WiRA: An Approach for Resource Control in WiMAX Systems

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***Abstract*—The emerging of *Quality of Service* (QoS)-enabled broadband wireless access technologies brings internetworking facilities by allowing high speed communications with traffic differentiation and bandwidth guarantees. However, end-to-end QoS in heterogeneous environments, where the network may be composed of links with different bandwidth capacities and QoS models, is still an open issue. This paper proposes a QoS control approach to guarantee the quality level of sessions crossing *Worldwide Interoperability for Microwave Access* (WiMAX) systems, independently of the QoS model or bandwidth capacity supported by neighbour networks. The proposed scheme is based on the coordination of resource allocation and QoS mapping/adaptation mechanisms, which allow the dynamic quality level control of sessions over heterogeneous environments. Simulation results shows the benefits of the proposed solution to reduce the session blocking probability and to improve the usage of network resources, while keeping sessions with an acceptable quality level during periods of congestion.**

***Index Terms*— Broadband Wireless Access, WiMAX, QoS Mapping, QoS Adaptation, Wireless Resource Allocation**

I. INTRODUCTION

THE increasing number of mobile devices together with the emergence of broadband wireless access systems allows fixed and mobile users in metropolitan area networks to access real-time communication sessions ubiquitously, such as IPTV and scalable video streaming. In addition to wireless and internetworking facilities, QoS guarantees and high speed transmission for communication sessions are also expected to be assured in broadband wireless access systems.

The WiMAX system, an IEEE 802.16 standardized architecture for all-IP networks, is the most attractive solution to broadband access in the next generation heterogeneous networks [1]. The WiMAX system provides differentiated levels of QoS for sessions, based on the combination of a set of communication service classes supported in both wired IP-based and wireless IEEE 802.16-based links. In the former, network elements with standard IP QoS models, such as *Differentiated Services* (DiffServ) [2] and *Integrated Services* (IntServ) [3] can be configured to guarantee QoS support for sessions crossing wired links. In the latter, several IEEE 802.16 QoS services are defined to provide packet differentiation on the wireless interface [4].

QoS models supported by WiMAX systems in wireless and wired elements, offer network services with different forwarding behaviours to packets, including performance metrics, such as bandwidth, delay and jitter. Therefore, sessions with similar QoS requirements must be mapped into the appropriated wired and wireless service classes. To that, it is required the use of a translation mechanism to allow an efficient mapping of sessions crossing domains implementing different QoS models. However, static approaches for QoS mapping between session requirements and network service classes, or even guidelines for IP QoS mapping, alone are not sufficient to assure the quality level of sessions. This is mainly due to the emergence of new QoS-aware sessions and network service classes with different configurations. In what concerns the latter, each mobile operator can use different parameters to configure its network classes.

Additionally, due to the existence of wired and wireless links with distinct capacities and the dynamic bandwidth behaviour of the resources assigned for service classes, QoS mapping procedures must be done in cooperation with QoS adaptation support. The later, in congestion periods, contributes to improve the usage of network resources and to avoid session blocking, while keeping those sessions with acceptable quality levels. Thus, the satisfaction of users is increased because the session degradation is, in general, less annoying than to have a session refused. For instance, if a session is mapped into an overloaded service class, a QoS adaptation mechanism must be triggered to adapt the session to the current network conditions and to avoid the session blocking. This procedure can be done by requesting to the QoS mapping the re-mapping of the session to a different service class or controlling the quality level of the session by dropping and adding low priority flows of a scalable session.

In addition to the QoS mapping and QoS adaptation mechanisms, an interface with a resource allocation scheme is essential to provide the control of network resources in wired and wireless service classes and to allow the configuration of the bandwidth required for the session in the selected classes. Summing up, the QoS control in WiMAX networks needs to be done by coordination of the QoS mapping/adaptation mechanisms with the resource allocation controller, in such a

[1] This work was done in the context of the Q3M project, sponsored by DoCoMo Euro-Labs.
At that time, Paulo Mendes was working at DoCoMo Euro-Labs.

way to provide the dynamic mapping between the session QoS requirements and the available service classes, to avoid the session blocking probability and to optimize the usage of network resources in WiMAX systems composed either by wired and wireless QoS elements.

This paper presents the *WiMAX Resource Allocation Control* (WiRA) approach to provide QoS control for sessions crossing WiMAX systems. This goal is achieved through the cooperation between dynamic QoS mapping, adaptation and WiMAX resource allocation controllers. Both upstream and downstream QoS control is supported independently of the underlying QoS model and link capacities in WiMAX systems and in neighbour networks. In order to increase the system flexibility, WiRA does not require the installation of extra modules in the end-hosts. Moreover, operational cost is reduced by decreasing intelligence on the central wireless element *Base Station* (BS) and avoiding QoS signalling exchanges on the wireless link. Simulation results present the benefits of this proposal to reduce the session blocking and to improve resource allocation, while keeping sessions with an acceptable quality level in a congestion period. To that, we analyzed the call blocking probability and the usage of network resources when WiRA is enabled.

The remainder of this paper is organized as follows. Section 2 presents relevant related work. An overview of WiRA is described in Section 3. Section 4 presents the WiRA performance evaluation. Finally, conclusions and future work are summarized in Section 5.

II. Related Work

QoS control in WiMAX networks has been addressed in the literature on a set of proposals. G. Carneiro, *et al* [9] proposes a solution that controls resource reservation in wired and wireless links within WiMAX networks. However, the way in which the QoS mapping control of sessions is implemented between wired and wireless links is not described. The network agents are coordinated by *Simple Network Management Protocol* (SNMP) messages, which are sent in the wireless link through the second management connection. The use of the second management connection can raise performance issues, because this connection is defined for delay tolerant traffic. Since many other IP protocol related messages (DHCP, TFTP, etc) share the same connection, the level of QoS provision will be affected [8].

X. Zizhen, *et al.* [10, 11] presents a method for realizing dynamic QoS in WiMAX systems. To that, this solution defines a signalling approach to establish a service channel and a Media Gateway (MG) which makes awareness of the type of a service requested by a calling user terminal. The claim of the solution is to establish a service channel from the MG to the subscriber station and, then, from the subscriber station to the base station, taking into account the bandwidth requested by the subscriber station. This solution increases the system complexity by requiring the installation of extra modules in end-host. Moreover, it is not useful alone in end-to-end communications between heterogeneous environments, since it only supports QoS control in the wired part, and does not implement translation for mapping.

In what concerns QoS mapping, the *QoS Gateway* (QoSGW) [12] is a centralized solution which acts as a QoS mediator between applications/devices and the underlying network QoS infrastructure. The QoSGW allows mapping between session requirements and classes of service supported by different QoS models [12]. The main drawback of QoSGW resides in the fact of requiring installation of proprietary modules on the end-hosts, reducing thus the system flexibility. The solution presented in [13] aims to allow end-to-end QoS support for application services in the context of effective QoS class mapping over heterogeneous networks. However, the solution uses a static QoS mapping scheme. Therefore, the quality level of the sessions is not guaranteed because it does not consider the current conditions of the preferred network service class.

J. Chen, *et al.* [6, 7] propose a solution which integrates the support of QoS models in wired elements, such as DiffServ, and IEEE 802.16, and QoS static mapping strategies. The QoS control is achieved by requiring the installation of extra modules on all network elements, including end-hosts, and the use of the *Resource Reservation Protocol* (RSVP) [5]. The RSVP messages can be sent in the wireless links through either, the primary or the second management connection. In the first case, the RSVP messages cross the wireless links encapsulated into DSA/DSC/DSD standard messages, contributing thus to increase the signalling overhead. In the second case, the QoS control operations can be delayed due to the queuing characteristics of the communication channel. Moreover, the static QoS mapping strategy allows only the mapping between DiffServ/IntServ and WiMAX QoS model, not on the reverse direction.

The analysis of related work has shown that none of the proposals satisfies all the requirements to provide a dynamic QoS mapping and QoS adaptation control for sessions crossing WiMAX systems. Most of the approaches do not re-map or adapt the session to the current network conditions to avoid the session blocking. In addition all presented solutions require the installation of proprietary modules in all network elements, including end-hosts. Thus, the system flexibility and operational costs are negatively affected.

To address the above challenges and, at the same time, to provide QoS control and accessibility support between wired and WiMAX networks, independent of the underlying QoS model, the University of Coimbra is working with DoCoMo Euro-Labs in the WiRA proposal, which will be presented in the next section.

III. WiMAX Resource Allocation Control

The QoS control supported by WiRA for real-time sessions crossing WiMAX networks is achieved by integrating QoS mapping and wireless resource allocation control. The cooperation between these two mechanisms provides QoS guarantees for sessions entering or leaving WiMAX networks, independently of the QoS model or the current network conditions. To cope with network heterogeneity, WiRA is based on the separation of session identifier and network locator. While the former has a global meaning, the latter is only relevant for the local network. Hence, each session is described in a *Session Object* (SOBJ) identified by a session identifier, which can be composed by a set of flows with different requirements, priority and bit rate. The QoS parameters of each flow are described in the QSPEC object [14], which includes performance values (e.g., bit rate, bandwidth guarantee, tolerance to loss, and delay jitter). These values can be quantitative (e.g. ms or kb/s) or qualitative (e.g. low, medium or high).

The SOBJ also includes information about the location of the user which requested the session (e.g., IP address of the sender and direction uplink/downlink in the WiMAX network). Besides the QoS control information described in the SOBJ, operators export information about wired and wireless-based classes, including performance metrics and the per class available bandwidth. Exporting theses QoS information, operators also keep their network infra-structure opaque. The generic definition of a SOBJ allows the use of any signalling protocol to transport the session QoS information, such as those defined in the *NSIS Working Group* [15], the *Session Initiation Protocol* (SIP) [16] or RSVP. This information can then be used by QoS mapping and resource allocation controllers to allow the session establishment with QoS support between networks with different QoS models.

A. *WiRA Agents*

The WiRA QoS control is supported by agents distributed along WiMAX networks, as shows Figure 1. On the one hand, *WiRA-Statefull* (WiRA-SF) agents are located in the wired edge WiMAX network element *Connectivity Service Network* (CSN), being responsible for the main WiRA control functions, such as access control of sessions and signalling initialization. The WiRA-SF agents implement all functionalities supported by the WiRA solution, being thus the more complex. WiRA minimizes the system complexity and operational cost by pushing the intelligence to the network edges. On another hand, *WiRA-Stateless* (WiRA-SL) agents are placed in the remainder WiMAX network elements (e.g., *Access Service Network – Gateway* (ASN-GW) and BS), implementing lightweight resource control to configure the QoS resources and the MAC classifier.

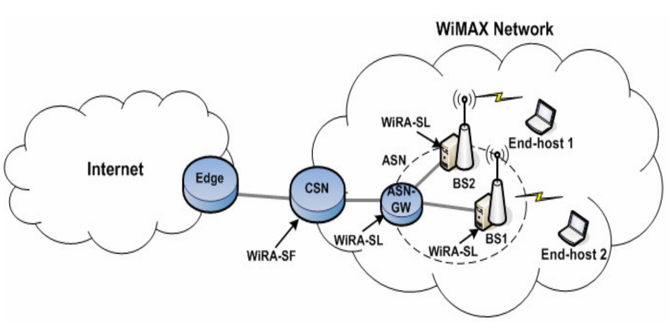

Figure 1 - WiRA Agents on the WiMAX network.

WiRA agents control the on-demand mapping of sessions (uplink and downlink) into the appropriated network services supported by both wired IP-based and wireless 802.16-based classes. When a session is leaving a WiMAX network, WiRA-SF performs the mapping according to the available inter-network classes or agreements.

B. *WiRA Interfaces*

The QoS control provided by WiRA is achieved through the use of open interfaces, which allow cross-layer interactions with external protocols or mechanisms, an easy deployment and applicability to heterogeneous QoS models. The interfaces supported by WiRA are as follows:

- *Application Interface* (AI): used to expose WiRA to external applications or mechanisms, in order to receive requests to control network resources for a session. To that, it must be provided the SOBJ and direction (uplink or downlink). Moreover, this interface is also used by WiRA agents to trigger the requester applications indicating the result of the accomplished operation, successful or not;
- *Wired Resource Control Interface* (WdRCI): used to interact with QoS control plane elements to configure resources required for sessions in wired links. For instance, the resource reservation is performed by the configuration of the QoS packet scheduler, such as *Weighted Fair Queuing* (WFQ) [17] and *Class Based Queue* (CBQ) [18]. Moreover, WiRA configures policies in order to mark incoming packets into a service class;
- *Wireless Resource Control Interface* (WrRCI): used to interact with WiMAX MAC layer to configure the MAC classifier. In addition, WiRA reserves resources in wireless link by requesting the MAC layer to establish a MAC transport connection communication with QoS guarantees;
- *Transport/routing Control Interfaces* (TCI): used to interact with external transport protocol to exchange QoS control information between WiRA agents. Therefore, WiRA uses *WiMAX ASN Transport Signalling Protocol* (WATSP) [19] as a transport signalling protocol. In addition, WiRA uses this interface to retrieve the outgoing interface from the unicast routing tables.

Figure 2 shows the interfaces supported by WiRA agents. WiRA-SF agents, support all interfaces, except the WrRCI, because WiRA-SF agents do not configure wireless network elements. Conversely, WiRA-SL agents, located at the BS, support WdRCI, WrRCI and TCI interfaces, since they configure wired and wireless network elements. Finally, the WiRA-SL agent in internal WiMAX network elements (ASN-GW) only supports WdRCI and TCI interfaces, since it is only designed to configure the local wired network element and to propagate the WiRA QoS messages.

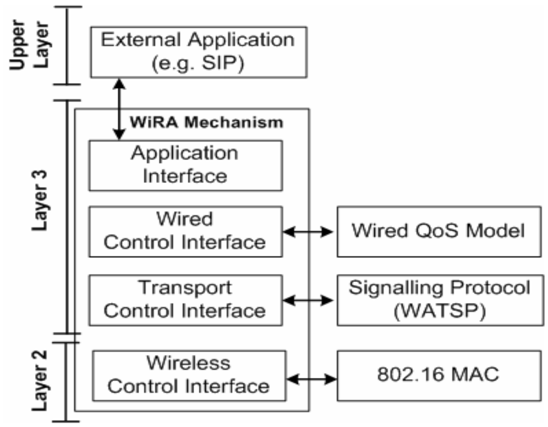

Figure 2 - Interfaces supported by WiRA agents.

C. *WiRA State*

The state storage in WiRA-SF agents, as support for performing WiRA functions, is maintained in four databases, as follows:

- *Wired Reservation Database* (WdRD): this database keeps information about wired network resources. It keeps information about service classes' capability (delay, loss, jitter, available bandwidth) per outgoing interface;
- *Wireless Reservation Database* (WrRD): this database is used by the WiRA-SF agent to control the wireless link utilization. Similarly to WdRD, the WrRD database keeps information about service classes, their characteristic and available bandwidth, for each BS in both directions (downlink/uplink);
- *Session Database* (SD): this database is used to control active sessions in WiMAX networks, storing information about the resources used by the sessions. This way, the SD stores the session identifier, flow identifier, service classes, BS, CID and bit rate used by each flow of a session.

The information stored in these databases enables WiRA to control QoS resources in the CSN-to-SS data path, without requiring information to be kept in the BS, ASN-GW and SS elements. The configuration of these databases must be done by the network administrator during the bootstrap, in order to support the WiRA operations.

D. *WiRA Functionalities*

QoS control is provided by WiRA by implementing the functionalities described next.

1) *WiRA Mapping and Adaptation*

The *WiRA Mapping and Adaptation* mechanism extends the functionalities defined in [20, 21], which takes as input the SOBJ and the information about the current network conditions. The main goal is to select the appropriated wireless and wired service classes, to then invoke the allocation of the required bandwidth. However, the mapping may be not optimal, for instance if the selected class has not enough bandwidth to assure the minimal QoS committed rate. In this situation, the WiRA QoS adaptation process is triggered to adapt the session to the current network conditions. As a result, WiRA avoids session blocking and improves the usage of network resources.

The adaptation process is based in three mapping methods are as follows:

- Perfect Match: supports the full QoS requirements and bandwidth committed for all flows of a session. In the unsuccessful case, such as when the suitable network class has not enough available bandwidth to assure at least the minimal packet loss rate of the session, the QoS adaptation is triggered;
- Sub-perfect Match: maps all flows of a network class that supports QoS parameters different from the ones described in the session object. This method avoids session blocking and the re-ordering of the session packets, since all flows are mapped to another class;
- Hybrid Match: assures the allocation of, at least, the flows of a session with high priority to the best network class. The remainder flows are mapped to a less suitable class.

The perfect match is assumed to be the preferred mapping method, and triggers the QoS adaptation mechanism whenever unsuccessful, to avoid session blocking. The process to choose which QoS mapping method to use can be based on a static or dynamic configuration. For instance, it can be configured by the service provider according to its business model, or on-demand by an external protocol. The Sub-perfect Match can be used in periods of congestion of a network class, since a perfect match is not possible and to keep the full rate of the session is the major importance. The hybrid method can be used when the packet re-ordering is not crucial. For instance, it can be appropriated for scheduled video and audio sessions, where it is more important to ensure an intelligible audio flow than a perfect video.

2) *WiRA Resource Allocation*

The *WiRA resource allocation* mechanism aims to reserve resources and configure markers for each session in the wired and wireless elements along the WiMAX network. In the former, the network resource allocation is implemented via the WdRCI interface. The reservations are accomplished through: (i) configuring QoS schedulers (in DiffServ and IntServ enabled networks); (i) requesting a Label Edge Router (LER) to create a Label Switched Path (LSP) with the required amount of bandwidth (in MPLS enabled networks); (iii) and requesting the WiMAX MAC layer to establish a new transport connection to SS with the requested QoS parameters. The packet marking is controlled by configuring QoS policies in such a way that the incoming packets are properly classified into service classes.

E. *WiRA signalling*

To simplify the WiRA implementation, the coordination between the WiRA agents is performed via the WATSP protocol, by using the *RR-Request* and the *RR-Response* messages. This set of signalling messages was extended by WiRA to carry the QoS information needed to support the

WiRA functionalities. Based on the additional information carried by WATSP messages, the WiRA agents along the WiMAX network execute a specific action.

F. *WiRA Illustration*

This section describes the operations carried out by WiRA to setup sessions in WiMAX networks in both downlink and uplink directions.

1) *Downlink Illustration*

An illustration of downlink QoS support operations in a WiMAX system during the setup of a scheduled audio and video session, represented by (S1), is outlined in Figure 3. The downlink process occurs whenever a SS in the WiMAX network wishes to subscribe a session. When triggered, the downlink process tries to ensure resources for the session by crossing the WiMAX network from the CSN to the SS.

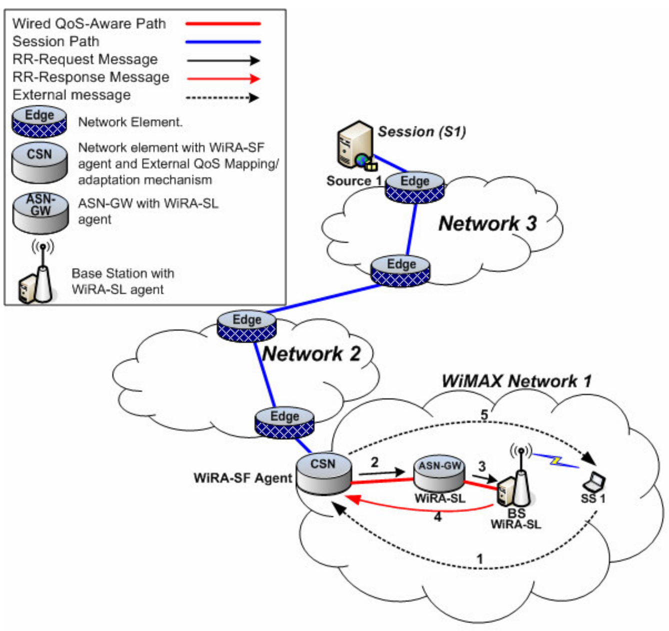

Figure 3 - WiRA Downlink Operation

The QoS control process is started when the receiver *SS1*, which is placed in the WiMAX network, subscribes the session *S1*. The receiver application (e.g., SIP), signals the CSN and other network elements, towards the *Source 1*, with the subscribe request.

The network agent receives the SOBJ and requests the activation of the WiRA-SF agent located in the WiMAX network edge (CSN). In turn, the WiRA-SF agent consults its databases, in order to obtain information about the available resources along the WiMAX network in wired and wireless elements, and starts the mapping control. Based on current network conditions and on the SOBJ information, the mapping control tries to perform the Perfect method to map the session for suitable service classes in wired and wireless elements. If such mapping is not optimal, for instance if the some preferred class has not enough bandwidth to assure the minimal QoS committed rate for the session, the QoS adaptation process is triggered to adapt the session to the current network conditions, which avoids the session blocking and waste of network resources when sessions are not supported in a class.

After the QoS mapping/adaptation process is successfully completed, the resource allocation process is triggered in order to perform resource reservation for the *S1* session along the WiMAX network. This way, the WiRA-SF agent located in the CSN performs the local wired resource allocation process, and signals the WiRA-SL agent located in the ASN-GW element, by the *RR-Request* message. Upon receiving the *RR-Request* message, the WiRA-SL agent performs the wired resource allocation process to configure the local allocation of resources for the *S1* session, and signals the WiRA-SL agent in the BS. In turn, the WiRA-SL agent in the BS performs the wireless resource allocation process, and informs the WiRA-SF, by a *RR-Response* message, about the state of operation, which in this case is success.

Finally, WiRA-SF updates its databases and informs the network agent about the success of the operation, which informs the user application of the successful establishment of the session through a SIP message. If, in any moment of the downlink operation, it is not possible to conclude the resource allocation process, the WiRA agent releases the local reserved resources, creates a *RR-Response* message and adds an error code. The *RR-Response* is sent through the reverse path, from the CSN to the WiRA agents, to release resources, and to notify the WiRA-SF agent and the network agent about the lack of success of the operation.

2) *Uplink Illustration*

The uplink process occurs whenever an application outside the WiMAX network wishes to subscribe a session offered by the *SS1* located in the WiMAX network. For it, the uplink process has the objective to ensure resources for the session from the SS to the CSN.

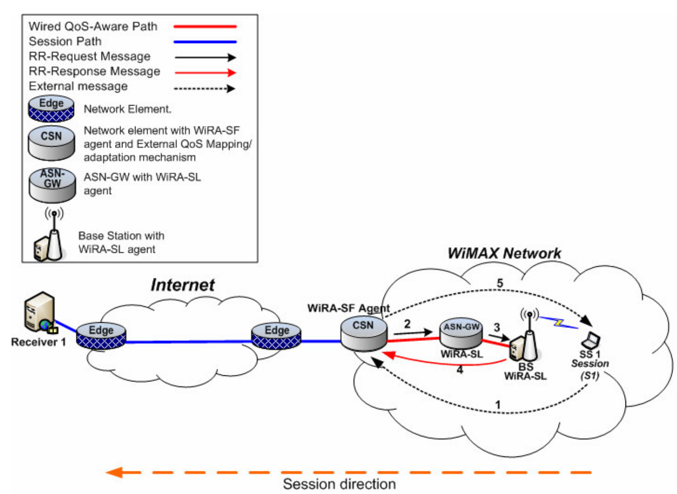

Figure 4 - WiRA Uplink Operation

The uplink operation starts when the user *SS1* application creates a session and signals (e.g., through SIP) the network agent in the CSN. The message must carry at least information about the session characteristics and direction (uplink in this case). The uplink process is similar to the downlink process, that is, the network agent activates the WiRA in the CSN to perform QoS control for the session, but in the inverse direction, from the BS to the CSN.

After the network agent receives the SOBJ, the WiRA is activated to perform QoS control for the session *S1*. In turn, the WiRA-SF agent discovers through its databases the network resources available along the WiMAX network and starts the mapping control. Based on the SOBJ information and the current network conditions, the mapping control tries to use the Perfect method to map the session. If it is not possible, the QoS adaptation method is performed to re-map the session flow, in such a way that avoids session blocking.

After the execution of the QoS mapping and adaptation processes, WiRA-SF signals other WiRA-SL agents along the WiMAX network to achieve resource allocation for the session. However the resource allocation is performed in the reverse path, that is, the WiRA-SL agent at ASN-GW performs the resource allocation in the outgoing interface from the ASN-GW to the CSN. The same way, the WiRA-SL agent in the BS requests the establishment of a transport connection from the SS to the BS with the QoS requirements requested and executes the resource reservation in the outgoing interface from the BS to the ASN-GW.

After configuration of QoS requirements in wireless and wired links, the WiRA-SL agent in the BS, signals the WIRA-SF in the CSN element informing about the success of the uplink operation. Upon receiving the confirmation, WiRA-SF updates its databases and informs the network agent about the success of operation, which informs the user application of the success establishment of session a through SIP message.

IV. Simulation Results

The impact of using WiRA to provide QoS control in WiMAX networks is evaluated through simulations. The experiments were carried out using the *Network Simulator*-2 (NS-2) [22]. The network topology used is composed by four different network elements, CSN, ASN-GW, BS, SS, operating in WiMAX PMP mode. In the links between the CSN, ASN-GW and BS, it is used the DiffServ QoS model. Three service classes are available: *Assured Forwarding* (AF); *Expedited Forwarding* (EF); and *Best-Effort* (BE). Each service class is policed to a physical queue that is served based on the WFQ discipline. In the wireless link, four service classes are defined according the 802.16d standard: Unsolicited *Grant Service* (UGS); *Real Time Polling Service* (rtPS); *Non Real Time Polling Service* (nrtPS); and *Best-Effort* (BE).

Since the packets are mapped from the wired service classes to the wireless service classes in the BS, all measurements were carried out in the BS. The capacities of the CNS-to-ASN-GW and ASN-GW-to-BS wired links are set to 100Mb/s. Furthermore, in the wireless links the uplink and downlink capacities are of 25Mb/s and 50Mb/s respectively. Moreover, the propagation delay in the wired part is of 1ms.

In order to avoid service class starvation, the network resources used by each class must not exceed a certain amount of bandwidth of the total link capacity. To that, a maximum reservation threshold is assigned to each service class in order to determine the limit of total resources of the link that can be used. In this scenario, the maximum reservation threshold of each service class is of 25%. Hence, the WiMAX service classes can admit a reservation request as long as the required amount of bandwidth is not superior to 25% of the total link capacity.

The sessions are based on well-know codecs, such as MPEG4 [23], where each session can be composed by a set of flows with well-defined priorities and rates. This way, the simulations consider that the session flow priorities start from the most important to the less important. Moreover, the session flows vary between 3 and 5 flows, having a constant bit rate of 32 Kb/s, 64 Kb/s, 128 Kb/s, 256 Kb/s and 512 Kb/s.

The simulations were performed with 1,000 resource reservation requests with a duration interval which varies between 10s and 30s. The duration interval times are chosen based on real traces [24, 25]. The simulation time is of 100s, considering the duration of the session. The reservation/release requests are triggered in the WiRA-SF agent at the CSN, and the simulation starts without resources allocated for any WiMAX service class.

Three set of tests are used to verify WiRA insights through analysis in the blocking probabilities and network resource utilization. All tests were carried out under the same simulation environment, and the difference between them resides in the QoS adaptation method supported. Whereas in the first set of tests, the sessions are handled when WiRA adaptation mechanism is disabled, in the second and third set of tests WiRA is configured with Sub-Perfect and Hybrid adaptation methods respectively.

Figure 5 shows the blocking probabilities measured in the first set of tests. In this case, a session is blocked whenever the service class can not assure all the QoS requirements. The results reveal a great variation of the blocking probability between the WiMAX service classes. For instance, the sessions mapped in the highest priority service class (*UGS*) are blocked from 11s up to 37s since its maximum reservation threshold is reached and there is no adaptation mechanism activated. From 37s, no session blocking was detected for *UGS* service class. The service class *UGS* have higher blocking probability than the remaining classes because more session requests for this class were generated in the tests.

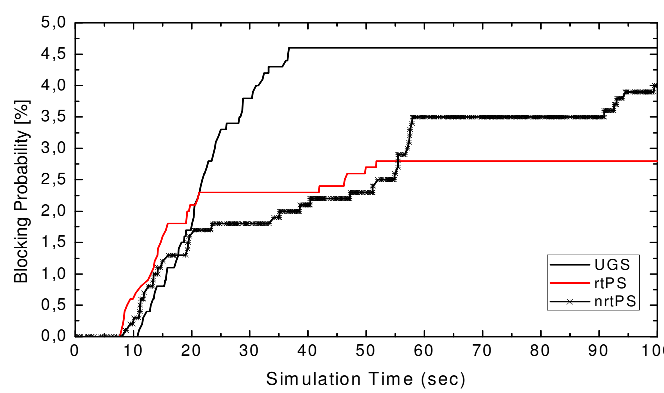

Figure 5 - Without Adaptation Method

Figure 6 shows the allocated resources in a per service class basis when no adaptation method is activated. The blocking of service class UGS from 37s (shown in Figure 5) happens no longer since resources are made available from this time due to the end of on-going sessions. Moreover, the reservations never exceed the maximum reservation threshold of service class UGS. The analysis in the service class with low priority (*nrtPS*) events shows a blocking probability variation from 9s up to 58s (in Figure 5). This variation is justified by the releasing of resources within this period of time which are triggered proportionally with the end of sessions. The same occurs in the time interval from 58s to 91s, where no blockings for *nrtPS*-alike traffic are detected.

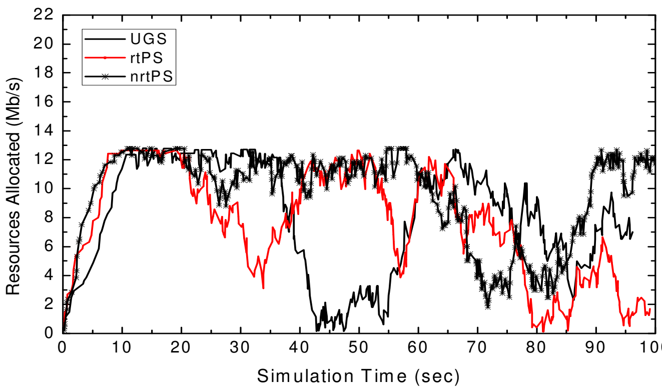

Figure 6 - Usage of network resources without adaptation method

The blocking probability and allocated network resources of the second set of tests are illustrated in Figure 7 and in Figure 8. Since WiRA is configured with the Sub-Perfect adaptation method, the simulation results reveal that the service class *UGS* have the lowest blocking probability (2.6%). This happens since the QoS adaptation mechanism re-maps *UGS*-alike sessions, under unavailable resources experience, to low priority service classes. In contrast to the first set of tests, the service class *nrtPS* have the higher blocking probability (4.5%), since its reservation requests cannot be re-mapped to another service class.

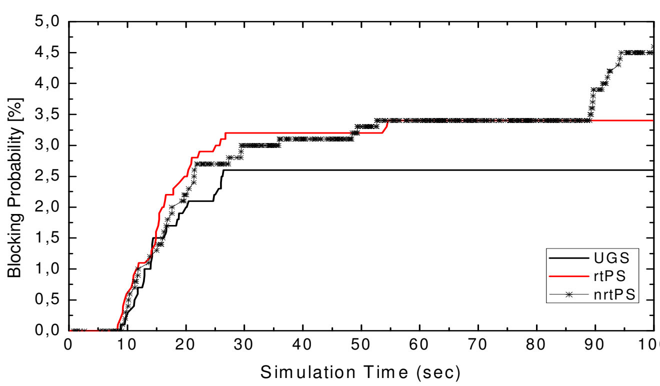

Figure 7 – Blocking Probability when Implemented the Sub-perfect Adaptation Method

The blocking probability in this set of tests is higher during the period from 9s to 52s. This is justified by the lifetime of the sessions exponentially assigned in this set of tests. From 53s up to the end of the simulation, most of the releasing events are stated, resulting thus in the blocking stabilization of all sessions. In the period from 89s up to 95s, it is only verified blockings for the *nrtPS*-alike sessions. The nrtPF-alike sessions are blocked within this period because they are assigned to the reservation requests of the remaining service classes. The absence of reservation requests for *UGS* and *rtPS* service classes from 95s to the end of simulation, associated with the releasing of resources in the *nrtPS* service class from 94s up to 96s allows no blockings for *nrtPS*-alike sessions. Furthermore, the blocking probability in the *UGS* service class decreased approximately 43.47% compared to the experiments without adaptation methods.

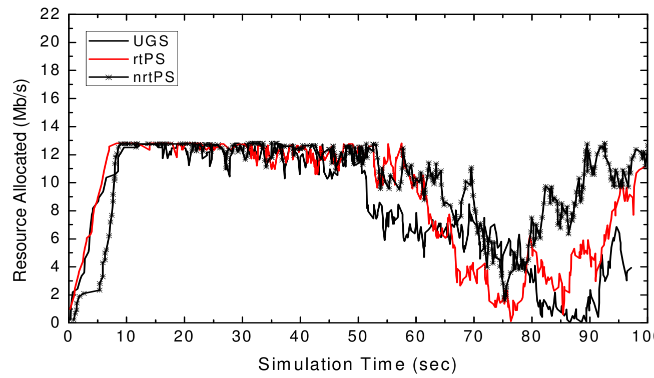

Figure 8 - Usage of network resources with Sub-Perfect adaptation method

Figure 9 and Figure 10 depict the blocking probability and resource allocation measured in the third set of tests. The QoS Hybrid adaptation method applied to the sessions under service class congestion experience represent a greater uniformity of blocking probability between WiMAX service classes compared to the other tests. This happens because, instead of the entire session, only some session-flows are re-mapped. In addition, the *UGS*-alike session blocking stated, in instant 94s, avoids achieving blocks in *nrtPS*-alike sessions up to the end of the simulation time. The blocking probability of *UGS*-alike sessions in this set of tests decreased 39.13% in comparison to the first set of tests, and increased in 0.07% compared with the second set of tests.

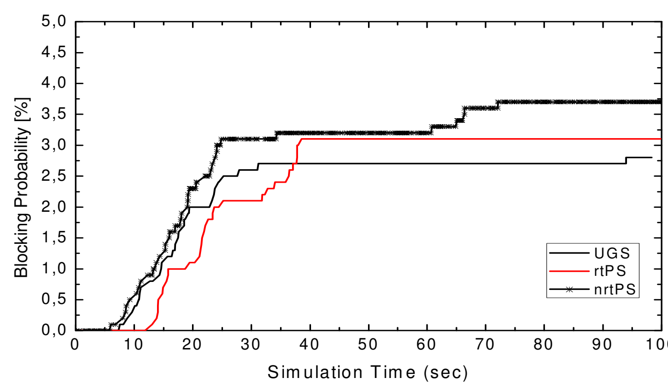

Figure 9 - Hybrid Adaptation Method

The simulation results depicted by Figure 10 show a higher number of *UGS*- and *nrtPS*-alike sessions admitted in comparison to the remaining set of simulation tests. This is justified by the high number of releasing events triggered for *rtPS*-alike sessions from instant 55s up to the end of the simulation.

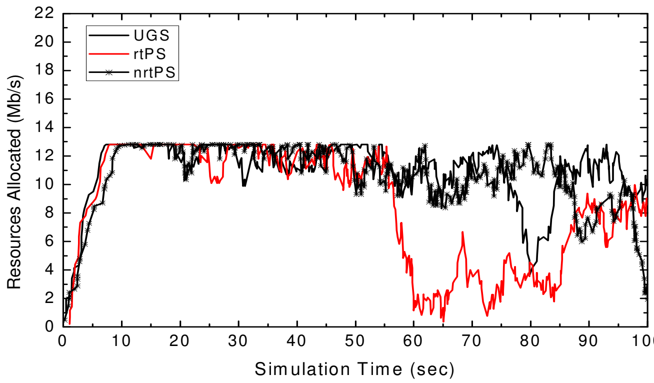

Figure 10 - Usage of network resources with Hybrid adaptation method

Summing up, the simulation results presented show that the use of WiRA QoS adaptation methods succeed in reducing the blocking probability, compared with the experiment without the adaptation mechanism. The use of adaptation methods may increase the efficiency of the usage of network resources through re-mapping sessions, experiencing congestion, to service classes with available resources. The drawback of the adaptation methods is that misplaced sessions (sessions which are not mapped to their appropriated service class) use network resources allocated to other WiMAX service class, increasing thus the blocking probability of sessions that are best suited to that service class. The use of a specific adaptation method or the combination of some of them depends on the session QoS requirements and on the services offered by the network. For instance, scheduled audio sessions can be adapted based on the Hybrid method, since it is more important to assure an intelligible audio flow than a perfect video. The WiRA mechanism succeeds to map and adapt sessions according to the session priority, which can reduce the impact on the session quality while avoiding blocking in WiMAX network.

V. Conclusion and Future Work

This document presents the WiRA proposal to provide QoS support for sessions crossing WiMAX networks, independently of the QoS model or the current network conditions of neighbour networks. WiRA is a flexible proposal, since it does not require the installation of extra modules in end-hosts to perform QoS control, such as, resource reservation. Moreover, the operational cost is reduced by decreasing the intelligence on the central wireless element, the BS, and avoiding QoS signalling exchanges on the wireless link.

The simulation results presented showed the benefits of WiRA control operations to provide QoS guarantees for sessions entering or leaving WiMAX networks. In addition, the results confirm that WiRA control is able to reduce the session blocking and to optimize the resources allocated for service classes, while keeping sessions with an acceptable quality level during congestion periods.

As future work, it is expected to evaluate the benefits of WiRA functionalities from the perspective of the users. To that, it is necessary to measure throughputs in SS elements.

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