connection – defined as an unidirectional link between a BS and a Subscriber Station (SS)/Mobile Station (MS) and identified by a *Connection Identifier* (CID) – it is possible to transmit data over the WiMAX network. Besides the transport connections, during the WiMAX system setup process three management connections are established (basic, primary and secondary).

Another important fact is the Service Flow (SF) definition in WiMAX. A SF is a unidirectional flow of packets with a particular set of QoS parameters; each allocated SF is identified by a particular *service flow identifier* (SFID). The QoS parameters can be, for example, the maximum sustained traffic rate, maximum burst rate, minimum tolerable rate, scheduling type, maximum delay, tolerated jitter and traffic priority. The WiMAX system then maps the SFIDs into unique CIDs. Service flows can also be mapped to DiffServ [11] code points or MPLS [12] flow labels to enable end-to-end IP-based QoS.

In order to support a wide variety of applications, WiMAX defines five distinct scheduling service classes:

- ***Unsolicited Grant Service (UGS)***, designed to support constant bit-rate applications, such as T1 emulation and voice over IP (VOIP) without silence suppression.
- ***Real-Time Polling Service (rtPS),*** for applications that generate periodic variable-size packets, like MPEG and VOIP with silence suppression.
- ***Non-Real-Time Polling Service (nrtPS)***, which supports applications like FTP that generate variable-size packets on a regular basis.
- ***Best Effort (BE) Service***, for low-priority applications like Web surfing.
- ***Extended real-time polling service (ertPS)***, a new scheduling service introduced with the IEEE 802.16e standard that builds on the efficiencies of UGS and rtPS.

To implement the QoS levels, the BS polls the SSs for bandwidth requests and schedules the requests it receives. The frequency and regularity of the polling depends on the QoS type of each SS connection. For example, rtPS connections receive periodic unicast polls, while BE connections are never polled individually, but must respond to multicast “contention request opportunities” or piggyback their requests on data traffic.

B. Mobility Support by the IEEE 802.16 technology

In addition to fixed broadband access and as stated in [2], WiMAX envisions four mobility-related usage scenarios:

- **Nomadic**. The user is allowed to take a fixed subscriber station and reconnect from a different point of attachment.
- **Portable**. Nomadic access is provided to a portable device, such as a PC card, with expectation of a best-effort handover.
- **Simple mobility**. The subscriber may move at speeds up to 60 km/h with brief interruptions (less than 1 sec) during handoff.
- **Full mobility**: Up to 120 km/h mobility and seamless handoff (less than 50 ms latency and <1% packet loss) is supported.

WiMAX networks will initially be deployed for fixed and nomadic applications and then evolve to support portability to full mobility over time.

C. Requirements for Heterogeneous Environments

The achievement of end-to-end QoS [13] [14] requires novel mechanisms in both the control and data plane. This paper is focused on the control plane mechanisms, related with negotiation that occurs between the user and the network in order to agree on the required QoS specifications and let the network appropriately allocate resources to each service. This negotiation is done through the means of signalling mechanisms, and its description goes beyond of this paper.

In heterogeneous environments, since the main goal is the integration of different technologies, the lower modules must be technology dependent. Therefore, it is mandatory to have an abstraction layer in order to allow a seamless integration of the distinct technologies. The abstraction layer manages the technology dependent modules, either by sending QoS requests to them or by collecting the required information from the technology in order to perform an efficient management of the air link resources, as well as admission control and policy management. In this sense, the interface with the WiMAX equipment assumes here remarkable relevance, since this is the module that enforces the QoS requests in the later and retrieves all the required information for the upper layer modules. According to the previously mentioned requirements, the 802.16 System Manager, acting as the technology dependent module, has been developed. It enforces QoS requests from the upper layer modules in the 802.16 network, respecting completely the 802.16f standard, and retrieves resources and topology information, which is crucial for the effective implementation of admission control mechanisms. Moreover, it allows a more efficient and precise control of the network and its elements.

D. WEIRD 802.16 System manager

Figure 1**Error! Reference source not found.** illustrates the simplified network topology that has been used in our developments.

In WEIRD project, the 802.16 System Manager, denoted as Adapter, interfaces with the resource controller in the ASN-GW and with the SNMP Agent module in the BS. The Adapter uses the SNMP protocol [15] when communicating with the SNMP Agent module, and alternatively the CLI/TELNET interface to obtain the required information when the SNMP interface is not available.

The WiMAX devices used to accomplish this work provide three distinct interfaces: HTTP, CLI/TELNET and SNMP. The SNMP protocol is the most proficient mean to interface with the WiMAX devices, but important information was not mapped in the MIBs of the equipment, so it was needed to find alternatives to get that information. The TELNET interface is considerable more efficient than the HTTP interface, so the choice of the CLI/TELNET interface was natural.

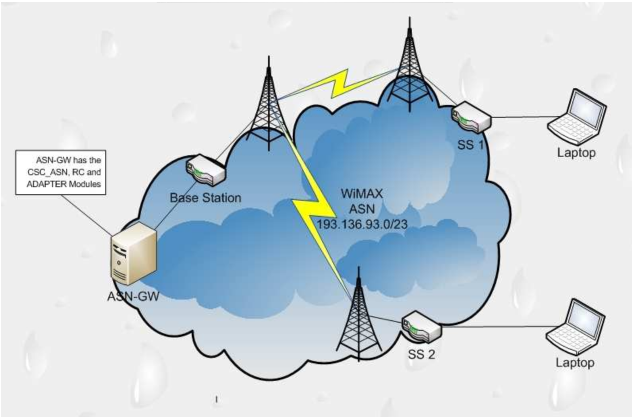

Figure 1: Access Service Network Topology

In order to be independent of the WiMAX equipment being used, the Adapter is further split into a common part, denoted as Generic Adapter, which abstracts which vendor equipment is being used, and a set of Vendor specific libraries to provide a differentiated SNMP request processing for each specific equipment vendor. In our case, the *Redline Communications Specific Adapter* has been implemented to interface with the WiMAX Redline Communications equipment.

The main features provided by the *WEIRD Adapter* are the following:

- Service Flow Management
- Resources Management
- Dynamic 802.16 Network Discovery

Service flows management is the capacity to manage and enforce the received QoS reservations, modifications and deletions requests in the Redline WiMAX equipment, using IPv4 and 802.3 Ethernet as the Convergence Sublayer (CS).

Resources Management consists in the aptitude to respond upon resources requests, collecting information from the 802.16 network as RF, Physical and MAC Parameters, including downlink and uplink available bandwidth for the SSs and packing that information to the higher layer management entities.

Finally, the Dynamic 802.16 Network Discovery is the ability to detect new SSs and BSs that join the WiMAX network, building the complete network topology in WiMAX segment in a dynamic way, and supplying at the same time relevant Physical and MAC parameters to the Network Management System. This WiMAX network discovery feature is implemented over the SNMP traps support by the Redline Communications WiMAX equipment.

III. 802.16 SYSTEM MANAGER ARCHITECTURE

This section describes the details of the developed Adapter architecture.

During the specification phase, it has been necessary to take into account the Redline Communications equipment limitations:

- Lack of support for important MIB objects related with resources management
- Lack of scheduling services: BE and rtPS

To implement all the Adapter functionalities, and according to the mentioned equipment limitations, it was necessary to carefully specify the Adapter architecture in order to achieve highest level, as possible, of transparency, openness, scalability and robustness [16]. When considering all these aspects, it is possible to reach a good abstraction level and build a better application, which can be easily modified/updated or integrated with other applications. All these premises were taken into account when specifying and implementing the Redline Adapter architecture, which is illustrated in**Error! Reference source not found.** Figure 2.

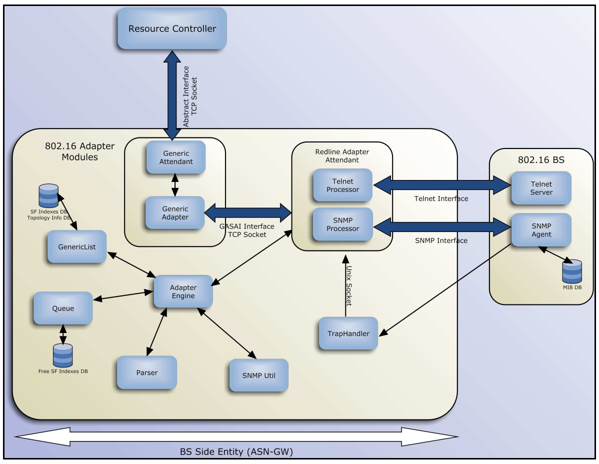

Figure 2: Adapter Architecture

The Adapter is composed by several modules and interfaces. The AI (Abstract Interface) is the interface defined between the Resource Controller and the Generic Adapter. The Generic Adapter is composed by the Generic Attendant and Generic Engine that abstracts the Vendor Specific Adapter that is being used. This module interfaces with the Vendor Specific Adapter through the GASAI Interface.

From now on, we will present a brief summary of the main functionalities of each module that composes the Redline Adapter:

***RedlineAdapterAttendant* –** Here is where all communication takes place. This module is responsible to maintain and manage the communication between the Generic Adapter, the BS and the *TrapHandler*. It multiplexes all the message requests by the use of a *select* function. It also launches the needed instances in order to setup the system and process all the requests that are sent to the *RedlineAdapterAttendant*. The *RedlineAdapterAttendant* is listening for asynchronous events that can be generated by the WiMAX network elements – BSs or SSs. Simultaneously, the *RedlineAdapterAttendant* is expecting Generic Adapter requests as well. Accordingly to the request received from the Generic Adapter, it uses the SNMP or the TELNET interface with the equipment to process the request; then it sends the response back to the Generic Adapter. For example, if a SF creation, deletion or modification request is received, the SNMP interface is used, whereas if a resources request is received, a combined CLI Telnet interface is used.

***AdapterEngine* –** It concentrates the main intelligence of the application. Almost all the processing work is done here. It processes the request and trap messages that are sent to the Redline Attendant. The processing work includes the conversion of the higher layer messages into SNMP messages (GET, SET) and vice-versa. It also converts the trap messages into comprehensive format to forward to the upper modules. As occurs with all modules, error checking is included to maintain the robustness and consistency of the application, assuring that the requested values are between the limits supported by the equipment.

***TrapHandler* –** It is a thread that interacts with the NET-SNMP [17] *TrapHandler*. The NET-SNMP *TrapHandler* receives a trap and redirects the trap Information to the standard input (STDIN). The *RedlineTrapHandler* is basically monitoring the STDIN and, according to the trap type received, it parses the STDIN, saves the trap information into the *struct trap_info* and sends it to the *RedlineAttendant* that will finish the processing.

***SnmpUtil* –** This module implements the low level primitives that interact with the BS, using the SNMP protocol. The NET SNMP API [17] was used in order to implement the *snmp_set* and *snmp_get* primitives that interact with the 802.16 equipment through the SNMP Protocol. It was also implemented one method to automate the SNMP session initiation supporting both the SNMPv2 and SNMPv3, to allow for future evolution of the SNMP agent. Two types of *snmp_get* primitives were implemented: one that gets a unique object identifier value by session, and other one, the *multi_get* that can be used to request multiple variables in one single session, packing the requested Object IDs (OIDs) into the same PDU.

***Parser* –** The *Parser* module is the one that makes possible the *get* of the primitive parameters that are not mapped in the BS SNMP Agent MIB, through TELNET. To implement this feature, several alternatives exist. One possible solution would be to use a TELNET JAVA API, but this would increase the integration difficulties with the developed C application. This way, the adopted solution was to automate telnet sessions through the use of scripts: the telnet session information that is written to the STDOUT is redirected to a file that is parsed after the telnet session finishes (this is an efficient way to obtain hardware information when the SNMP protocol is not supported).

***Queue* –** It implements a FIFO of integer values that is used to save the service flow indexes that are set free when a service flow is deleted.

***GenericList* –** Implements a generic and dynamic list module that can handle all kinds of data needed by the *RedlineAdapter*. This module defines the service flow index structures and topology information structures that save all the topology information (BSs and SSs information). The service flow indexes structure saves all the associated indexes needed to modify or delete a previous reserved service flow.

Adapter Operation

When the system is initialized, the 802.16 network is detected – i.e., the Adapter detects the SSs and BSs. The Topology Information is saved in the correspondent database, and a message is sent to inform the upper modules. Any other SS or BS can join the system during the initiation procedure or later during the normal operation. Afterwards, the upper modules interfacing with the Adapter can start sending service flow management or resources management requests. If the 802.16 network topology changes during this phase, the upper modules are informed.

IV. ARCHITECTURE EVALUATION

The 802.16 System Manager functionalities have been tested with varied parameters in order to validate the implemented work. The performance tests were accomplished for two distinct modes of operation, the point-to-point and the point-to-multipoint.

These results were obtained for a 256K bandwidth allocation request. Half of the samples are from the downlink direction and the other half are from the uplink direction. The time values represent the round-trip delay of SNMP request via Ethernet link in milliseconds.

Figure 3 illustrates the mean reservation time per flow.

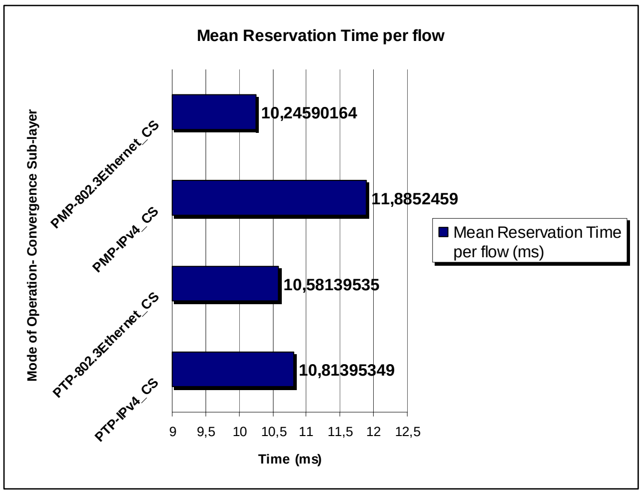

Figure 3: Mean Reservation Time per Flow

The results show that the performance is independent of the mode of operation of the 802.16 network and independent of the CS being used. The largest value of reservation time is below 12 *msec*. Using distinct CS or requesting a high amount of service flow reservation requests does not interfere with the performance as can be observed in Table 1, since the mean reservation time per flow does not increase with the number of reservations.

Service Flow Reservations Number	Time (ms)	Mean Reservation Time per flow (ms)
1	10	10,81395349
5	60	
10	110	
20	230	
50	520	
100	720	10,6
500	5640	

Table 1: Reservation Time accordingly to the SFs resquest number

The following graphic illustrates the service flow management limit time per flow. Besides the reduced reservation times, the implemented solution has shown that the service modification and deletion times stay under the 5 ms. The variations are very small and, in practice terms, they can be considered as null.

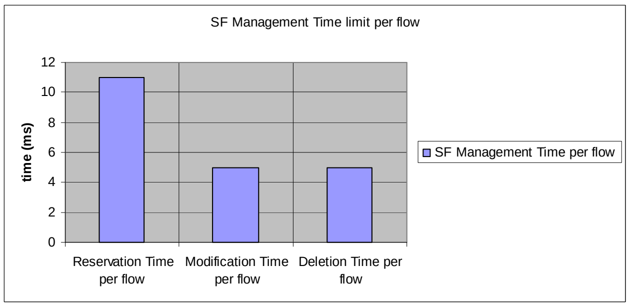

Figure 4: SF Management Time Limit per Flow

V. CONCLUSION AND FUTURE WORK

This paper addresses the real-time and dynamic support of QoS in the IEEE 802.16 technology, depicting ways to overcome some of its limitations. We have designed and implemented the 802.16 System Manager to automate service flow and resources management in the WiMAX network in order to achieve an architecture with end-to-end QoS and mobility support.

The developed 802.16 System Manager was mainly based in the SNMP protocol and enforces the QoS requests received from upper layers into the Redline WiMAX equipment using the SNMP protocol. On the other hand, alternative ways to implement the required functionalities without the SNMP protocol have also been addressed. Moreover, performance measurements were done considering distinct modes of operation and different requests number, showing the stability and flexibility of the 802.16 System Manager. The developed work enhanced the WiMAX as a broadband wireless access network supplying full QoS support and mobility, key features in the demanding next generation networks.

The experiments accomplished along the project confirm the expectations related to the 802.16 technology in terms of performance, allowing high quality audio and video communications under a variety of usage scenarios.

As future work, some improvements can be performed, especially improving the admission control module, and updating the Adapter considering the 802.16e standard.

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