IROISE: A New QoS Architecture for IEEE 802.16 and IEEE 802.11e Interworking

Kamal Gakhar, Annie Gravey and Alain Leroy
Department Of Computer Science, ENST Bretagne, 29238 Brest Cedex 3, France
Email: firstname.lastname@enst-bretagne.fr Fax: +33 2 29 00 12 82

Abstract— **This article proposes a new architecture, which once implemented, would help in achieving end-to-end quality of service (QoS) requirements of an application which is being served in an interworking system of IEEE 802.16/WiMAX and IEEE 802.11e/WiFi networks. Our approach strives at mapping the QoS requirements of an application originating in IEEE 802.11e network to a serving IEEE 802.16 network and assuring the transfer of data having appropriate QoS back to the application in IEEE 802.11e network. We discuss how an application flow specifies its QoS requirements, either in an IEEE 802.11e or IEEE 802.16 network and the mechanisms that ensure that these requirements are known to the serving network. We identify the necessary parameters, as per advice in the standards, that could stipulate the QoS requirements for an application depending upon traffic type it represents. We propose the mapping of various parameters for different kinds of flows which would ultimately make sure that an application receives the QoS it requested. The resulting architecture would work as a hybrid of two different kinds of networks.**

I. Introduction

IEEE 802.11e [1] and IEEE 802.16 [2] networks, while in operation, employ base station(s) (BS), subscriber station(s) (SS), QoS access point(s) (QAP), non-access point QoS station(s) (non-AP QSTA). The need for efficient interworking between IEEE 802.16 and IEEE 802.11e networks arises in order to support quality of service (QoS) for delay sensitive, bandwidth intensive applications such as VoIP, video transmissions, large volume FTP etc. With the introduction of IEEE 802.11n, which promises at least 100Mbps, some time soon in the future, an interworking between two standards should result in true mobility for users demanding good QoS. However, QoS for these applications can only be maintained when the serving network somehow knows and understands the requirements of the requesting application(s) and the implied architecture could assure that the application would get the best possible service. The WiMAX forum envisages this interworking in the not so distant future [3]. A detailed study had been done regarding interworking between HiperLAN/2 and HiperMAN and extending this approach to IEEE 802.11 networks [4]. However, it fell short of purposing any final architecture which, in the end, could support end-to-end QoS for an application being served in an interworking system between IEEE 802.16 and IEEE 802.11 networks. In this paper, we introduce a new QoS architecture that aims at supporting this interworking. It is named **IROISE**, inspired from the project in which it is conceived. In section II we discuss the mechanisms proposed in IEEE 802.11e to support the QoS followed by the details of how IEEE 802.16 presumes to support QoS for different traffic types in section III. Section IV introduces QoS architecture for interworking including a scrutiny of proposed mapping. The paper concludes with perspectives in section V. The full details of various terms and procedures discussed in this article can be found in the standards [1] [2].

II. QoS support in IEEE 802.11e

Basic IEEE 802.11a/b/g standards offer only the Best Effort (BE) service to an application flow using the channel access functions like Distributed Coordination Function (DCF) or Point Coordination Function (PCF). However, the IEEE 802.11e draft [1] proposes new enhanced mechanisms, which once implemented, promise to ensure good QoS to an application flow depending upon its traffic category/type. The first improvement is the introduction of enhanced channel access mechanisms, namely, Enhanced Distributed Channel Access (EDCA), which is a contention-based channel access, enriching the existing Distributed Coordination Function, and the Hybrid Coordination Function Controlled Channel Access (HCCA), a controlled channel access, which improves upon Point Coordination Function. These two entities are managed by a centralized controller called Hybrid Coordinator (HC) which is a module found in QoS Access Point (QAP). The second significant proposition is the facility of traffic differentiation via utilizing Traffic Specification (TSPEC). A TSPEC describes the traffic characteristics and the QoS requirements of a traffic stream (TS) to and from a non-AP QSTA (a STA that supports the QoS facility but is not an AP). The frame format of a TSPEC element gives us an idea about traffic and QoS specifications, as in Fig. 1. The relevant details of these parameters have been discussed in the draft standard [1] as well as in [5] [6]. It offers a means of admission control and reservation signaling for an application flow at MAC level between mobile terminals and the AP in a network. Admission control is performed by the HC, included in QAP. It serves to administer policy or regulate the available bandwidth resources. It is also needed when a QSTA desires guarantee on the amount of time that it can access the channel.

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As per the draft standard, there are two ways in which QoS can be characterized:

- **prioritized QoS**: The service provisioning is such that the MAC protocol data units (MPDUs) with higher access category/priority are treated with preference over MPDUs with a lower priority. This provisioning is provided through the EDCA mechanism which, in turn, provides aggregate QoS service.
- **parameterized QoS**: MPDUs are treated depending upon the parameters associated with them. It is mainly provided through the HCCA mechanism but may also be provided by the EDCA mechanism when used with a TSPEC for admission control. The applications are provided with par-flow QoS service.

In order to provide QoS support in an IEEE 802.11e network the following phases are passed by:

- Computing a TSPEC according to a given application flow (traffic and QoS requirements).
- Setting up a network facility (i.e setup of a traffic stream (TS)).
- Handling the MPDUs according to whatever has been negotiated during the setup phase.

Lets see these steps in detail.

A. Setup Process

Setting up a TS (Fig. 2), a virtual connection, is the basic process to ensure that the QoS requirements of an application are entertained. TS is a set of MSDUs to be transferred subject to the QoS requirements of an application flow to the MAC. The non-AP QSTA SME (station management entity) decides that a TS needs to be created for an application flow and assigns it a traffic stream identity (TSID). The SME generates an MLME-ADDTS.request (MAC layer management entity request) containing a TSPEC. A TSPEC may also be generated autonomously by the MAC without any initiation by the SME. The SME in the HC decides whether to accept the TSPEC as requested or not, or to suggest an alternative TSPEC and sends its response to the requesting non-QAP STA. Once the request for TS setup is accepted, a traffic stream is created, identified within the non-AP QSTA by the TSID and a direction assigned to it. In the HC at QAP, the same TS is identified by a combination of TSID, direction and non-AP QSTA address. The TSID is assigned to an MSDU in the layers above the MAC in the QAP containing the HC.

Once traffic arrives at QAP, a traffic classification (TCLAS) specifies certain parameters to identify the MSDUs belonging to a particular TS. The classification is performed above the MAC_SAP at a QAP. The QAP uses the parameters in the TCLAS elements to filter the MSDUs belonging to a TS so that they can be delivered with the QoS parameters that have been set up for the TS. Traffic classification could also take place at non-AP QSTA with multiple streams, however, it is beyond the scope of the draft standard. TSPEC coordinates

Element ID	Length	TS Info	Nominal MSDU Size	Maximum MSDU Size	Minimum Service Interval
1	1	3	2	2	4

Maximum Service Interval	Inactivity Interval	Suspension Interval	Service Start Time	Minimum Data Rate
4	4	4	4	4

Peak Data Rate	Burst Size	Delay Bound	Minimum PHY Rate	Surplus Bandwidth Allowance	Medium Time
4	4	4	4	2	2

Fig. 1. Traffic Specification Element Format

resource reservation within an HC and is also responsible for its scheduling policy. The Traffic Specification allows a more extensive set of parameters than may be needed, or may be available, for any particular instance of parameterized QoS traffic (thus remains implementation dependent). It also allows other parameters to be specified that are associated with the traffic stream, such as traffic classifier and Ack policy. TSPECs are constructed at the station management entity (SME), from application requirements supplied via the SME, and with information specific to the MAC layer. Although the construction process of a TSPEC is beyond the standard's specification some "Admissible" TSPECs are discussed in the standard to facilitate the admission control process. This represents a set of necessary parameters in order for TSPEC to be admitted. However it is not sufficient to guarantee TSPEC admittance, which depends upon channel conditions and other factors. The complete table can be referred to in the draft [1].

B. QoS Traffic Handling

The QoS Control field in the MAC frame format (Fig. 3) facilitates the description of QoS requirements of a particular application flow. It is a 4-bit field that identifies the traffic category (TC) or TS to which a frame belongs and various other QoS-related information about the frame that varies by frame type and subtype. The bits 0-3 are used as traffic identifier (TID). TID is a value used by higher-layer entities to distinguish MSDUs to MAC entities that support QoS within the MAC data service. There are 16 possible TID values, 8 of them identify TCs (0-7) and the other 8 identify parameterized TSs (8-15) and are assigned traffic stream identities (TSIDs). The TID is assigned to an MSDU in the layers above the MAC.

1) QoS using EDCF: Mapping of user priorities (UPs) in EDCF is shown in Fig. 4. Each QSTA has 4 queues (ACs) and supports 8 UPs as defined in 802.1D [7]. These priorities vary from 0 to 7 and are identical to IEEE 802.1D priority tags. An MSDU with a particular UP is said to belong to a TC with that UP.

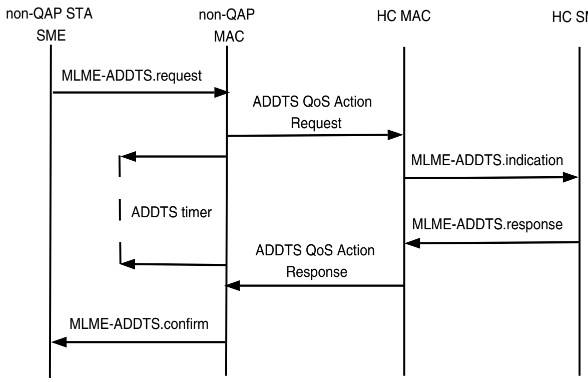

Fig. 2. TS Setup in IEEE 802.11e

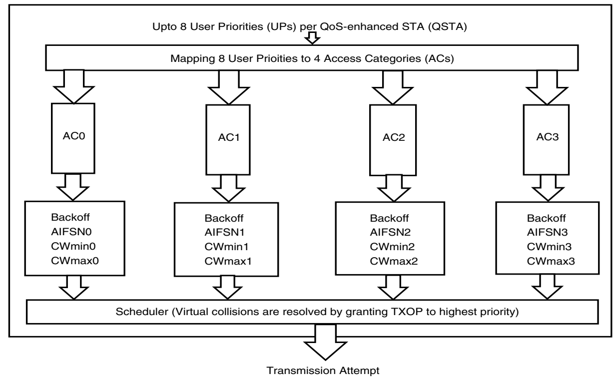

Fig. 4. Mapping by EDCF in IEEE 802.11e

Octets: 2	2	6	6	6	2	6	2	0-23424	4
Frame Control	Duration ID	Address 1	Address 2	Address 3	Sequence Control	Address 4	QoS Control	Frame Body	FCS

Fig. 3. The 802.11e MAC Frame

2) QoS using HCF: Designed for parameterized QoS support, HCF can start the controlled channel access mechanism in both contention-free period (CFP) and contention-period (CP) intervals. During the CP, a new contention-free period named controlled access phase (CAP) is introduced which is the combination of several intervals during which frames are transmitted using HCF-controlled channel access (HCCA) mechanisms. The QAP scheduler computes the duration of polled-TXOP (transmission opportunity) for each QSTA based upon the TSPEC parameters of an application flow. The scheduler in each QSTA then allocates the TXOP for different TS queues according to priority order. Similar to the process as in Fig. 4, frames with TID values from 8 to 15 are mapped into eight TS queues using HCF controlled channel access rules. The reason for seperating TS queues from AC queues is to support strict parameterized QoS at TS queues whereas prioritized QoS is supported at AC queues.

III. QoS SUPPORT IN IEEE 802.16

The IEEE 802.16 MAC is *connection-oriented* (Fig. 5). All traffic is carried on connection(s), even for flows of connectionless protocols, such as IP. MAC layer functioning is divided in three parts: Service Specific Convergence Sublayer (SSCS), MAC Common Part Sublayer (MAC CPS), and Security Sublayer. For the implementation of the convergence sublayer two standard options are available, namely, ATM convergence sublayer, and Packet convergence sublayer (considered here). As defined in the standard, a **service flow** (SF) is a unidirectional flow of MAC service data units (MDUs) on a connection that is provided a particular QoS. On the other hand, a **connection** is a unidirectional mapping between the base station (BS) and a subscriber station (SS) MAC peers for transporting a service flow's traffic. Each traffic flow is a part of some service flow. When a subscriber station is introduced in a network it is assigned up to three dedicated connection identities (CIDs) for the purpose of sending and receiving control messages. These are namely, Basic (short, time-urgent MAC management messages), Primary (longer and delay-tolerant management messages) and Secondary (optional) (delay tolerant, standards-based like DHCP, TFTP) management connections, reflecting the fact there are inherently three different levels of QoS for management traffic between an SS and the BS.

A. Connection Setup for QoS

The connection setup is the first crucial step to ensure QoS as it paves the way to transfer the QoS requirements for different application flows that are being assigned to some service flow. The QoS parameter negotiations for an application flow, before it enters the MAC SSCS, are done by the network management entity, the details of which are beyond the scope of the standard (the suggested parameters are discussed later). The BS and SS(s) provide this QoS according to the ***QoS Parameter Set*** negotiated by the network management entity for the service flow. Service flows exist in both uplink and downlink directions and may also exist without actually being activated to carry traffic. All service flows (*provisioned*) have a 32-bit service flow ID (SFID) whereas *admitted* and *active* service flows also have a 16-bit connection ID (CID), which in particular, is provided by the BS. Once ***AdmittedQoSParamSet*** is accepted by the Authorization Module at the BS, a service flow becomes *active* and is provided a CID which is then used (in addition with SFID) for further transfer of data. As discussed by the authors [8] the management messages make it possible to setup a connection and are demonstrated in Fig. 6. In fact, dynamic connection changes as well as deletion of a connection follows the same cycle.

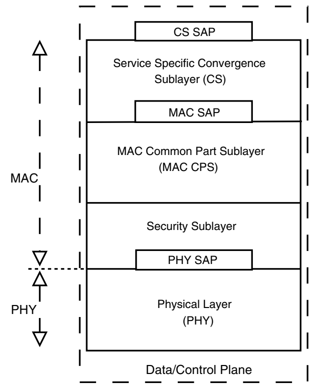

Fig. 5. The MAC in IEEE802.16

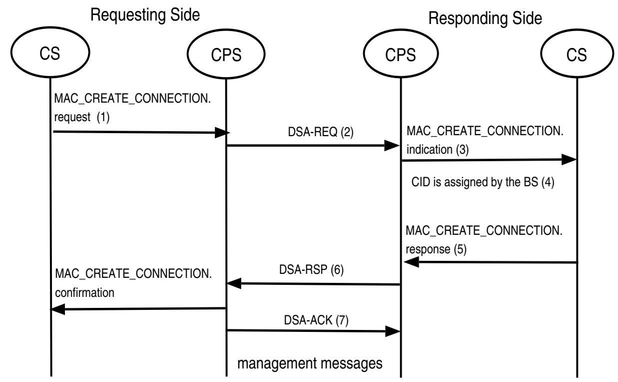

Fig. 6. Connection Setup

B. *QoS Assurance and Mechanisms*

The principal method for assuring QoS is to associate packets entering the MAC SSCS to a service flow as identified by its SFID and CID. The SSCS performs **classification** of an incoming MAC SDU and **associates** it either to an existing service flow or demands creation of a new connection for transmission between MAC peers. Several classifiers may each refer to the same service flow (as many application flows may be associated to a service flow). The ***classifier priority*** is used for the ordering of classifiers to packets. Uplink classifiers are applied at the SS whereas downlink classification is done at the BS. The MAC CPS facilitates the core functionality of *system access*, *bandwidth allocation*, *connection establishment* and *connection maintenance*. To facilitate different types of traffic, four scheduling services are discussed in the standard. These are: (a) **Unsolicited Grant Service** (UGS) for service flows that generate fixed size data packets on a periodic basis, like, VoIP without silence suppression. (b) **Real-Time Polling Service** (rtPS) to support service flows that generate variable data packets on a periodic basis, like, MPEG video, and probably VoIP with silence suppression. (c) **Non-Real Time Polling Service** (nrtPS) that handles service flows that require variable size data grant burst types on a regular basis, like, high bandwidth FTP. (d) **Best Effort** (BE) for the rest of data.

The QoS for the above discussed traffic categories is attributed through QoS parameters. The service flow management encodings, as found in the standard [2], designate a list of parameters associated with uplink/downlink scheduling for a service flow. A list of mandatory QoS parameters associated with each traffic category can be seen in Tab. I.

TABLE I
MANDATORY QOS PARAMETERS FOR TRAFFIC CATEGORIES

UGS	Maximum Sustained Traffic Rate, Maximum Latency, Tolerated Jitter, and Request/Transmission Policy
rtPS	Minimum Reserved Traffic Rate, Maximum Sustained Traffic Rate, Maximum Latency, and Request/Transmission Policy
nrtPS	Minimum Reserved Traffic Rate, Maximum Sustained Traffic Rate,, Traffic Priority, and Request/Transmission Policy
BE	Maximum Sustained Traffic Rate, Traffic Priority, and Request/Transmission Policy

IV. INTERWORKING: QOS ARCHITECTURE AND MAPPING

In this section we address the "matching" between traffic parameters as found in IEEE 802.16 and in IEEE 802.11e systems. In IEEE 802.16, we deal with various application flows by handling them via various scheduling services as in Tab. I. In IEEE 802.11e, the access mechanisms help in achieving QoS requirements for an application. However, this similitude does not mean a direct conversion of traffic category from one system into another and vice-versa.

Our proposition for a hybrid architecture can be seen in Fig. 7. The radio gateway (RG), as perceived, works as a Subscriber Station for the IEEE 802.16 network and also as a QAP for the IEEE 802.11e network. In order to address the goals set for the project work (providing real-time audio/video, audio/video on demand, precious data transfer) we have identified the following traffic classes which could be made up of various traffic parameters found in the drafts/standards. These classes are worked out depending upon a traffic type and its QoS requirements and should not be conflicted with categorized traffic services in Tab. I

- **CBR with Real-Time Traffic (C1)**: Applications like real-time audio/video fall into this class. The desirable characteristics for this class are very limited packet losses, minimum latency delays and very little jitter.
- **VBR with Real-Time Traffic (C2)**: Examples of traffic for this class include video on demand (streaming) and variable rate VoIP. Again, packet losses, minimum latency delays and jitter limits apply to such traffic though their values could be more tolerable compared to those of class C1.

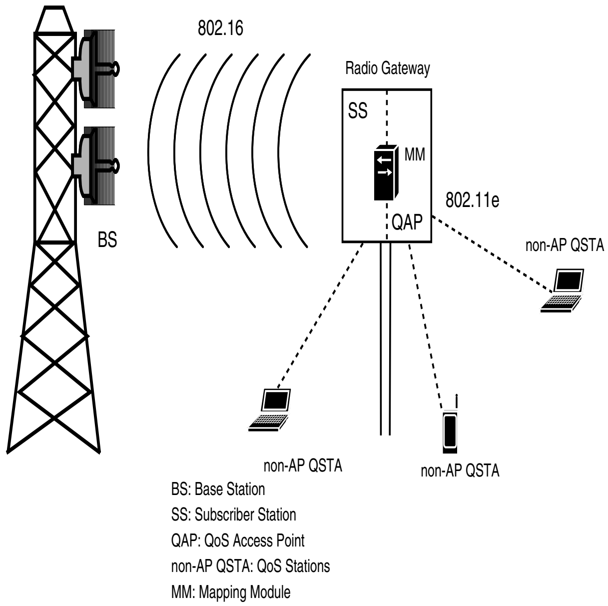

Fig. 7. IROISE: The Proposed Architecture

- **VBR with Precious Data (C3)**: This class addresses traffic type like large data files. However in this case traffic characteristics are more delay tolerant with a need of minimum packet loss.
- **Unspecified Type (C4)**: This class contains simple best effort type traffic such as web access, emails etc. So the traffic is purely BE.

Lets zoom-in on the radio gateway as in Fig. 8. The QAP module, after receiving a request from a non-AP QSTA, forwards the traffic identifier (TID) of an application flow along with the priorities/parameters that convey QoS requirements of an application to the mapping module (MM). The MM then maps the incoming traffic parameters to the ones that are supported for an IEEE 802.16 application flow. Based upon the traffic priorities discussed in an IEEE 802.11e network (first 8-bits of TID) as well as the traffic classes (per-flow traffic characteristics) worked out above, we propose two different kinds of mappings. The first kind of mapping is "**prioritized mapping**". In this mapping, the traffic priorities for an application flow, as in 802.1D [7], coming from a WiFi network are mapped to the corresponding traffic class in an IEEE 802.16 network and vice-versa. The second kind of mapping is per-flow "**parameterized mapping**" as illustrated in Fig. 9. It depends upon optional/mandatory traffic parameter requirements for an application flow though more optional parameters (found in the drafts/standards) could be used depending upon the technical and/or the financial requirements of a network. However the handling for these two kinds of mappings remain MM implementation dependent.

Following this mapping the whole process of connection setup in an IEEE 802.16 network (as discussed ear-

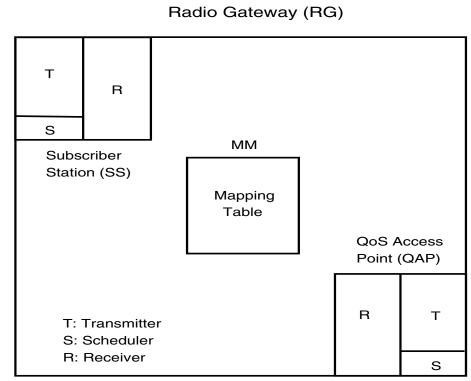

Fig. 8. RadioGateway supporting QoS

lier) requesting QoS for an application flow is executed by the SS module present on the RG. As discussed in [2], the QoS requirements for an application flow can be sent in MAC_CREATE_SERVICE FLOW.request along with the scheduling required. However, whether the request is served or not depends upon the resources available to the BS. Similarly, for the downlink, once the SS receives an application flow it is forwarded to the MM. The MM identifies the incoming flow with its SFID and associates it with the corresponding TID that it received with the request from a non-AP QSTA. This mapping between SFID and TID would then be used until the completion of data transmission for an application flow. Obviously, during this whole process we will need to buffer the incoming traffic at the RG being used.

We now discuss the proposed mapping in detail. For this sort of mapping to work the traffic characteristics pertaining to a class, as seen in the mapping table, in one system (say IEEE 802.11e) should be interchangeable with the similar traffic characteristics in the other system (say IEEE 802.16).

- Both Maximum Sustained Traffic Rate and Peak Data Rate specify the peak information rate of the service in bits per second. They do not include MAC overhead such as MAC and PHY headers.
- Maximum Latency and Delay Bound asserts the maximum latency periods within their respective networks, representing a service commitment, starting at the time of arrival of a packet at the local MAC sublayer till the time of successful transmission of the MSDU to its destination.
- The following terms are used in the following equations: D : Delay, $\max D$: Delay Bound, D_q : "Queueing" Delay, D_t : Transmission Delay, J : Tolerated Jitter. We consider that D_q includes all types of delay (buffering, scheduling, retransmission) except transmission delay. Note that $\max D$ and data rate are **not** independent and also D_t is proportional to data rate. Indeed, we observe that:

$$D = D_q + D_t, \min D \geq \min D_q + \min D_t$$

IEEE 802.11e	IEEE 802.16
Traffic Class C1	Traffic Class C1
Peak Data Rate	Maximum Sustained Traffic Rate
Delay Bound	Maximum Latency
(DataRate + Delay Bound)	Tolerated Jitter
Traffic Class C2	Traffic Class C2
Minimum Data Rate	Minimum Reserved Traffic Rate
Peak Data Rate	Maximum Sustained Traffic Rate
Delay Bound	Maximum Latency
Burst Size	Maximum Traffic Burst
Traffic Class C3	Traffic Class C3
Minimum Data Rate	Minimum Reserved Traffic Rate
Peak Data Rate	Maximum Sustained Traffic Rate
User Priority	Traffic Priority
Burst Size	Maximum Traffic Burst
Traffic Class C4	Traffic Class C4
Peak Data Rate	Maximum Sustained Traffic Rate
User Priority	Traffic Priority

Fig. 9. Parameterized Mapping

$$\text{and} \quad \max D \leq \max D_q + \max D_t$$

Also, we can say that

$$\max D_q \leq \max D - \min D_t \quad \text{and} \quad \min D_q = 0$$

Jitter for an application can be defined as:

$$J = \max D - \min D$$

We introduce an upperbound for "jitter" experienced by an application in an IEEE 802.11e network (no notion exists in [1]). Using the above equations we deduce an upper bound for jitter as:

$$J \leq \min(\max D, \max D + \max D_t - 2 * \min D_t) \tag{1}$$

Therefore from the values of Data Rate and Delay Bound of an application request from an IEEE 802.11e network, J in an IEEE 802.16 network could follow the upperbound deduced in (1).

- Both Minimum Data Rate and Minimum Reserved Traffic Rate are the minimum data rates specified in bits per second and map to similar requirements of an application flow. In this mapping MAC headers are not counted.
- Traffic Priority determines the priority among two service flows identical in all QoS parameters except priority. However for class C3/C4 type traffic from an IEEE 802.11e network, traffic priority is mapped onto by user priority (UP) assigned to an application flow. So UP and Traffic Priority play a similar role when it comes to mapping.
- Burst Size specifies the maximum burst of the MSDUs belonging to a TS which arrives at the MAC SAP at peak rate. Maximum Traffic Burst describes the maximum continuous burst the system should accommodate for a service. It also assumes that the service is not currently using any of its available resources i.e. the instant when an MSDU arrives at MAC.

V. Conclusion and Perspective

The proposed mapping may evolve further in details but is not the only factor that will count when it comes to ensure QoS. The process of establishing data transmission including buffering, proposed mapping , setting up of a new connection etc. will take some initial "setup" time. A synchronization should be ensured between the arrival of data at the RG and transmission opportunity (TxOP) available to QAP module. That will largely depend upon the behavior of the mapping module (MM) which ensures the mapping. The role of MM is multifold: It has to ensure the integrity of the incoming and the outgoing traffic (in either direction). The scheduling policy for the traffic inside the RG has to make sure that application flows are channeled to the corresponding connections (real/virtual). Two possible outlooks could be either to do this in an aggregate or per-flow handling of traffic. Besides the traffic handling inside the RG, scheduling policies within the individual networks should ensure that QoS sensitive applications get served in time along with the bandwidth constraints which in turn would also depends upon the dimensioning of such a system. These concerns are under study and are subject to further research.

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