Low-cost QoS-enabled Wireless Network with Interworked WLAN and WiMAX

Humaira Haffajee and H. Anthony Chan
University of Cape Town, South Africa
humaira.haffajee@accenture.com; h.a.chan@ieee.org

Abstract

The WLAN and WiMAX standards are candidate solutions for a low-cost broadband wireless network. Interworking the two networks, using the network-layer QoS mechanisms of the Next Generation Network, will allow them to complement each other. This paper proposes integrating the WLAN and WiMAX link-layer QoS mechanisms of the NGN to ensure that QoS is maintained over the wireless link. The wireless QoS mechanism in WLAN and WiMAX are analyzed and an integration framework is proposed.

1. Introduction

Laying down last-mile copper wire or cable to provide broadband communication to users who are not served by the existing wire-line infrastructure is not always feasible. Laying down wires may be prohibitively expensive or the terrain may make the task difficult.

Wire-line infrastructure is also inflexible. If wires are laid down to serve a business, the network operator needs to be assured that the business will continue to use that infrastructure for a long time so that the operator will eventually see a return on its investment. A solution to the cost and inflexibility problems of wire-line deployment is to use broadband wireless networks as an alternative.

IEEE 802.11 (WLAN) and IEEE 802.16 (WiMAX) are wireless broadband network standards. WLAN offers high data rates within a 100m range whereas WiMAX offers lower data rates in an 8km range. Instead of selecting one network to provide access to network services, interworking both networks can use each network's advantages.

WLAN and WiMAX have different link-layer QoS mechanisms. The task of interworking the QoS of these networks requires developing mechanisms to hide these differences from the user. This task involves looking at a network *architecture* that is able to host both networks, studying each network's *link-layer* QoS and then looking at the *network entities, and signaling* required to make the networks work together.

This paper analyzes interactions between different layers and network entities which are necessary to provide QoS when interworking WLAN and WiMAX into the NGN. A design to inerwork QoS in WLAN and WiMAX is presented.

2. QoS mechanism in the NGN

This section focuses on the QoS mechanisms that the NGN provides to allow the network to provide different services.

2.1. IETF Differentiated Services standard

The IETF developed Differentiated Services (DiffServ) to overcome the scalability limitations of IntServ [1]. Diffserv is centered on the idea of a Service level agreement, which is a contract between the customer and ISP, specifying the level of service to be provided to the customer. The service level can be mapped to one of the groups of Per-Hop Behaviours described below:

1) *Expedited service:* Guaranteed delay and jitter
2) *Assured services:* Guaranteed bandwidth but no guarantees on queuing delay
3) *Olympic service*: Gold, silver and bronze best effort

Although there are similar service classes in IntServ, each IntServ flow can have its bandwidth and buffer size tailored to its needs. In DiffServ, resource allocation is determined according to the service class, which means that there are only 64 possible service combinations.

2.2. NGN admission control

Admission control admits flows into the network if the network can support the QoS requirements of the flow and the admission of the flow does not severely degrade existing flows. It ensures that there are not too many flows competing for the limited network resources. Each edge network contains a QoS Broker [2], which admits

Manuscript received November 14, 2005
This work is supported in part by Telkom, Siemens, and National Research Foundation, South Africa with funding from the Broadband Communication Centre of Excellence.

individual flows from users into the edge network. The edge network QoS Broker will interact with Access Routers to obtain information from them on resource availability.

The Edge QoS Broker must make an admission control decision based on the state of many elements in the network. It must determine whether the resources available in the network can support the requirements of the flow. If resources are available, it admits the request and configures the routers in the path of the flow. If not it rejects the flow. Figure 1 outlines the admission control function of the QoS Broker.

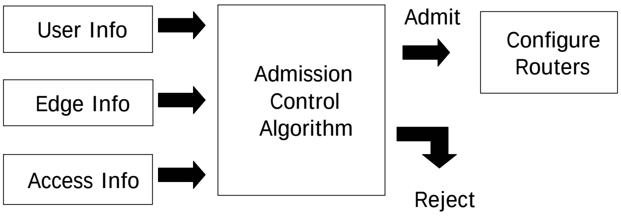

Fig. 1. QoS Broker admission control decision.

The information required for the admission control decision [2,3,4] can be grouped into three categories:

1) *User Info:* The QoS Broker requires information about the QoS needs of users application, user subscription information from the AAA server, and mobility information from a mobility module.
2) *Edge Info:* Information from routers is required to prevent connection from being admitted to oversubscribed routes.
3) *Access Info:* Additionally, we suggest that the QoS Broker should monitor the Access Points and Base Stations to determine whether bandwidth and buffer space are available in the wireless networks. The variability and scarcity of wireless bandwidth makes this monitoring important.

The Mobile Node (MN) performs signaling with the QoS Broker if it wants to establish a QoS-enabled flow. If the QoS Broker admits the flow, it configures the Edge and Access Routers. This configuration ensures that appropriate traffic policing and shaping rules are used to maintain the required QoS [2].

2.3. QoS in wireless access

The Edge QoS Broker must make an admission control decision DiffServ and admission control will not suffice if the individual links along the path cannot ensure that QoS constraints are met. The 802.11e and 802.16 networks are broadcast networks. Competition among nodes for use of the shared broadcast medium leads to collisions and long delays if there is no control over access to the medium. The 802.11e and 802.16 standards define Multiple Access Protocols (MAC) in the link-layer to control when nodes access the medium.

The Moby Dick architecture [3] shows how QoS can be provided at a network level. It does not specify how traffic is prioritized at the link-layer. The integration of WLAN and WiMAX QoS into the NGN architectures which is proposed is not tied to the WLAN and WiMAX standards, but will be able to interwork with future wireless standards.

3. Wireless link-layer QoS mechanisms

This section looks at how different levels of Quality of Service are provided over the wireless link in WLAN and WiMAX. It also shows how admission control occurs in these two networks.

3.1. Analyzing QoS in WiMAX

This section provides a summary of the important mechanism, from the WiMAX specification [5], which are required to provide QoS and admission control.

3.1.1. MAC layer connections. The WiMAX MAC is connection oriented. Each connection is associated with a set of QoS attributes and a scheduling service appropriate for the data that the connection will transport. A Connection identifier (CID) is contained in the header of each frame to identify which connection it belongs to. A connection serves as a mapping between adjacent MAC layers. Each Subscriber Station (SS) has a MAC address differentiating it from other SSs within the same cell and may have many MAC layer connections to a Base Station (BS).

3.1.2. MAC layer scheduling services. Different scheduling services are provided for different types of traffic. Table I below shows the four scheduling services.

The Unsolicited Grant Service (UGS) is suitable for constant bit-rate data, which has fixed size packets and periodic transmissions. A fixed number of slots are provided in every frame and small additional bandwidth requests can be made. UGS is more efficient for constant bit-rate packet because it avoids the overhead of regular polling from the BS.

The Real-time Polling Service (Rt-ps) requires the BS to poll the SS for use of slots in each frame and is better suited for real-time variable bit rate data. It is more efficient than UGS since slots can be used by other connections if the SS does no use them.

Non Real-time Polling Service (Nrt-ps) is used for variable bit rate data which can tolerate some delay.

3.1.3. MAC layer connections. A service flow is defined to be a "unidirectional flow of packets with a set of QoS requirements" [5]. Packets received from the network layer are classified by the IP Convergence sub-layer into a connection, defining where the packets are delivered to in the peer Convergence sub-layer. The Service Flow is assigned a connection, a set of QoS attributes and one of the scheduling services, described in the previous section.

TABLE I

Comparison of WiMAX Scheduling Services

Rt/nrt	Scheduling service	Data type	Application example
Real time	Unsolicited grant service	Constant bit-rate	Voice
	Real-time polling service	Variable bit-rate	Video
Non real-time	Non real-time polling service	Variable bit-rate	FTP
	Best effort	Contention	E-mail

A Service Flow can be in the Provisioned, Admitted or Active states. Each state has a set of QoS attributes. Attributes in the lower sets must be a subset of those in the higher sets, ensuring that only provisioned attributes can be admitted and only admitted attributes can become active.

3.1.4. WiMAX admission control. The MAC Common-Part Sublayer (CPS) and Service Specific Convergence Sublayers (SSCS) take part in the admission control process. The BS SSCS requests the creation of a Service Flow from the BS MAC CPS. An authorization module in the BS checks whether the newly requested Admitted attributes is a subset of the Provisioned QoS Parameter Set to permit the admission request to continue. The BS MAC layer then sends a Dynamic service addition (DSA)_request message to the MN MAC CPS. The DSA_request message contains the Service Flow ID, requested Service Flow QoS attributes, scheduling service required, and the SSCS classification rules.

The SSCS can then set up the connection, which it identifies with a CID. If the convergence sublayer creates the connection successfully, it sends a positive response, containing the CID of the created connection, to its CPS.

The MAC CPS sends a DSA_response message to the BS MAC, containing the CID of the created connection if the creation was a success. If it was a failure, an error message is returned. The BS MAC CPS sends a confirmation message containing the CID to the BS convergence sublayer. Lastly, the BS MAC responds with an acknowledgement, which signals that data can be transmitted over the connection.

3.2. Analyzing QoS in WLAN

The 802.11e draft standard is an extension to the current 802.11 standard. Similar to the current standard, the 802.11e standard contains two co-ordination functions. Together they are called the Hybrid Co-ordination Function (HCF). The first co-ordination function is the Enhanced Distributed Co-ordination function (EDCF), which is a QoS enabled version of DCF. The second is the HCF Controlled Channel Access (HCCA), which is similar to the PCF.

3.2.1. Enhanced distributed co-ordination function. EDCF extends DCF by allowing the MAC layer to prioritize traffic into one of four queues, which are called Access Categories (ACs). Each AC has three parameters that can be adjusted to give it a different priority: the minimum and maximum contention window (CW) size and the AIFS (arbitration interframe space). Higher-priority ACs have smaller CWs and shorter AIFSs. Smaller CWs mean that the AC selects its random back-off from a set of smaller numbers. The AIFS determines how long an AC must wait before it transmits. Since each AC decides when to transmit independently, a virtual collision resolution mechanism is required to select which AC can transmit if more than one AC's back-off timer expires simultaneously. [6]

After sensing an idle medium, each AC waits its AIFS and then starts its back-off timer. If an AC is the only one whose back-off has expired, it transmits a frame. Otherwise the virtual collision resolution mechanism selects the frame from the highest priority AC. Table II [7] gives a possible mapping between AC and application type.

Table II

Mapping between Access Categories and Application types

Access Category	Application
0	Background
1	Best Effort
2	Video
3	Voice

EDCF also allows the AP to signal the requirement for centralized admission control using an Admission Control Mandatory bit in the beacon frame [8].

3.2.2. Hybrid controlled channel access. The HCCA provides a contention-free service using QoS signaling, scheduling and admission control. A super-frame has a contention-free period followed by a contention period. A mobile node, wanting to transmit data, uses MAC QoS signalling to set up a Traffic Stream. Up to eight Traffic Streams can exist and each traffic stream serves packets with the same QoS requirements.

Industry is divided on whether the HCCA will be implemented with EDCA. The following issues are being considered [9]:

- PCF's complexity made it unsuccessful - vendors might expect the same from HCCA
- The WiFi Alliance will certify EDCA compliance sooner
- Current operating systems cannot support HCCA but can support EDCA

Implementation of HCCA depends on whether EDCA is able to satisfy user QoS requirements.

3.2.3. WLAN Admission control. The Station Management Entity (SME) was defined in the original 802.11 standard [10]. It is a layer-independent management entity, which interfaces with layer management entities on one side and the network management system on the other side. In the 802.11e standard the SME decides whether or not to accept an admission request. The AddTS messages carry the TSPEC containing either AC requirements.

The mobile node's SME initiates the admission control request by sending an AddTS request to the MAC layer management entity (MLME). The AddTS request contains the Traffic specification (TSPEC) of the flow. The mobile node's MAC layer then sends a message containing the TSPEC to the MAC layer of the Access Point. The AP's MLME intercepts the message and requests an admission control decision from the AP's Station Management Entity. The Station Management entity carries out the admission control decision and sends a response back to the AP's MLME. If the request was accepted, the mobile node can transmit data.

4. A design to integrate WLAN and WiMAX

The previous section described the WLAN and WiMAX link-layer QoS. The QoS Broker and DiffServ classes used in the NGN were also described. Section 3.2 describes a design for integrating the WLAN and WiMAX link-layer QoS into the NGN network. It is clear that these mechanism work differently in both networks.

A mapping between the WLAN and WiMAX link-layer classes and the NGN DiffServ classes, which operate at the network layer, is given. Section B describes the network entities required for the integration.

3.2. Mapping DiffServ to link-layer services

The DiffServ Code Point (DSCP) is marking each packet and causes routers to forward the packets with different priorities [11], which can be mapped to the wireless link-layer services to ensure that prioritization occurs over the wireless link. We propose to map the DSCP to the link-layer scheduling services in WiMAX and in WLAN according to their priorities. The lower DSCP classes are mapped to the lower priority classes in WiMAX and to the lower Access Categories in WLAN, and vice versa. The mapping is given in Table III.

TABLE III
Mapping of scheduling services to DiffServ Code Point

Priority	DSCP Class	WiMAX Scheduling	WLAN Scheduling
0	Best effort	BE	AC 0
1	Best effort	BE	AC 0
2	Assured 1	Nrt-ps	AC 1
3	Assured 2	Nrt-ps	AC 1
4	Assured 3	Rt-ps	AC 2
5	Assured 4	Rt-ps	AC 2
6	Expedited	UGS	AC 3 / TS 0
7	Expedited	UGS	AC 3 /TS 1

The column on the left shows the priority of the scheduling services with zero as the lowest priority. The second column gives the DiffServ classes matching the priorities in the first column. DiffServ classes use the first 3 bits of the DSCP. The two DiffServ Best Effort classes can be treated differently by setting the DSCP drop-precedence bits differently. The class with priority 0 can have a high drop precedence and the class with priority 1 can have a low drop precedence. These classes are the Best Effort and Non Real-time Polling services in WiMAX and the lower priority ACs in WLAN.

4.2. Architecture to integrate WiMAX and WLAN

We next include link-layer QoS in WiMAX into the Moby Dick architecture in our design. The QoS mechanism in the existing Moby Dick architecture is primarily at the network layer, whereas the QoS services in WiMAX are at the link-layer. We need to integrate these different mechanisms.

This design uses a data plane, which are on the left of each stack in Fig 2, and a management plane, which are on the right of each stack there. The QoS Broker makes admission control decisions and communicates the results to the management entities in the Access Router and BS or AP. The Management entities interface with the data plane to allow the management entities to configure the protocol layers in the data plane.

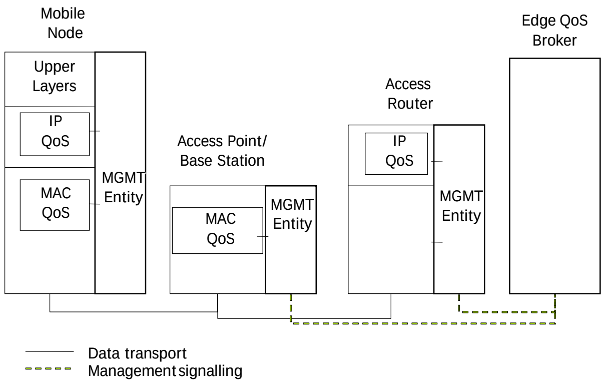

Fig. 2. Management and data plane for integrating WLAN/WiMAX into NGN

The authorization module is part of the BS MAC and must accept or deny admission of Service Flow. The authorization module is labeled as the MAC QoS module and it outsources decisions to the QoS Broker via the Management entity. Similarly, the Access Router MLME in WLAN receives admission decisions from the QoS Broker via the management entity.

5. Integrating WiMAX into NGN

This section describes the signaling required to set up a QoS-enabled call. It uses the Moby Dick signaling but adds the signaling required to set up the QoS-enabled connections in the link-layer (Figure 3).

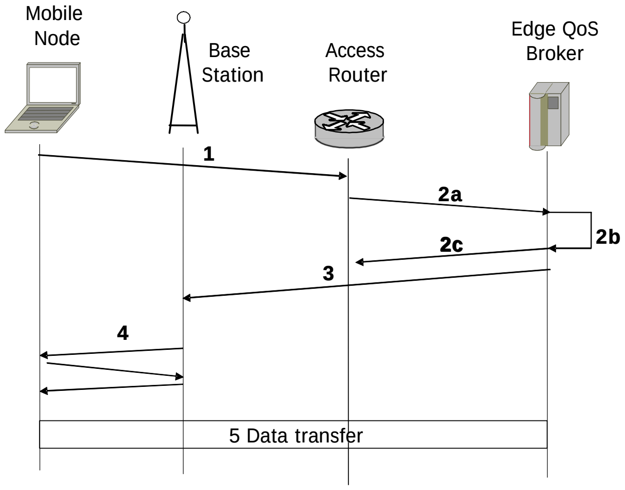

Fig. 3. Message sequence chart showing WiMAX QoS signaling

1. User QoS Signaling: The user sends an IP packet, with a DSCP appropriate for the data it is trying to transmit, over a basic transport connection.

2 NGN Admission Control [3]

2a: Access Router interception: The Access router's QoS Manager intercepts the IP packet. If it has QoS Policies it forwards the packets. If not it sends an Admission Control request message to the QoS Broker.

2b: QoS Broker decision: The QoS Broker decides whether the access network and the edge network have enough resources for the connection.

2c: Acceptance: If the connection is accepted the Access Router Management entity configures its IP layer according to parameters sent by the QoS Broker.

3. Service flow set up: The QoS Broker also sends a message to the BS management entity with the Service Flow parameters required to set up a QoS-enabled transport connection. The BS management entity gives the admission decision to the Authorization module in the MAC Layer. The BS management entity also informs the convergence sublayer to request a connection set-up and provides it with the necessary classifiers.

4. QoS-enabled connection setup: The BS convergence sublayer sets up a QoS-enabled transport connection with the MN using the QoS attributes from the QoS Broker. The scheduler ensures that the QoS can be maintained.

5. Data transfer: Data can now be transferred over the connection. End-to-end QoS will be maintained using DiffServ in the routers and the Service Flow specifications over the wireless link.

6. Integrating WLAN into NGN

The 802.11 standard defines a Station Management Entity (SME) for the MAC and Physical layers and a Mac-Layer Management entity (MLME). The MLME is part of the 802.11 specification. It is part of the MAC layer and is the module which communicates with the layer-independent SME. The MLME can monitor events in the MAC layer and create appropriate MAC management messages.

This design extends the SME to interface with the IP layer. The SME in the MN will be used to configure the MAC layer QoS mechanisms to match the end-to-end IP QoS, determined by the DSCP. Fig. 4 describes how WLAN is used to signal the user's network layer QoS requirements to the Access Router.

1. User QoS signaling: QoS signaling for a newly arrived mobile node is simpler in WLAN than WiMAX because EDCA is not connection oriented. A DSCP packet can be transmitted immediately, without signaling to establish a link-layer connection.

Fig. 4 describes how QoS-enabled link-layer ACs are set up.

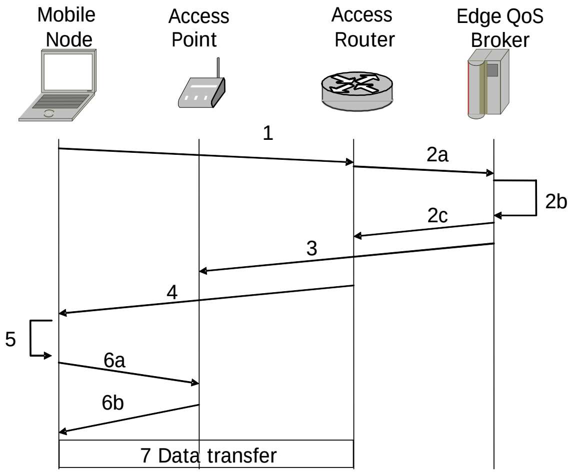

Fig 4 Message sequence chart showing user QoS signalling with WLAN

2. NGN Admission Control: As for WiMAX
3: Configure Access Point: If the MN was admitted, the QoS Broker must send a management message to the Access Point SME to inform it to admit the connection.
4: Signal acceptance to MN: The 802.16e specification requires MNs to request QoS-enabled connections. This makes admission control from the QoS Broker slightly difficult since the admission decision needs to be relayed back to the MN for the connection to be set up. To allow the MN to request the connection it was decided to transmit the DSCP back to the MN to inform it about the successful admission. This step was avoided with WiMAX because WiMAX allows connections to be established by the BS.
5. IP QoS Mgmt entity intercepts: The design requires an IP QoS Manager to be implemented in the MN IP layer. It intercepts the message with the DSCP and sends a request to the SME. The SME must instruct the MLME to create the connection.
6. QoS-enabled connection setup:
6a AddTS request: The MN MAC transmits an AddTS_request with the QoS attributes from the MLME.
6b AddTS response: The AP SME automatically accepts the connection because the QoS Broker instructed it to do so in step 5. The AP MAC creates Access Categories for the MN and replies with an AddTS_response message.
7. Data transfer: Data can now be transferred over the connection. QoS will be maintained using higher priority ACs as well as end-to-end DiffServ mechanisms for QoS sensitive traffic.

A design for integrating WLAN and WiMAX into the NGN was presented. It first mapped the WLAN and WiMAX link layer QoS to the DiffServ classes. A network architecture showing the entities necessary for interworking each network into the NGN was then given. After the architecture was given, a detailed call-flow, to set up a QoS-enabled call, was described using message-sequence diagrams.

7. References

[1] P.F. Chimento, “Tutorial on QoS support for IP”, <online> http://ing.ctit.utwente.nl/WU1/publications/qos-tutorial.pdf
[2] J.-C. Chen, A. McAuley, A. Caro, S. Baba, Y. Ohba, P. Ramanathan, “QoS Architecture Based on Differentiated Services for Next Generation Wireless IP Networks”, <online> http://ietfreport.isoc.org/idref/draft-itsumo-wireless-diffserv/
[3] Victor Marques, Rui L. Aguiar, Carlos Garcia, Jose Ignacio Moreno, Christophe Beaujean et al. “An IP-based QoS architecture for 4G operator scenarios”, <online>
[4] Xin Gang Wang, Geyong Min, John E. Mellor, “Adaptive QoS control in cellular and WLAN interworking networks”, Department of computing, School of informatics, University of Bradford
[5] IEEE standard 802.16-2004, “Air interface for fixed broadband wireless access systems” <online> http://www.ieee.org
[6] Yang Xiao, “IEEE: 802.11e: QoS Provisioning at the MAC layer”, IEEE Wireless Communications, June 2004
[7] G. Boggia, P. Camarda, L.A. Grieco and S. Mascolo, “Feedback-based bandwidth allocation with call admission control for providing delay guarantees in IEEE 802.11e networks”, November 2004 <online> http://www.sciencedirect.com/science
[8] Timo Vanhatupa, “QoS approaches for 802.11 environment”, <online> www.cs.tut.fi/kurssit/8304700/sem4talk3.pdf
[9] “Providing QoS in WLANs”, Intel White paper, <online> www.intel.com/network/connectivity/resources/doc_library/white_papers/303762.htm
[10] IEEE standard 802.11-1999, “Wireless LAN Medium Access Control and Physical Layer Specifications”, <online> http://www.ieee.org
[11] “Implementing Quality of Service Policies with DSCP”, <online> http://www.cisco.com/warp/public/105/dscpvalues.html#dscpandassuredforwardingclasses