

The Cost of Using IEEE 802.16d Dynamic Channel Configuration

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Abstract — *Ubiquitous broadband Internet access is an important requirement to satisfy user demands and support a new set of real time services and applications. IEEE 802.16, as a Broadband Wireless Access technology, can significantly contribute in this area. It is able to provide high throughput over large distances, with intrinsic QoS support, in Line-of-Sight and Non-Line-of-Sight environments. This paper discusses a network architecture, based on IEEE 802.16d compliant equipments, which is able to support real-time services with QoS integration through dynamic configuration of the 802.16 channel, using the NSIS framework. Tests have been carried out to evaluate the QoS performance of the defined architecture, demonstrating that it is perfectly capable of handling and supporting real time services, using dynamic configuration of the 802.16 channel, without introducing an excessive cost in the network.*

Index Terms—NSIS, QoS, WEIRD, WiMAX

I. INTRODUCTION

The main objective of this paper is to evaluate the cost of using dynamic configuration of IEEE 802.16d Service Flows (SF) using the Next Steps in Signalling (NSIS) framework for Quality of Service (QoS) signalling. The framework for this evaluation is the implementation carried out in the scope of the WEIRD (*WiMAX Extension to Isolated Research Data networks*) project [1]. The evaluation of the NSIS framework, in terms of processing time and the supported number of reservations, allows to determine the cost of using dynamic configuration of the 802.16 channels.

The aim of the WEIRD project is to deploy, evaluate and enhance WiMAX technology as the access technology for a set of European research units with remote and impervious testbeds which are interconnected by the European research backbone network GEANT2 and relevant National Research and Education Networks (NRENs), as illustrated in Figure 1.

The designed and implemented architecture in the WEIRD project is focused on the WiMAX technology, following the recent architecture standards, such as IEEE 802.16d/e [2] [3], IETF 16ng [4] and WiMAX Forum [5] [6], as well as the Next Generation Network (NGN) [7] [8] trends. The defined system

is QoS-oriented and supports both local and global mobility scenarios. Authentication and authorization mechanisms, seamless integration of both IPv4 and IPv6 protocols, and WiMAX vendors' independency are key requirements that must be fulfilled as well.

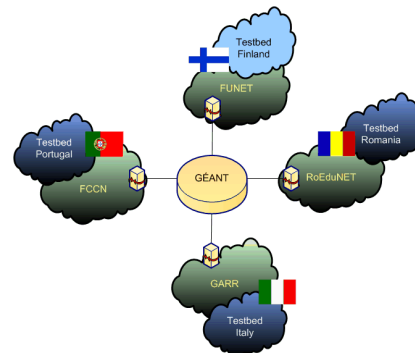


Figure 1 : WEIRD project European testbeds interconnection through GEANT research network

The paper starts by providing an overview of the QoS signalling used in the WEIRD project, followed by an identification of related work. In order to evaluate the cost of the proposed dynamic configuration approach, a testbed was installed and is presented in section IV. The following section presents and discusses the obtained results. Section VI summarises the paper and identifies guidelines for further work.

II. QoS SIGNALLING IN WEIRD

The IEEE 802.16d/e standard does not define an end-to-end system. Instead, it only comprises the definition of the PHY and MAC layers from the architectural stack. In order to fill this gap, the WiMAX Forum, particularly the Network Working Group (NWG), is currently defining a high-performance “All-IP” end-to-end network architecture to support fixed, nomadic, portable and mobile users. Additionally, the IETF 16ng is also working towards the specification of IPv4 and IPv6 support over IEEE 802.16d/e

using the Ethernet, IPv4 and IPv6 Convergence Sublayers (CS) [9] [10].

Besides the definition of an end-to-end IP framework, the WiMAX Forum also aims to ensure full interoperability between the Base Stations (BSs) and the Mobile/Subscriber Stations (MSs/SSs) from different WiMAX vendors. The WiMAX Forum extends the IEEE 802.16d/e architecture by defining a Network Reference Model (NRM). The NRM is a logical representation of the WiMAX network architecture, based on a set of functional entities and standardized interfaces, known as Reference Points (RPs) – R1 to R8. Using this model, multiple implementation options for a given functional entity are allowed, maintaining interoperability across them through the usage of the RPs. The WEIRD overall infrastructure, presented in Figure 2, is based on the NRM. Three functional entities are defined: *Connectivity Service Network* (CSN), *Access Service Network* (ASN) and the *Customer Premise Equipment* (CPE). The CPE is the terminal equipment responsible for establishing radio connectivity with the BS. For IEEE 802.16d, the CPE might be composed by single-user SSs or multi-users SSs (MSS) when a LAN/WLAN is connected to the SS. Regarding IEEE 802.16e, a single-user Mobile Station (MS) is the envisaged scenario. The ASN is generally composed by several BSs connected to several ASN-Gateways (ASN-GW). The ASN-GW is the gateway for the ASN, establishing connectivity with the CSN. The ASN includes a set of functionalities in order to provide radio connectivity to WiMAX subscribers. Additionally, it also performs relay functions to the CSN in order to establish IP connectivity and authentication mechanisms. Finally, the CSN holds the DHCP, DNS and AAA (Authentication, Authorization, and Accounting) servers, as well as the Application Function (AF) – in this case the SIP Proxy. Moreover, the CSN is responsible for establishing connectivity with the IP backbone.

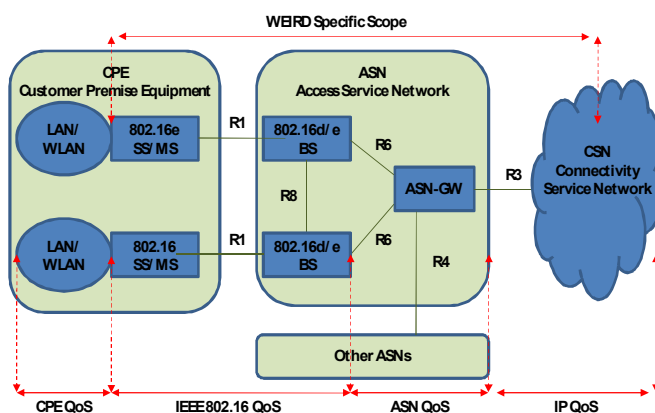


Figure 2: WEIRD Overall Infrastructure

Following the NGN trends [11], the WEIRD system follows a multi-plane structure. Vertically, it is composed by two stratum – the *Applications and Service Stratum* and the *Transport Stratum*. The former contains the functionalities related with the management and control of the applications, independently of the network transport. The *Transport*

Stratum manages and controls the available resources, and is also responsible for data flow through the several network infrastructures. Since this vertical approach decouples the applications and services from the transport technologies, it enables the support of several core and access network technologies.

Horizontally, the WEIRD architecture is split in three parallel planes – *Management*, *Control* and *Data Plane*. The *Management Plane* is responsible for medium and long term tasks, such as QoS provisioning through the Network Management System (NMS) and traffic management. On the other hand, the *Control Plane* provides the functionalities for the short term operations, including QoS reservations triggered by the QoS signalling protocols and resource control functions.

Figure 3 depicts the WEIRD *Control Plane* modules and interfaces. Despite the 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 [12] and legacy applications are supported. For SIP based applications, the *SIP User Agent* (SIP UA) in the MS directly communicates with the *SIP Proxy* in the CSN. On the other hand, for legacy applications, a specific module has been specified in the MS – *WEIRD Agent* – to adapt and configure the QoS parameters required for the legacy applications.

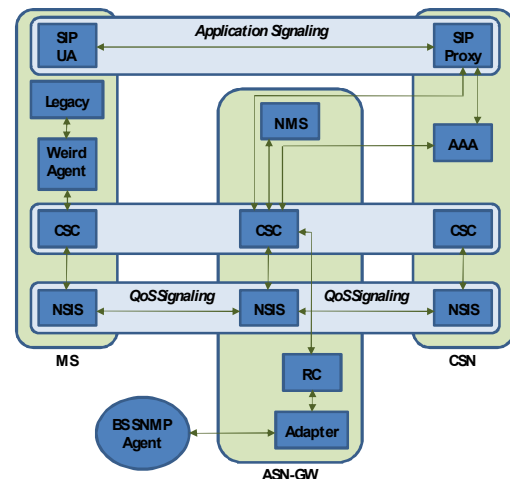


Figure 3: WEIRD Architecture – Control Plane

The *Connectivity Service Controller* (CSC) modules, located in all entities of the NRM, hold the most important functions of the system in terms of QoS control. 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 resources allocation and admission control in both the ASN and on 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, and forwards the gathered QoS information towards the CSC_{ASN} using a Diameter (Gq/Gq') interface [13]. For legacy applications, the CSC_{MS} communicates with the *WEIRD Agent* to obtain the required QoS parameters and

provides this information to the main QoS coordination point – *CSC_ASN*.

The communication between the several *CSCs* (MS, ASN and CSN) is performed through the usage of the NSIS framework protocols. NSIS decomposes the overall signalling protocol suite into a generic (lower) layer and specific upper layers for each specific signalling application. In the lower layer, General Internet Signalling Transport (GIST) [14] offers transport services to higher layer signalling applications for two purposes: sending and receiving signalling messages between neighbour hops (NSIS entities), and exchanging control and feedback information. Above this layer, there is the NSIS Signalling Layer Protocol (NSLP) layer [15], which generically stands for any protocol within the signalling application layer. Both layers used in the core of the architecture are, respectively for the NTLP and NSLP layers, GIST and QoS NLSP. When SIP or legacy applications request admission, and its parameters are sent to the *CSCs*, NSIS signalling is in place between them to reserve network resources for the applications and guarantee the QoS requirements.

After receiving the QoS reservation requests the *CSC_ASN* triggers the *Resource Controller (RC)* module. Since all the functions related with the WiMAX link are managed and controlled by this module, it can be seen as the *WiMAX link manager*. Moreover, the *RC* acts as an *abstraction layer* between the upper modules of the architecture and the lower ones. It hides all the WiMAX technology related functionalities from the above modules of the architecture. One of the most important tasks of the *RC* is to manage QoS on the WiMAX link – *Service Flow Management*. Therefore, it handles the creation, modification and deletion of SFs in the WiMAX link, as well as the associated *Service Classes (SCs)* and *Convergence Sublayer Classifiers*. According to the IEEE 802.16d/e standards, three different types of SFs are distinguished and supported by the *RC*: *Provisioned Service Flows* which are created via provisioning by the NMS; *Admitted Service Flows* which have resources reserved by the BS, but not yet active; *Active Service Flows* which have the resources already committed and prepared to be used for data transfer. With respect to the *Convergence Sublayer Classifiers*, the *RC* currently supports the Ethernet CS and the IPv4 CS.

Finally, to enforce the QoS decisions on the WiMAX system, the *RC* triggers the *Adapter* module on the ASN-GW. The *Adapter* interfaces with the WiMAX system using the SNMP protocol [16]. Therefore, it has to translate the received QoS reservation request from the *RC* to the WiMAX system MIB (Management Information Base) specific objects. From all the modules defined on the WEIRD architecture, this is the only one that is *dependent* on the specific WiMAX equipment that is used. Therefore, different WiMAX vendor equipments can be seamlessly integrated within the WEIRD architecture, only by developing a new *Adapter*, and without requiring modifications over the remaining modules.

III. RELATED WORK

There are some projects that work and propose new models for the support of QoS mechanisms in 802.16 technologies.

The Advanced Resource Management Solutions for Future all IP heterogeneous Mobile Radio Environments (AROMA), a Sixth Framework Programme (FP6) European project, aims at providing enhancement on resource management issues for all the wireless systems based on IP, taking into account 2G, 2.5G, 3G and 3.5G networks, including WiMAX technology and its services.

Another FP6 project highlighting the importance of the WiMAX technology is the Wireless Infrastructure over Satellite for Emergency Communications (WISECOM), of which goals are studying, validating and developing communications infrastructures. This project considers the integration of satellite communication systems and terrestrial wireless communication to attend emergency scenarios, being the former used where terrestrial communication is prohibitive. The technologies supported in this project are mainly GSM, UMTS, WiFi and WiMAX.

The FP6 Physical Layer DVB Transmission Optimisation (PLUTO) targets to develop techniques for broadcast transmitter networks, in order to reduce the complexity and power consumption of end user equipment taking technologies like DVB-T, DVB-H and DAB, along with WiMAX.

The Scalable, Ultra-fast and Interoperable Interactive Television (SUIT) is another project that is concerned about ensuring that broadcasting networks (BNs) are able to serve moving users, at high speed. Thereby, SUIT manages at the play-out with DVB-T/H and WiMAX networks as well as to use these both technologies to reach high speed mobility.

These are some of the projects that, at the moment, are working with WiMAX technology, proposing some mechanisms that support applications requirements. However, none of them offer a truly paradigm to differentiate traffic, integrating WiMAX technology with IP networks and offering an end-to-end- support.

In a mobile environment perspective, the Designing Advanced network Interfaces for the Delivery and Administration of Location independent, Optimised Personal Services (DAIDALOS) project [19] defines a NGN environment, where the seamless integration of heterogeneous network technologies such as WiMAX, WiFi and UMTS, is envisaged. The defined architecture provides seamless QoS support using NSIS as the QoS signalling protocol, separating end-to-end (E2E) QoS control at layer three from link-local QoS at layer two. Despite IEEE 802.21 [21] has been natively defined to provide media independent mobility management services, DAIDALOS has properly extended it with a new set of MIH (Media Independent Handover) commands and events to support QoS reservation mechanisms towards the access technologies.

As in DAIDALOS, WEIRD also uses NSIS protocols to perform the necessary signaling for resource reservation. QoS Specification (QSPEC) [17] specifies different QoS parameters that characterize a given QoS Model. WEIRD has

extended the generic QSPEC objects to include specific QoS parameters of WiMAX, which include the following parameters: Minimum Reserved Traffic Rate, Maximum Sustained Traffic Rate, Scheduling Class, Unsolicited Grant Interval, Minimum Latency and Tolerated Jitter.

Given the particularity of WEIRD, a mapping between the WEIRD QoS Model (based in WiMAX) and the DiffServ QoS Model has also been done. Table 1, depicts the correspondence of the DiffServ Classes of Service (CoS) and the WiMAX CoS, The IEEE 802.16e specification adds the Extended real-time Polling Service (ertPS) scheduling service. The ertPS class is suited for VoIP applications with silence suppression.

DiffServ CoS	WiMAX CoS
EF	UGS
EF	ertPS
AF3	rtPS
AF2	nrtPS
BE	BE

Table 1: Mapping between DiffServ CoS and WiMAX CoS

WEIRD has also implemented the QoS-NSLP AUTH specification [18], which extends the basic functionalities of QoS-NSLP to support authentication and authorization of resources, probed or granted in QUERY and RESERVE messages.

IV. EVALUATION ENVIRONMENT

A. Testbed Description

To evaluate the designed and implemented solutions, a testbed has been installed. The demonstrator, illustrated in Figure 4, is based on commercial 802.16 equipments certified by the WiMAX Forum.

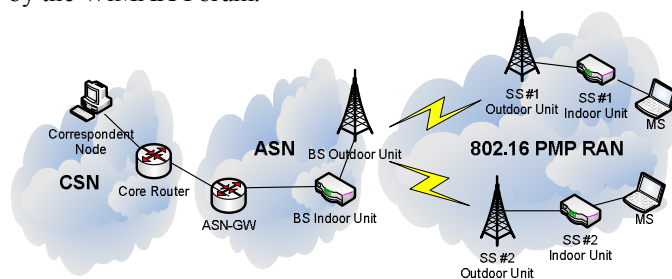


Figure 4: Testbed Deployment

The testbed is composed by one BS and two SSs, creating an 802.16 PMP Radio Access Network (RAN). MSs are directly connected to the SSs, creating a typical last mile scenario. Furthermore, both the CSN and the ASN have been implemented as well, according to the NRM defined by the WiMAX Forum. Finally, the ASN is composed by the BS directly connected to the ASN-GW.

B. Performance Tests Description

The performance tests have been performed between the

MS and the Correspondent Node (CN) on the CSN. The data and signaling paths (path-coupled mode) include all NSIS aware nodes. MS hosts the WEIRD Agent (WA) by which downlink and uplink reservations are performed.

Each test is defined for a specific number of reservations, thus the available bandwidth for each test is different as well. Table 2 summarizes the bandwidth characteristics for each reservation test.

Number of Reservations and Bandwidth (DL/ UL)		
2 Res	→ DL 9 Mbps	UL 9 Mbps
32 Res	→ DL 36,6 Kbps	UL 36.6 Kbps
64 Res	→ DL 18,3 Kbps	UL 18,3 Kbps
256 Res	→ DL 4 Kbps	UL 4 Kbps

Table 2: Reservations Characteristics

V. RESULTS

A. NSIS Processing

The NSIS framework includes different protocols, which have to be evaluated individually to measure NSIS performance as a whole. The evaluated protocols and the respective parameters are depicted in Table 3.

Protocols	Evaluated Parameters
GIST	Processing time (message processing and internal processing).
QoS-NSLP	Processing time (message processing and internal processing).
QoS-NSLP Auth	Processing time.
QSPEC	Serialization/Deserialization, message mapping and serialization of Message Routing Information (MRI) object.

Table 3: NSIS protocols and evaluated parameters

QSPEC serialization is performed in the *CSC_MS*, since MS is the sender. Each *CSC*, implemented in *JAVA*, before sending messages to the QoS-NSLP (also implemented in *JAVA*), serializes the QSPEC and maps WEIRD message types to NSIS message types. In the tests performed, MS is the network element which introduces more delay due to processing, since it has to convert the user parameters to the WEIRD QSPEC objects containing traffic parameters and classifier parameters. MS also performs the serialization of the MRI which is used for QoS-NSLP routing signalling messages.

QoS-NSLP deals with the application signalling, and has a northbound interface, Resource Management Function (RMF) interface, with the *CSCs* and a southbound interface with GIST. The processing in each QoS-NSLP aware node includes two main features. The first is message parsing (QUERY, RESERVE, and RESPONSE), needed to request to the *CSC*

the policy and admission control functions. The second concerns state maintenance, in order to verify if reservations should be refreshed. Figure 5 depicts the processing time of QoS-NSLP, AAA and RMF. The results show that the processing time increases with the number of reservations, due to the incremented amount of reservations states, as well as the increased processing load for signalling messages. For instance, single QoS-NSLP processing for 2 reservations presents a low value, approximately $83ms$, which increases to $105ms$ in the case of 256 reservations.

QoS-NSLP AUTH adds extensions to QoS-NSLP to allow the authentication of QUERY and RESERVE messages. The QUERY messages are authenticated based on a trust relation between CSC and QoS-NSLP, whereas the RESERVE messages require AAA authentication (included in $QoSNSLP+RMF+AAA$) since the grant of resources needs user authentication and authorization. Therefore, when QoS-NSLP receives a QUERY message, the message is sent back to the RMF in order to be authenticated.

The impact of using AAA functions, both with QoS-NSLP alone ($QoSNSLP+AAA$), and with QoS-NSLP plus RMF functions ($QoSNSLP+RMF+AAA$) is illustrated as well. For instance, the processing time of the QoS-NSLP only is $83ms$ while the processing time including AAA functions is $137ms$.

The component which introduces the highest processing overhead is the RMF module, due to the policy and admission control functions performed by the CSCs. These functionalities include QSPEC deserialization and communication with the RC to perform resource reservation in the WiMAX segment, among others.

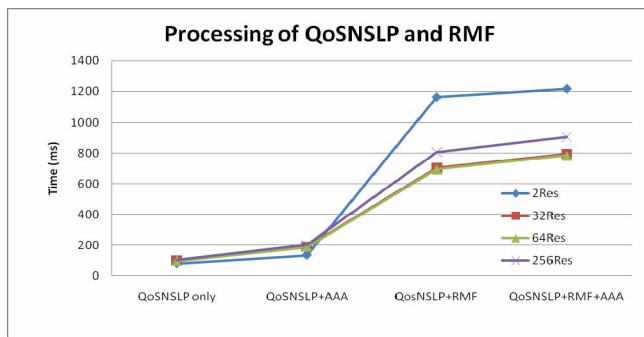


Figure 5: QoS-NSLP and RMF processing

Regarding the number of reservations, the processing of QoS-NSLP is minimal when compared to the processing of RMF. The average values of QoS-NSLP and RMF processing of all functional entities (MS, ASN and CSN) is also shown in Figure 5. For instance, the 2 reservations case is the worst since the message association establishment and initialization of sessions in the RMF, ignited by the first message, have a greater impact in the overall performance. However the remaining cases (32 to 256) show that subsequent processing times are lower reducing the average value. This is mainly due to the usage of the message association re-use, which allows improved performance.

GIST provides the transport mechanisms for the applications signalling. The main processing roles of GIST are

to handle QoS-NSLP messages (for instance, to decode the MRI in order to create the association with the next GIST-peer), to perform state management and to decide the transport mode (for instance, the C-Mode, if guarantees are needed).

Figure 6 depicts the comparison of GIST processing in the WiMAX segment (between MS and ASN) and in the Ethernet Segment (between ASN and CSN). GIST establishes associations with peers that are GIST aware and that are in the data path. Therefore GIST in the MS associates with GIST in the ASN and then ASN associates with CSN. The values measured include the association time, the time required to transport QoS-NSLP data messages, and the decision on the transport mode, according to the message received and the session state. The 2 reservations case has higher values (approximately $146ms$ MS \rightarrow ASN segment) since such processing involves mainly the message association setup between GIST peers. Nevertheless, GIST processing increases with the number of reservations – for instance with 256 reservations GIST processing takes approximately $114ms$.

The difference found between MS \rightarrow ASN (*line with dots*) and ASN \rightarrow CSN (*line with squares*) segments result from the delay introduced by the WiMAX air link on the former case.

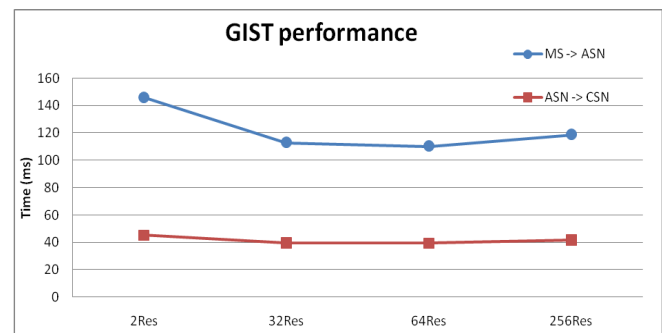


Figure 6: GIST performance

The results presented in this section demonstrated that the processing overhead introduced by the NSIS signalling within the WEIRD system is within acceptable bounds, when there are multiple requests that are able to reuse the same GIST association. In this situation, an initial setup time of around $800ms$ is a reasonable price to pay, when compared, for instance with application level signalling (e.g. using the Session Initiation Protocol [23]), for the level of QoS which will be provided during the flow lifetime.

B. Resource Controller

As exposed in Section II, the RC is the WiMAX link management module. It has a northbound interface with the upper modules of the architecture (CSC_ASN) that are unaware of the WiMAX technology specific details, and a southbound interface with the *Adapter*. The RC has been implemented in C++, using a set of hash tables to store the service classes, service flows and classifiers for the WiMAX link, as well as a state machine to control the status of the SFs.

Figure 7 presents the session establishment times, including request and response timings, measured on the RC. The vertical axis depicts the measured time in microseconds – μs .

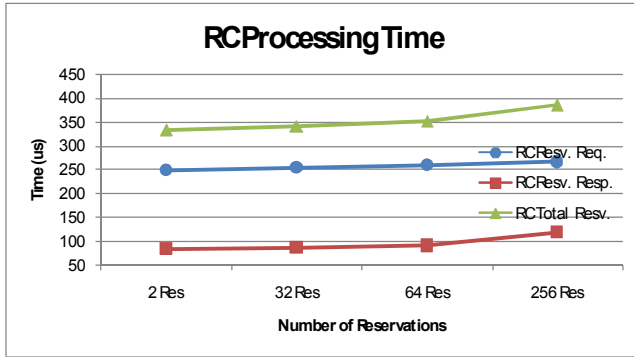


Figure 7: RC Request, Response and Total Processing Time vs Number of Reservations

The *line with dots* represents the amount of time spent by the *RC* to process a reservation request received from the *CSC_ASN*. Basically, this time is due to the creation of a new entry in the correspondent hash tables of the *RC*, the translation of the general received QoS parameters to WiMAX compliant ones, as well as to the update of the SF state machine. As expected, the measured time (approximately 250 us) is low, linear and independent of the number of QoS reservations that are being performed. The *line with squares* depicts the time required by the *RC* to process a reservation response message received from the *Adapter*. In this case, the *RC* must search on the hash tables the *SF Identifier* (SFID) that matches the one received from the *Adapter* and update the state machine accordingly. Since the size of the hash table increases with the number of requested reservations, it is expected that the amount of time required to perform the lookup is higher for the 256 reservations case. However, the maximum value measured is 120us for 256 SF reservations.

C. Adapter & 802.16d

After the *RC* processes the QoS request, it sends the reservation information towards the *Adapter*. The main role of the *Adapter*, as detailed in Section II, is to enforce the reservation requests in the WiMAX system. Particularly, the *Adapter* shall translate the received QoS parameters to the correspondent IEEE 802.16f MIB objects [21] and send the SF establishment request to the BS using an SNMP message. Thereafter, the BS will trigger the SF activation in the WiMAX system using the 802.16d DSA (Dynamic Service Addition) MAC Management messages, as defined in [2]. The *Adapter* module has been implemented using C and the Net-SNMP API [22] has been chosen to establish the SNMP interface with the WiMAX BS.

Figure 8 illustrates the measured time results obtained for the *Adapter* (including the WiMAX system).

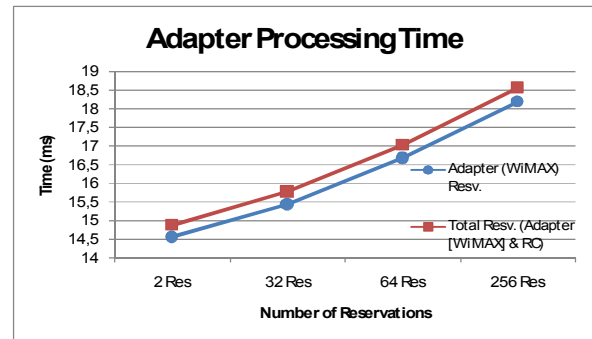


Figure 8: Adapter (WiMAX System) Processing Time vs Number of Reservations

One can see that the amount of time required by the *Adapter* and the WiMAX system to establish the SF is not considerably affected, despite the number of reservations significantly increases for each measurement. The overall measured variation between 2 and 256 reservations is approximately 3.5ms. Therefore, we verify that, even for the worst case scenario (256 reservations test), the time spent by the system to establish the SF is very small (18.5ms) and perfectly capable to efficiently handle applications with real-time requirements without traffic disruption.

D. E2E modules chain

An important aspect to consider is the overhead introduced by each functional entity (MS, ASN and CSN) in the reservation process. Figure 9 depicts the processing time in the MS, ASN and CSN. ASN, by performing radio connectivity functionalities and relay functions to the CSN, introduces more delay in the overall chain. The 2 reservations, with processing time in the order of 844ms in the ASN, represent the worst case, caused by session setup in the different modules and other initial and required processes like message association of GIST. Such processing time can be reduced with QUERY messages of QoS-NSLP that probe the network for available resources. GIST creates the message association to assure the transport of these QoS-NSLP data messages, thus the reservation messages will use message association re-use which have an improved performance. Also, when there are 256 reservations, the processing time in the ASN increases due to the need to perform all the functions of the *CSC_ASN*.

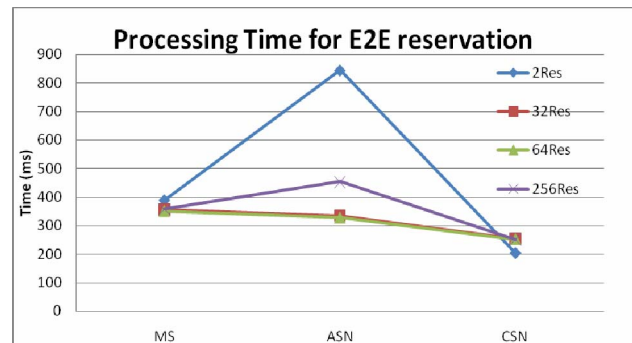


Figure 9: Processing Time

Figure 10 depicts the performance of each software

component, which leads to the conclusion that the processing overhead introduced by the CSCs modules has the highest impact in the reservation process. For instance, in the 32 reservations case the processing of *CSC_MS*, *CSC_ASN* and *CSC_CSN* takes 500ms, in total.

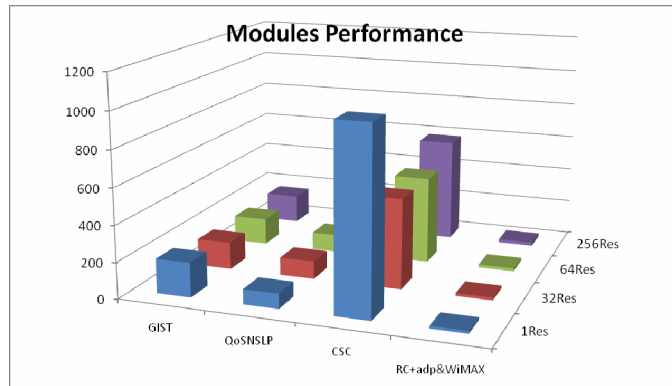


Figure 10: Software Modules Performance (ms)

The different implementation languages and the specificity of each module justify the differences between the best performing module (*RC*) and the worst (*CSCs*). Despite the decreased performance in the 2 reservations case, in medium reservations numbers (32 and 64), the performance of modules has not a significant impact in the dynamic channel configuration process.

VI. CONCLUSIONS

The use of the NSIS framework for the dynamic configuration of IEEE 802.16d channels has been studied and evaluated in this paper. The presented solution was implemented in the scope of an European project, also briefly presented here.

The evaluation took into account the various protocols and mechanisms associated with the NSIS framework, namely GIST, QoS-NSLP, QoS-NSLP Auth and QSPEC, and showed that the WEIRD architecture allows dynamic and effective channel configuration, at reasonable cost, leading to increased adaptability.

The end-to-end processing overhead introduced by the NSIS signalling integrated in the WEIRD system is within acceptable bounds, when there are multiple requests that are able to reuse the same GIST association. In this situation, an initial setup time of around 800ms is a reasonable price to pay, when compared, for instance with application level signalling, such as the Session Initiation Protocol, for the level of QoS which will be provided during the flow lifetime [24].

Although the presented solution is working, thus demonstrating the basic concepts behind the WEIRD architecture, further tests and optimizations must be made. This will be the subject of further research in the immediate future.

ACKNOWLEDGMENT

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