A QoS Model based on NSIS signalling applied to IEEE 802.16 networks

Nicola Ciulli[1], Giada Landi[1], Marilia Curado[2], Gabriela Leao[2], Thomas M. Bohnert[2], Fabio Mitrano[3], Cristina Nardini[3], Gabriele Tamea[3]

[1]Consorzio Pisa Ricerche (CPR)
[2]University of Coimbra
[3]University of Rome "Sapienza"

Abstract **- IEEE 802.16 networks provide mechanisms for QoS support at MAC level, but end-to-end QoS issues are not addressed in detail in the standards. This paper presents an analysis and an experimental validation of a comprehensive solution that describes and implements end-to-end QoS in networks with IEEE802.16e segments. A complete QoS model has been specified, defining the traffic descriptors, the QoS parameters and the resource management functions for networks with WiMAX access. This QoS model has been applied to the Next Step in Signalling (NSIS) protocol suite and its impact has been evaluated on end-to-end QoS when heterogeneous network domains are involved. This work is based on the of results of activities focussed on the study of signalling protocols, carried out within the EU Integrated Project WEIRD (WiMAX Extension to Isolated Research Data networks).**

I. INTRODUCTION

In recent years, Broadband Wireless Access (BWA) technologies have been developed by integrating the multiplicity of high speed broadband wired technologies, like xDSL and Ethernet LANs, with the flexibility of wireless connections, like IEEE802.11 [1]. In the framework of a continuous improvement of the available throughput and radio signals coverage, IEEE802.16 project (commonly known as WiMAX) emerged as one of the most promising standards for BWA. In fact, WiMAX is capable of reaching remote areas with high data rate transfer, mobility support and a native Quality of Service management (even if just limited to the wireless IEEE802.16 links) [2, 3].

Focusing on QoS issues in WiMAX, current research is still missing an investigation of the QoS assurance problem in an end-to-end scope. This paper tries to fill in this gap by defining a new framework, compliant with the end-to-end architecture defined by the WiMAX Forum [5] and integrated with the Next Steps In Signalling (NSIS) architecture [4]. A new QoS model for WiMAX domains will be presented, with a definition of the related QoS parameters, traffic descriptors and Resource Management Function (RMF) for QoS provisioning. The NSIS protocol mechanisms have been used in order to assure inter-domain QoS signalling between the WiMAX segment adopting the proposed QoS model and external domains. The presented approach is discussed by taking into consideration the coherence of the end-to-end QoS signalling along heterogeneous networks possibly exporting different QoS mechanisms.

The paper is organized as follows. The state of the art in BWA, especially in WiMAX, is briefly described in section 2 along with the issues concerning end-to-end QoS support. The proposed QoS model and the NSIS signalling innovation to support end-to-end QoS with WiMAX access networks are described in section 3. The remaining section 4 describes a real scenario where the proposed solution is deployed and validated.

II. STATE-OF-THE-ART

The IEEE 802.16 Working Group defines the air-interface specification for Metropolitan Area Network in the IEEE802.16d [2] and IEEE802.16e [3] standards. The former defines the PHY and MAC layer for fixed networks, while the latter describes the extensions for mobility support. The standards also define a connection oriented approach for QoS support: Service Flows (SFs), MAC transport services that provide unidirectional transport of packets between the Base Station (BS) and the Mobile Station (MS), are created per-connection with information on scheduling classes, QoS parameters and classifiers. The scheduling classes defined by the IEEE 802.16d standard are: *Unsolicited Grant Service* for real time uplink SFs with fixed size data packets on a periodic basis, *Real-Time Polling Service* (rtPS) for real time uplink SFs with variable size data packets on a periodic basis, *Non-Real-Time Polling Service* (nrtPS) supporting delay-tolerant data streams with variable sized data packets for which a minimum data rate is required, and *Best Effort* supporting data stream for which no minimum service level is required. The IEEE 802.16e standard also defines the *Extended Real Time Polling Service* in which the BS provides unicast grants in an unsolicited manner with dynamics allocations. SFs can be created and modified through MAC message exchanges between BS and MS. The exchange of Dynamic Service Addition (DSA), Dynamic Service Change (DSC) and Dynamic Service Deletion (DSD) messages can be BS-initiated or MS-initiated.

While the IEEE standards define only the air-interface between the BS and the MS, the WiMAX Forum [5] provides an IP-based end-to-end WiMAX Network architecture [5], including some specifications for the functionalities supported

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by the Access Service Network (ASN) and the Connectivity Service Network (CSN). In the WiMAX Network architecture, the ASN gateway (ASN-GW), located between the ASN and the CSN, is in charge of the ASN management including, but not limited to, mobility and QoS functionalities.

NSIS protocol suite has been defined as end-to-end QoS signalling protocol. In particular the QoS NSIS Signalling Layer Protocol (QoS-NSLP) [6] is used to signal the application QoS requirements and request the resource allocation along the full path of data flows. The NSIS protocol supports the interoperability between different QoS-enabled domains defining distinct QoS-Models (QOSM) depending on the underlying network technologies. The QoS-Model defines the QoS parameters, the traffic descriptors and the methods to provide the desired QoS through the RMF specification for the NSIS nodes of a specific domain. The QoS parameters and the traffic descriptors are encapsulated in an object called QSPEC [7] and are interpreted by NSIS nodes according to the QOSM.

Two different types of QSPECs are defined: *Initiator* and *Local* QSPEC. The former is created by the QoS NSIS Initiator (QNI) according to its own QOSM and includes both domain-specific parameters, that may be ignored if not understood by the next NSIS peers, and common parameters that should be processed by all the NSIS nodes along the path. The Local QSPEC is created at the edge node between two QoS enabled-domains through a coherent mapping of the Initiator QSPEC parameters. It is added on the top of the QSPEC stack and it is propagated with the Initiator QSPEC, so that the NSIS nodes within the local domain can perform simpler processing and analyze only the local QSPEC. In such scenarios, only the NSIS edge node must support more QoS models, while the internal nodes can support only the local QoS model.

A QOSM for Differentiated Service (DiffServ) networks is described in [8], while QOSMs for IntServ and 3GPP networks are proposed in [9] and [10]. The QOSM for DiffServ networks is evaluated in [11] in an heterogeneous networks environment comprising both wired and wireless networks.

III. A GENERALIZED WIMAX QOS MODEL

The FP6-IST WEIRD project [12] aims at integrating the WiMAX segment in an end-to-end network architecture, with guarantees of end-to-end QoS. Therefore, the resource allocation in the WiMAX radio link needs to be incorporated in a wider framework that enables different applications to obtain consistent QoS guarantees along the complete path, across heterogeneous domains with a variety of QoS characterizations.

The QoS NSLP protocol is adopted to both signal the application QoS requirements and request the resource allocation along the end-to-end path of data flows. The full path includes at least a WiMAX domain and other different QoS-enabled domains, with specific QSPEC parameters and methods to achieve QoS for a data flow. Both these aspects are included in the QoS model supported by each domain.

Currently, NSIS QoS models are defined only for DiffServ, IntServ and 3GPP domains, while a general-purpose WiMAX QoS model is still missing. In the remaining part of this section a proposal for a generalized WiMAX QoS model is presented, describing the QSPEC format and the RMF through a set of QoS architectures for different signalling scenarios. Since one of the main objective is the interoperability between the WiMAX network and other domains, a specific section will be dedicated to the mapping between the WiMAX QoS model and QoS models of external domains, discussing the loss of details in case of translation into QoS models supporting coarser QoS description, and its impact on the end-to-end QoS guarantees.

WiMAX SF parameter	Description	QSPEC parameter
Scheduling Class	Scheduling type enabled for the associated service flow	WiMAX parameter - SchedulingClass
Min Reserved Traffic Rate	Minimum rate reserved for the service flow in bits per second	TMOD - rate
Traffic Priority	Parameter used to determine precedence in request service and grant generation	WiMAX parameter – W_TrafficPrio
Max Sustained Traffic Rate	Peak information rate of the service in bits per second	TMOD – peak data rate
Maximum Traffic Burst	Max burst size that shall be accomodated for the service	TMOD - size
Request - Transmission Policy	Parameter used to specify a set of options for bandwidth requests or PDU formation	WiMAX parameter – RxTxPolicy
Tolerated Jitter	Maximum delay variation for the connection	WiMAX parameter – ToleratedJitter
Maximum Latency	Maximum latency between the ingress of a packet to the Convergence Sublayer and the forwarding of the SDU	WiMAX parameter - MaxLatency
SDU Size	Length of the SDU in case of fixed-length SDU service flow	WiMAX parameter - SduSize
SDU Inter Arrival Interval	Interval between SDU arrivals as measured at MAC SAP	WiMAX parameter - SduIntArrInterval
Unsolicited Grant Interval	Interval between successive data grant opportunities (for UGS)	WiMAX parameter – UnsolicGPInterval (if SchedulingClass = UGS)
Unsolicited Polling Interval	Maximal interval between successive polling grant opportunities (for ErtPS and rtPS)	WiMAX parameter – UnsolicGPInterval (if SchedulingClass = rtPs or ertPS)

Table 1 – Mapping WiMAX Service Flow parameters into the Generalized WiMAX QoS Model

QSPEC

The proposed WiMAX QSPEC includes the mandatory traffic model parameter (TMOD), which defines the traffic descriptors, and WiMAX-specific QSPEC parameters that can be used in order to complete the description of the WiMAX SFs. The proposed QSPEC is based on the IEEE 802.16e QoS framework, so some parameters are not defined in the 802.16 “d” version and can be ignored in 802.16d domains.

The WiMAX SFs are characterized by the parameters described in Table 1. As specified in the table, some of them can be mapped into existing parameters defined by the generic QSPEC specification [7], while a new WiMAX parameter has been defined in order to carry the remaining values. This parameter consists of a container including a set of sub-parameters, following the format of a sequence of 32-bit words (Figure 1). The common header comprises the ID, the length and the flags M, E and N, as defined in [7]. The M flag should be set to 0, so that the WiMAX parameter can be ignored by NSIS nodes that do not support the WiMAX QoS model.

Flags	Container ID	Flags	Length = 4
SchedulingClass	W_TrafficPrio	RxTxPolicy	SduSize
ToleratedJitter			
MaxLatency			
UnsolicGPInterval		SduIntArrInterval	

Figure 1. WiMAX QSPEC parameters

Resource Management Function (RMF)

The IEEE 802.16 standard defines both a BS-initiated and a MS-initiated mechanism to configure the SFs in the wireless link. The proposed architecture adopts the BS-initiated approach, specified as mandatory in the standard. Therefore, the MS acts as an internal node of a WiMAX domain, supporting only the WiMAX QoS model, but it is not in charge of the WiMAX channel configuration. The entity that manages the creation and modification of SFs is the ASN-GW, through a direct interaction with the BSs under its control.

Three different scenarios can be distinguished according to the roles of the MS and the ASN-GW in the NSIS signalling. In the first case (Figure 2) the MS acts as a QNI and creates the Initiator QSPEC following the WiMAX QoS model specification. Such QSPEC is sent to the ASN-GW that acts as a generic edge QNE. This entity performs the resource allocation in the WiMAX link and, since it supports both the WiMAX QoS model and the QoS model of the external domain, is in charge of the QoS mapping and the creation of the local QSPEC for the external domain.

In the second case (Figure 3) the application QoS parameters are transferred from the MS to the ASN-GW using application layer signalling (SIP-SDP). Such parameters are intercepted by the SIP Proxy and notified to the ASN-GW. The Connectivity Service Controller (CSC) on the ASN-GW coordinates the WiMAX resource allocation and the end-to-end NSIS signalling. The ASN-GW has the role of the QNI and creates the initiator QSPEC following the external QoS model format.

The third case concerns the NSIS signalling coming from an external non-WiMAX domain and addressed to the MS, that acts as a QNR. The QNE on the ASN-GW must translate from the external QSPEC into the WiMAX QoS parameters and allocate resources in the radio link.

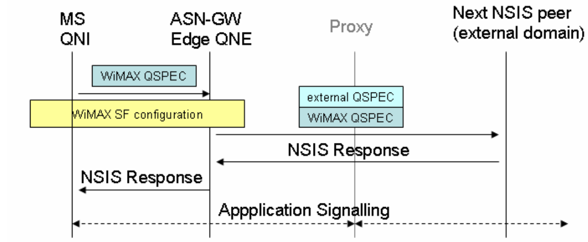

Figure 2. NSIS signalling initiated by the MS

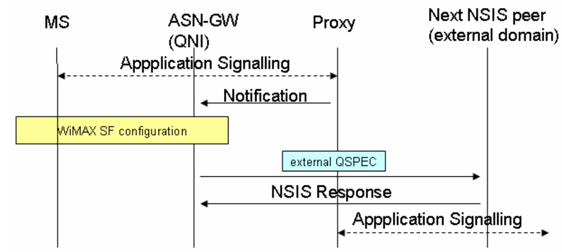

Figure 3. NSIS signalling initiated by the ASN-GW

QSPEC Translation Mechanism

As analyzed in the previous section, the ASN-GW is an NSIS node located at the edge of a WiMAX domain, so it supports both the WiMAX QoS model and the external QoS model. In order to reach the interoperability between the WiMAX segment and the external domain technology, the ASN-GW performs a translation between the QoS parameters received through the QSPEC or the application signalling and the parameters used in the next domain. The level of detail in the two QoS descriptions can be different and this aspect can have a strong impact on the actual end-to-end QoS guarantees.

The translation procedure consists of two different steps. The first step provides a lossless mapping, while the second step can introduce loss of QoS details depending on the QoS description and mechanisms adopted in the next domain. In the first phase the CSC translates the received QoS parameters into an internal QoS model that includes a detailed description of the QoS requirements through a full set of parameters. This set consists of the union of the application parameters and the QoS parameters of each domain covered by the ASN-GW. This global QoS model can be considered as an intermediate entity towards the external domain-specific QSPEC and provides an abstraction that allows the ASN-GW to describe the applications QoS requirements independently from the specific domain. This first mapping is lossless as the internal QSPEC includes all the original parameters as well as their translation.

The second translation from the CSC internal QoS model to the external domain QoS Model could be lossy if the next domain uses a coarser QoS description. In this case, the second mapping can have a strong impact on the end-to-end QoS guarantees, due to the loss of parameters.

Figure 4 shows a WiMAX end-to-end scenario, including a DiffServ domain in the core network. The NSIS QoS protocol can be applied between the two ASN-GWs using the RMD-QoS model [8]. The proposed mapping between WiMAX

Scheduling Class and DiffServ PHB QoS Class is showed in Table 2. In this scenario, a subset of the QoS attributes defined for the WiMAX framework, like latency and jitter, cannot be assured in the DiffServ domain. The actual mapping depends on the resource provisioning for each DiffServ class, but the details about WiMAX-specific parameters will be lost and end-to-end guarantees about latency or jitter will not be assured.

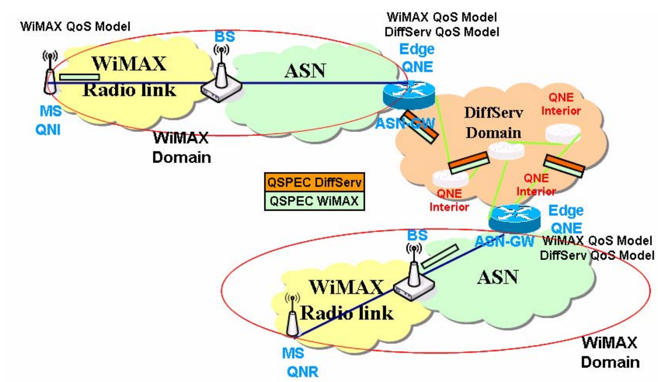

Figure 4. End-to-end WiMAX scenario, including Diffserv core network

On the other hand, a scenario including only WiMAX and 3GPP segments adopts QoS models based on similar QoS description, with the same level of details. Actually, in both scenarios the QoS parameters should control the characteristics of the radio channels in order to optimize the wireless resource utilization, which is significantly scarcer than the bandwidth in wired networks. Therefore the translation from the CSC internal QoS model into the 3GPP QoS model is lossless, since parameters, e.g., jitter and latency are defined for both WiMAX and 3GPP networks. Moreover, the traffic classes defined for the 3GPP framework are very similar to the related WiMAX scheduling classes, as showed in Table 2.

WiMAX Scheduling Class	DiffServ PHB	3GPP Traffic Class	Service Example
UGS	EF	Conversational	VoIP without VAD
ErtPS	EF	Conversational	VoIP with VAD
rtPS	AF4	Streaming	Audio/Video streaming
nrtPS	AF3	Interactive	Transactional Services
	AF2		Web Browsing
	AF1		Telnet
BE	BE	Background	E-mail download

Table 2 – Traffic class mapping for WiMAX, DiffServ and 3GPP domains

IV. EXPERIMENTAL VALIDATION

The validation process has been carried on using the WEIRD test-beds in Finland, Italy, Portugal and Romania, interconnected via dedicated connections over the pan-European GÉANT2 backbone network. Each test-bed includes one or more WiMAX Redline SU-O SSs served by an ASN consisting of Redline AN-100U BSs and ASN-GW. All the functionalities of the CSC and the NSIS module have been implemented in the WEIRD prototype of the ASN-GW, which is running on Intel IA-32 platforms with a Linux Debian 3.1 (stable version) with kernel v2.6.15. The NSIS software consists of the GIST v11 and QoS NSLP v11 implemented by the University of Coimbra [13]. The Resource Control (RC) module and the Adapter have been developed in order to allow the actual configuration of the SFs in the WiMAX links. The connection with GÉANT2 is assured by the CSN, that includes the border router, the AAA server and the WEIRD SIP server.

Each test-bed is designed to support specific applications, like telemedicine, video streaming, volcano monitoring and fire prevention. In order to validate the proposed NSIS QoS Model for WiMAX networks, it has been applied to the video streaming application, adopting the signalling mechanism where the MS acts as a QNI. This choice allows us to verify the potentiality of the Initiator WiMAX QSPEC to specify the parameters of an application with strict QoS requirements in terms of bandwidth and delay. Moreover this validation procedure is able to test if the QoS model fits WiMAX scenarios, providing an efficient mechanism to configure the WiMAX segment. Two different scenarios are considered: the former is composed of only a WiMAX access network while the latter consists of a CSN that uses DiffServ as QOSM.

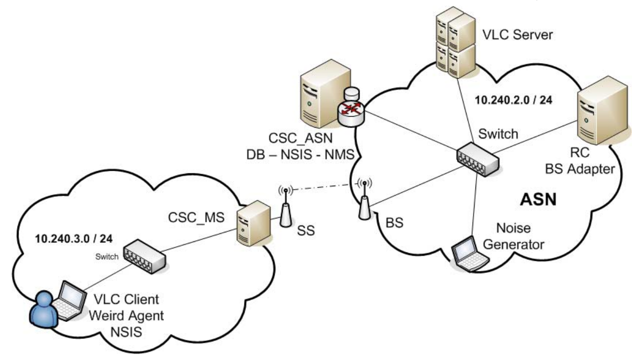

Figure 5 – WiMAX QoS Test-bed

The first one (Figure 5) is used to monitor connections established between two terminals (VLC media player client and server) through the WiMAX link. The client is attached to the MS, while the server is included in the ASN. The CSC on the ASN-GW takes into account the WiMAX SFs established over the BS-SS link by interacting with the RC. The RC itself is in charge to handle the BS SFs configuration through an adapter implemented accordingly to the BS proprietary vendor features. The noise generator is introduced to emulate additional traffic. Since the ASN is configured to be over-provisioned compared to the WiMAX throughput, no loss of QoS details has occurred and the QoS requirements are assured. Other tests have been performed in a scenario including two distinct ASNs connected through a generic domain NSIS-enabled. In this case we don’t have any loss in QoS description, since the generic NSIS QSPEC includes all the application QoS parameters.

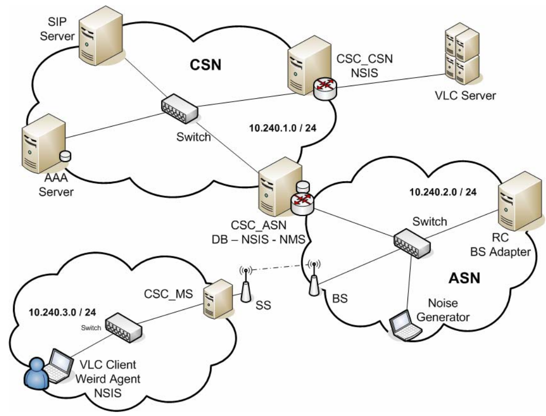

Figure 6 - WiMAX DiffServ QoS Test-bed

The second scenario, shown in Figure 6, is currently addressed in order to test the functionalities related to the interoperability between domains with heterogeneous QoS technologies and models. In this case the traffic flows are routed through a CSN supporting DiffServ architecture. Since the DiffServ QOSM is unable to assure some constraints, such as maximum latency and jitter, and no knowledge about the underlying DiffServ topology is provided to the CSC modules (the remote network can only be considered as a black box) in order to perform some Admission Control (AC) action, we expect the overall transport plane to be unable to guarantee the same level of QoS experienced in the previous scenario.

These validation scenarios prove the effectiveness of the WiMAX QoS model to provide a full set of parameters that completely describe the SF characterization and enable the ASN-GW to configure the WiMAX link for traffic flows with different requirements. In case of interoperability with different domains, we must accept a loss for some details if a coarser QoS description is adopted in the external domain, so that end-to-end QoS guarantees cannot be assured.

V. Conclusions And Future Work

This paper presents a QoS model for the NSIS signalling framework. The model specifically applies to networks comprising WiMAX access in the end to end path. Such QoS model supports a detailed description of QoS requirements and traffic characterization for a large set of applications, since WiMAX access networks enable different types of traffic to be served with strict QoS guarantees for bandwidth, jitter, latency and other parameters. In case of interoperation with different network domains characterized by a rougher QoS description, the translation between the QoS models is lossy since some parameters are missing in the second domain. The actual impact on applications depends on both traffic type and missing parameters. The absence of guarantees for latency or jitter may have a small impact on applications like FTP, while it is a stronger limitation for real-time applications.

The proposed solution proved to be able to provide suitable mechanisms for QoS signalling in WiMAX scenarios, supporting a complete description of the parameters required for the WiMAX link configuration. The RMF enables the ASN-GW to control the SF management with a network-initiated approach, which giving the opportunity to perform efficient AC procedures on the WiMAX and the ASN segments. The solution has been described in the following scenarios: NSIS signalling initiated by the MS, NSIS signalling initiated by the ASN-GW and NSIS signalling coming from external domains. Scenarios involving mesh networks with direct connections among MSs are left for further studies.

Future work will comprise the execution of further tests to verify the interoperability of the proposed solution with other QoS models. In case of DiffServ networks involved in the end-to-end path, we expect a lossy handling of QoS classes, because the WiMAX network uses a more detailed QoS description than the one possible in DiffServ networks. Further studies should concentrate on how to minimize such a loss, e.g. in case two WiMAX ASNs are connected through a black-box DiffServ network. A possible solution under investigation for this scenario is based on an edge ASN-GWs which monitors the edge-to-edge packet forwarding and an edge-to-edge measurement based admission control.

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