IP and WiMAX coalition

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***Abstract*—The IEEE 802.16 standard focuses on the MAC and physical layers. Its deployment needs a seamless integration with IP related protocols. This paper presents a review of approaches for IP support over WiMAX, including current efforts being developed to specify end-to-end architectures. The QoS mapping between IP QoS settings and IEEE 802.16 MAC layer QoS definitions is also addressed. Moreover, the handover process is described taking into consideration the assistance that the IEEE 802.16 handover process can provide to mobile IP protocols in order to achieve seamless handovers.**

***Index Terms*—WiMAX, QoS, End-to-End Architecture, IP Mobility, IEEE 802.16e, FMIPv6.**

I. Introduction

The IEEE 802.16 standard has evolved through different versions. The IEEE 802.16d [1] and the IEEE 802.16e [2] are considered the most significant. While the IEEE 802.16a was the first release, the IEEE 802.16d, also known as 802.16-2004, has specified the use of 10GHz and 66GHz spectrums and introduced the support for indoor Customer Promises Equipment (CPE). The IEEE 802.16e, the last release, has pushed the mobility support through the operation on the 2GHz and 6GHz licensed bands.

The WiMAXForum has conceived, based on the IEEE 802.16e standard, the mobile Worldwide Interoperability Microwave Access (WiMAX) profile [3] to define an end-to-end system solution for a mobile WiMAX network. It has also proposed a WiMAX network IP-Based architecture with different functional entities, such as the Mobile Station (MS), the Access Service Network (ASN) and the Connectivity Service Network (CSN).

The IEEE 802.16 MAC layer is composed by different sublayers, the convergence sublayer, the MAC common part sublayer and the security sublayer. IEEE 802.16d and IEEE 802.16e define different classes of service, namely, Unsolicited Grant Services (UGS), real Time Polling Service (rtPS), Extended real Time Polling Service (ErtPS) (only in IEEE 802.16e), non real Time Polling Service (nrtPS) and Best Effort (BE). Jianfeng Chen et al. [4] have proposed a cross-layer QoS architecture defining the mapping between IntServ and DiffServ traffic classes into the IEEE 802.16d QoS service classes.

IEEE 802.16e specifies the mobility support, including the power and handover management procedures. The power management process is based on two power modes, the Sleep and Idle modes. Three handover modes are considered, one mandatory and two optional. The Mobile IPv4 (MIPv4) support in the IEEE 802.16e standard is quite limited. However the network working group of WiMAXForum, on Stage 2 [5], extends the mobile IP support, specifying MIPv4 and Mobile IPv6 (MIPv6) protocols. The Stage 2 specification overviews mobility in the WiMAX network IP-Based architecture. Heejin et al. [6] describe mobility support based on the Fast Mobile IP Handover (FMIPv6) protocol, proposing an integrated and centralized architecture for IEEE 802.16e.

This paper is organized as follows: Section II compares the different wireless standards with IEEE 802.16. Section III reveals the IP challenges on IEEE 802.16. Sections IV and V address QoS and Mobility aspects in IEEE 802.16 networks. Finally, the document ends with the conclusion.

II. Wireless Standards

This section overviews the IEEE 802.16d and the IEEE 802.16e standard versions comparing them with the IEEE 802.11 and IEEE 802.20 standards and with the 3G related standards.

The IEEE 802.11 standards are designed for local area networks, operating on license free bands. The MAC layer uses the Carrier Sense Multiple Access-Collision Avoidance as access scheme, which is based on the Carrier Sense Multiple Access-Collision Detection. The IEEE 802.16 is a broadband wireless access standard intended for metropolitan or wide area networks performing on different propagation environments, line of sight and non line of sight. The improved features of the standard such as, a more effective use of the spectrum, the possibility to configure frequency channels, adaptive radio frequency channel bandwidth and reuse of channels, allow the operation on licensed and license-exempt bands and an increased cell capacity.

The IEEE 802.20 [7] mobile broadband wireless access standard is designed to provide a global mobility solution. The low latency provided and the support of high throughput allow real-time data transmissions. Mobile WiMAX based on IEEE 802.16e [2], is a mobility solution, supporting high data rates up to 70 Mbps, overcoming the 16 Mbps supported by IEEE 802.20. Although the improved IEEE 802.20 version supports mobility, it is not yet well specified to run on licensed bands bellow 3.5GHz. Mobile WiMAX is already defined to operate on licensed and license-exempt bands.

The 3G networks are based on the Code Division Multiple Access (CDMA), and Wideband Code Division Multiple Access standards. Both operate on licensed bands and have a fixed channel bandwidth, 1.25 MHz and 5.0 MHz, respectively. IEEE 802.16e supports scalable channelizations from 1.25 to

20 MHz. IEEE 802.16e also provides high data rates with low latency. Moreover, the IEEE 802.16e allocates bandwidth per user to assure connection-oriented QoS, as opposite to the users shared bandwidth on 3G networks.

IEEE 802.16e is the most improved wireless standard when evaluating performance (bandwidth and latency), coverage (distance between BSs), reliability (QoS is supported on its core design and not as an extension), security (provides lower layer mechanisms for authentication, integrity and replay protection) and mobility (specifies different types of handover and power modes).

The WiMAXForum is addressing the unspecified items of the IEEE 802.16e standard to promote interoperability and facilitate network deployments. The mobile WiMAX profile [3], specifies the mandatory and optional features to define an end-to-end system solution for a mobile WiMAX network. The mobile WiMAX can be deployed as an access technology, replacing Wi-Fi or even DSL and cable modems. It can also provide connection between different technologies, for instance, it can connect different Wi-Fi networks. The mobile WiMAX systems offer scalability in both radio access technology and network architecture, providing a cost-effective network infrastructure when compared to 3G.

III. IP CHALLENGES ON WIMAX

This section presents fashions on how IP can be coupled with the IEEE 802.16 standards and the problems which may arise. It also provides an overview of the convergence layers of IEEE 802.16 and exhibits the network architecture promoted by the WiMAXForum.

A. End-to-End WiMAX Architecture

The network working group of WiMAXForum presents a Network Reference Model and the WiMAX Network IP-Based architecture [3] [5], depicted on Figure 1. The End-to-End WiMAX architecture aims to provide support for voice, multimedia and emergency services and for mobile telephony communications using VoIP services operating on IEEE 802.16 networks.

The WiMAX Network Reference Model is a logical representation of the network architecture revealing the functional entities and their interactions through the reference points. The logical entities represent a grouping of functional entities and include the Mobile Station (MS) or Subscriber Station (SS), the Access Service Network (ASN) and the Connectivity Service Network (CSN). The manufacturers can implement the logical entities freely (i.e. one or more physical device per entity), as long as the functional and interaction requirements are respected.

The WiMAX network IP-based architecture details the entities within the functional groupings of ASN and CSN. The user terminals, namely the SS or MS, are equipped with IEEE 802.16 interfaces, that connect to the Base Stations (BS). The network access provider provides access to the WiMAX networks on the ASN. The Network Service Provider (NSP) places network elements, such as routers, AAA proxy/servers, on the CSN in order to provide IP connectivity to the SS/MS.

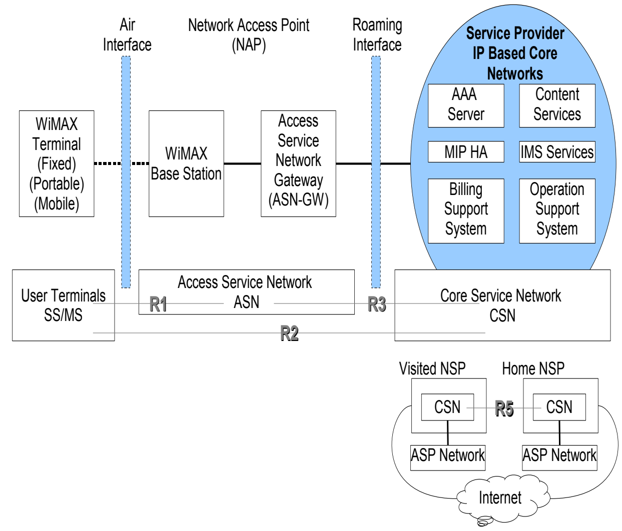

Fig. 1. The WiMAX Network IP-Based Architecture and Network Reference Model

B. IEEE 802.16 Network Entry

This subsection introduces the network entry process defined in the IEEE 802.16d standard.

The network entry process lets a SS communicate with a BS through the following steps: First, in the downlink channel synchronisation phase, the SS scans for a channel on a pre-defined list and after founding and synchronising the downlink channel at the physical level, searches the information about the downlink and uplink; Second, in the initial ranging phase, the SS sends ranging request messages using minimum transmit power, which is increased until the reception of a ranging response; Third, in the capabilities negotiation phase, the SS announces its capabilities to the BS, including the modulation levels supported, the coding schemes, the rates and the duplexing methods; Fourth, in the authentication phase, if supported by the SS and BS, the SS sends a X.509 certificate of the manufacturer and a description of the supported cryptography algorithms to the BS which validates the SS identity and determines the cipher algorithm and protocol to use; Fifth, in the registration phase, the SS registers after a successful authentication; Sixth, in the IP connectivity phase, if IP is used, the SS starts DHCP to get an IP address; Finally, the transport connection creation phase takes place.

C. IP over IEEE 802.16

This subsection provides an overview how IP is supported in IEEE 802.16.

The Convergence Sublayers (CS) of the MAC layer permit IP and other protocols to operate over IEEE 802.16. The functions of the CS is related to the acceptance, classification and processing of higher-layer Protocol Data Units (PDUs), to deliver CS PDUs to the appropriate MAC service data point and receive CS PDUs from a peer entity. The different CS specified by IEEE 802.16e are: First, the ATM CS to treat

ATM cells; Second, the IPv4 CS to analyse IPv4 packets; Third, the IPv6 CS to process IPv6 packets; Fourth, the IEEE 802.3/Ethernet CS to classify Ethernet frames; Fifth, the IEEE 802.1Q CS to process VLAN frames; And finally, the IP header-compression CS to compress IP and high layer header on the Robust Header Compression or Enhanced Compression Real Time Protocol format. For instance, the last CS overrides the limited performance of payload header suppression mechanism for VoIP packets.

The CS uses different parameters to classify the upper layer PDUs. The IP CS uses the type of service, transport protocol, IP source and destination address, and source and destination ports range. The IEEE 802.3 CS utilises the source and destination MAC address, Ethertype/SAP and can use the IP classification parameters if IP is encapsulated in Ethernet frames. WiMAXForum has defined the IP CS mandatory for the Mobile WiMAX profile and maintained the Ethernet CS optional.

IEEE 802.16 also defines the MAC common part sublayer, which is optimised for the Point-to-Multipoint and Mesh modes. The generic MAC PDU has a 6 bytes header format with different fields, such as the header type, the connection identifier (CID), the CRC indicator, the length of the MAC PDU and a type field to indicate subheaders and special payload types.

The connections are established using the signalling messages of the MAC layer, which is connection oriented. The downlink connections can be multicast or unicast and start on the BS. The uplink connections, starting on the SS towards the BS, are unicast. The MAC Service Data Units (SDUs), carrying user data, are packed into MAC PDUs. IEEE 802.16 uses CID to identify MAC PDUs and not the MAC address as other standards. Each connection is associated with service flow characteristics which allow the provision of QoS.

The classifiers apply matching criterias to user data packets. On a successful match, the packet is delivered to the service access point to be transmitted on the connection referenced by CID, otherwise it is discarded. The classifiers consist on different elements: a protocol matching criteria, a classifier priority, a reference to CID and Payload Header Suppression (PHS) rules. The PHS allows the improvement of the usage of the air link resources by suppressing from the MAC SDUs the repetitive portions of payload headers from the higher layers.

Junghoon Jee et al. [8] have drafted several problems and goals on the IP implementation over IEEE 802.16. IEEE 802.16 does not allow a smoothness integration of the IP protocols. The main causes constraining such integration are:

1) The Point-to-Multipoint architecture. The standard does not specify a native multicast support on the link layer, which allows current IP services on Ethernet or Wi-Fi.
2) The limited Ethernet capability. The Ethernet CS is the Ethernet capability layer of the IEEE 802.16 and only specifies how to encapsulate Ethernet frames over the IEEE 802.16 connections. It does not emulate the Ethernet functionality, and multicast/broadcast frames can not be processed by the IEEE 802.16 MAC layer solely, needing an Ethernet/bridge layer.
3) The communication with SSs on the same IP link. IEEE 802.16 has no support from MAC/physical layers to permit the direct communication between SSs attached on the same IP link.

The restrictions identified impose limits to IPv4 and IPv6 operation. The IPv4 limitations are related to the non multicast nature of IEEE 802.16 and to the ARP cache. IEEE 802.16 frames do not include the MAC address which allows to set the ARP cache in order to support DHCP address management. MIPv4 relies on multicast messages to discover mobility agents on new subnetworks. The IPv6 is also affected, since IPv6 behaviour relies on the link layer information. For instance, the neighbour cache is built from the MAC address which is not included in IEEE 802.16 frames. The duplicate address detection mechanism requires multicast support to correctly detect duplicate addresses on a subnetwork.

Next developments of the Ethernet Capability of IEEE 802.16 may include the support of broadcast/multicast at the physical level. Additionally, protocols such as DHCPv4, DHCPv6 and MIPv4 may be modified in order to remove the need for a multicast/broadcast environment. Further investigation can also focus on the mesh architecture to allow the direct communication between SSs.

IV. Quality of Service

The QoS and the reliable transport of information must be assured, since many applications are sensitive to delay and have special bandwidth requirements. The heterogeneous characteristics of broadband wireless access networks (i.e. line of sight and non line of sight conditions) rise up difficulties to the QoS support in wireless networks. In this kind of networks QoS is managed at the MAC layer in order to cope with the unpredictability and variability of the air links.

A. IEEE 802.16 MAC QoS support

This subsection describes the IEEE 802.16 mechanisms for QoS support.

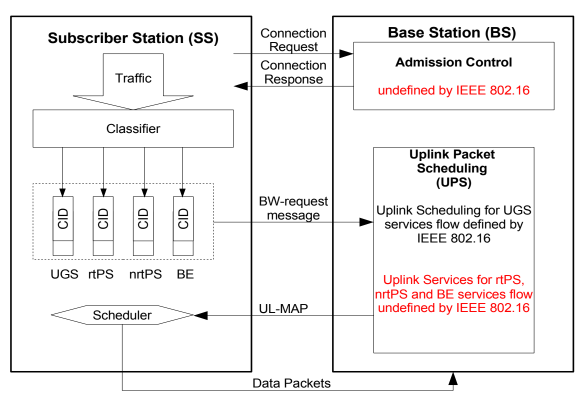

Fig. 2. IEEE 802.16 QoS Architecture

In IEEE 802.16, the bandwidth is granted to the SSs on demand. The Uplink Map messages (UL-MAP), broadcasted by the BS, instruct the SS how on to use the uplink channel.

The Information Elements (IEs), encapsulated in the UL-MAP messages, include transmission opportunities, like the time slots that SS can use to transmit data. The IEs are determined based on the bandwidth request sent from the SS to the BS. The size of the grant given to the SS is determined by the BS based on the bandwidth request received, on the active uplink connection and on polling (if needed).

Bandwidth request messages can be sent using the bandwidth request header messages, that do not contain any data payload but specify the bandwidth request field which indicates the number of bytes requested. With the deployment of an OFDM physical profile, the bandwidth request messages are sent in content intervals, whilst with OFDMA the CDMA codes are sent in contention intervals in order to obtain allocation to sent bandwidth request messages.

Figure 2 illustrates the IEEE 802.16 QoS Architecture described by Dong-Hoon Cho et al. [9]. The Uplink Packet Scheduling (UPS) in the BS allows the allocation of bandwidth to the MS/SS. The MS/SS has to control the allocated bandwidth for uplink.

Since MAC is connection oriented, the application establishes connection with the BS, therefore BS assigns an ID to the connection (CID) with which the service flows are associated. The main issues present on the IEEE 802.16 QoS architecture are:

- No definition of the admission control process. In the SS, the packets from application layers are classified based on CID and forwarded to the appropriate queue. The scheduler retrieves packets from queues and transmits them, in the defined time slots.
- No definition of the uplink scheduler. The mechanisms that determine the IEs in the UL-MAP are not defined. The BE, rtPS, nrtPS and ErtPS scheduling services are undefined, only the UGS is defined.
- The SS MAC has no scheduler. Only the BS MAC defines a scheduler. Claudio Cicconetti et al. [10] refer that a SS MAC scheduler could infer more precisely the grant of its connections. The bandwidth requests are done per connection but granted by the BS to the SS as a whole.

QoS is provided per service flow and the QoS parameters, associated with a service flow, define the order of transmission and scheduling on the air link. The service flow parameters can be dynamically managed through MAC messages. The different scheduling services supported by IEEE 802.16e, their respective requirements and applications are described on Table I.

Name	Requirements	Applications
UGS Unsolicited Grant Service	Maximum sustained rate, maximum latency tolerance and jitter tolerance	VoIP, constant bit rate (CBR)
rtPS Real-Time Polling Service	Minimum reserved rate, maximum sustained rate, maximum latency tolerance and traffic priority	Streaming audio or video (MPEG), variable bit rate (VBR)
ErtPS Extended Real-Time Polling Service	Minimum reserved rate, maximum sustained rate, maximum latency tolerance, jitter tolerance and traffic priority	Voice with Activity Detection (VoIP)
nrtPS Non-Real-Time Polling Service	Minimum reserved rate, maximum sustained rate and traffic priority	File Transfer Protocol (FTP)
BE Best-Effort	Maximum sustained rate and traffic priority	Data Transfer, Web Browsing and others, no QoS guarantee

TABLE I
THE SCHEDULING SERVICES SUPPORTED BY IEEE 802.16E.

The MAC management messages are created with Dynamic Service Addition Requests (DSA-REQ) containing, among others, the following items:

- The service flow parameters, which specify service flow traffic characteristics and scheduling requirements.
- The CS parameter encodings, which describe specific parameters of the service flows.

The DSA-RSP replies to a received DSA-REQ and contains the service flow parameters, a flag indicating the success of the transaction and other optional parameters. The Dynamic Service Changes (DSC) messages are used to change the parameters of existent service flows. The DSC-REQ is used to request the modification of parameters and in response the DSC-RSP is applied. The Dynamic Service Deletion (DSD) messages are employed to delete service flows that are no longer needed. The DSD-REQ can be sent by the SS or by the BS. The DSD-RSP are generated in response to DSD-REQ. All the response messages are acknowledged with the respective ACK messages.

Funqiang Liu et al. [11] have proposed an algorithm aiming to achieve QoS on the IEEE 802.16 mesh mode, with low delay and low packet drop rates. The algorithm relies on different fields of CID, such as: probability of a packet being dropped when congestion occurs and reliability of a packet, if the packet is retransmitted on an error situation.

B. *IP QoS over IEEE 802.16*

This subsection describes how the existent IP QoS settings can be combined with the IEEE 802.16 QoS settings.

The IEEE 802.16d QoS architecture, can support IntServ and DiffServ services, in the Point-to-Multipoint mode. Under the mesh mode, IEEE 802.16 can not assure end-to-end QoS, since QoS is only supplied inside an hop range. Nevertheless, the priority/class field of CID allows the distinction of different services. With the Resource Reservation Protocol (RSVP) QoS is provided in two steps: First, a secondary management connection is shared for RSVP to provide QoS support for upper layers; Second, primary management connection is used for DSA/DSC/DSD messages to provide MAC layer QoS.

Jianfeng Chen et al. [4] propose a cross-layer QoS control based on enhancements to the RSVP. The suggested architecture is composed by different steps and envisions traffic classification and mapping strategies for IntServ and DiffServ Services. Within the IntServ, the sender searches the PATH message for the traffic specification information. The mapping parameters between IntServ packets and DSA messages is as follows: UP/Bottom bound of BW corresponds to maximum sustained traffic rate or minimum reserved traffic rate; delay to tolerated jitter and jitter to maximum latency. With the DiffServ, the differentiated services codePoint is used to provide classification. The definition of Per-Hop Behaviour (PHB) to specify the forwarding treatment for packets are: expedited forwarding assumes low delay, low jitter and low loss services; assured forwarding provides different levels of forwarding assurances for IP packets. The proposed cross-layer QoS defines the mapping between the different traffic classes and the QoS service classes of IEEE 802.16d. Table II demonstrates the mapping rules for IntServ and Table III exhibits the mapping rules for DiffServ. The way how information can be exchanged between different layers, to guarantee an end-to-end QoS solution, needs further research.

V. Mobility

IPv4 and IPv6 have not been designed to support mobility natively. The mobility support was engaged based on the fact that the access point does not change its location. New protocols have been proposed, Mobile IPv4 (MIPv4) and Mobile IPv6 (MIPv6). Besides this, IEEE 802.16d has been proposed for fixed broadband access, only the IEEE 802.16e [2] envisions mobility.

A. IEEE 802.16e - The mobile version

This subsection introduces the mobility support of IEEE 802.16e.

IEEE 802.16e introduces improvements on the power management and handover procedures. On the sleep power mode, the MS negotiates inactivity periods to minimise the MS power usage and the resources of the serving BS. The MS can also scan other BSs to collect the necessary information to assist handover. With the Idle mode, the MS is available periodically for downlink broadcast traffic messaging without registering at a specific BS, thus the MS does not need the handover procedures, simple and timely methods alert the MS about possible pending downlink traffic.

The handover process can be used in distinct situations, like a better QoS service or an higher signal quality at another BS. IEEE 802.16e does not specify the such handover decision algorithm. The handover process consists on distinct stages: First, cell reselection, the neighbour BS information is evaluated to determine the MS interest in handover; Second, handover decision and initiation, the decision to handover may originate at the MS or the serving BS, using the MOB_MSHO-REQ or MOB_BSHO-REQ messages; Third, synchronisation to target BS downlink, MS synchronises to obtain downlink and uplink transmission parameters; Fourth, ranging MS and target BS conduct initial ranging, the target BS may request MS information over the backbone to the serving BS to skip one or several steps of the network entry process; and Finally, termination of MS context.

IEEE 802.16e defines three different handover modes: First, the Hard Handover which corresponds to the mandatory handover process; Second, the optional Fast Base Station Switching (FBSS); And Finally, the optional Macro Diversity Handover (MDHO). With FBSS and MDHO modes the MS and the BS maintain a diversity set that corresponds to a list of BSs involved in FBSS/MDHO with MS. When operating in FBSS the MS only communicates with the anchor BS for uplink/downlink messages and traffic, whilst in the MDHO the MS communicates with all the BSs in the Diversity Set.

The MS can learn the network topology using different methods: First, using a neighbour advertisement, the BS broadcast messages including the network topology at regular intervals; And Next, via scanning, the MS seeks and monitors the available BS that is suitable as handover target.

B. IP Mobility over IEEE 802.16e

This subsection provides an overview of the IP Mobility implementation over IEEE 802.16e.

IEEE 802.16e defines the fields that must be used when Mobile IPv4 is employed. These fields are described and encoded according to RFC 3344:

1) Home address is “0.0.0.0” when MS tries to obtain an IP address dynamically.
2) Home agent field address is “0.0.0.0” when MS tries to get an IP address in the visited network.
3) Network access identifier, defined on RFC 2789 must be included to identify the Mobile IP user.
4) Challenge extension, defined on RFC 3012, might be included in the agent advertisement message.
5) A 128-bit key may be shared between an MS and an authentication and service authorisation server.

The network working group of WiMAXForum, on Stage 2 [5], addresses the macro mobility or CSN anchored mobility, considering MIPv4 and MIPv6 mobility management protocols. The specification addresses the placement of the mobility agents, foreign agents (FA), home agents (HA) in the WiMAX network IP Based architecture and signalling between different entities to trigger upper mobility management protocols. The specification includes details for MS MIPv4 and not MIPv4-aware, the last are assisted by the proxy MIP specification.

The specification also considers the ASN anchored mobility or micro mobility evolving only the IEEE 802.16e standard, since no change on FA or access router happens.

Heejin Jang et al. [6] describe two possible mobile architectures based on the Fast Mobile IP Handovers (FMIPv6) for IEEE 802.16e:

- Centralised architecture, the BS and the access router form a single subnet. The handovers can be performed inside a domain using only the link layer mobility. Nevertheless, between different domains the IP mobility support is required.
- Integrated architecture, The BS and the access router are on the same box. A subnet contains only one access router and one BS. This architecture has an easier implementation, nonetheless, each handover requires the IP mobility support.

Both proposed architectures try to override the lack of synchronisation between IEEE 802.16 MAC and IP layers with new functionalities: First, the handover preparation which is triggered with the Link_Going_Down trigger indicating the

Traffic Class	Bandwidth Requirements	Delay / Jitter / Loss Rate	MAC layer Service
Hard QoS guarantee (VPN tunnel, T1/E1)	Constant bandwidth	Minimum packet delay, jitter and loss rate	UGS
Soft QoS guarantee (VoIP, VoD, digital TV, FTP)	Guaranteed Not guaranteed	Regular delay, jitter require long delay, jitter require	rtPS nrtPS
Best Effort (HTTP)	Only basic connection	N/A	BE

TABLE II
MAPPING RULES FOR INTSERV SERVICES

Traffic Class	Service Description	MAC layer Service
Hard QoS guarantee (VPN tunnel, T1/E1)	Critical	UGS
Soft QoS guarantee (VoIP, VoD, digital TV, FTP)	Flash, Immediate Priority	rtPS nrtPS
Best Effort (HTTP)	RunTime	BE

TABLE III
MAPPING RULES FOR DIFFSERV SERVICES

start of the handover process; And Next, the handover execution, optimised with the Link_Switch and Link_Up triggers which inform IP layer of the IEEE 802.16 network entry completion.

VI. CONCLUSION

IEEE 802.16 is a revolutionary broadband wireless access standard overcoming the limitations of other wireless standards. The integrated QoS support and the operation on licensed and license-exempt bands constitute such examples.

However, the integration with existent protocols such as IP needs deeper research. Cross-layer design for QoS and Mobility, with detailed information exchange between MAC and IP layers, are needed. Moreover, the normal classification that operates on the Convergence Sublayer is not enough to provide seamless handovers or end-to-end QoS assurances.

This paper, aimed at describing the IP over WiMAX framework, demonstrates open issues that can be addressed in future researches.

VII. ACKNOWLEDGEMENTS

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REFERENCES

[1] IEEE, "IEEE 802.16-2004 Standard for Local and Metropolitan Area Networks Part 16: Air Interface to fixed and Mobile Broadband Wireless Access Systems," 2004.

[2] IEEE, "IEEE 802.16-2005 Standard for Local and Metropolitan Area Networks Part 16: Air Interface to fixed and Mobile Broadband Wireless Access Systems," 2005.

[3] W. Forum, "WiMAX Forum Mobile System Profile Release 1.10 Approved Specification (Revision 1.2.2)," November 2006.

[4] J. Chen, W. Jiao, and Q. Guo, "An Integrated QoS Control Architecture for IEEE 802.16 Broadband Wireless Access Systems," in *IEEE Globecom 2005*, November 2005.

[5] WiMAXForum, "WiMAX End-to-End Network Systems Architecture (Stage2: Architecture Tenets, Reference Model and Reference Points) [Part 2]," August 2006.

[6] H. Jang, J. Jee, Y.-H. Han, S. D. Park, and J. Cha, "Mobile IPv6 Fast Handovers over IEEE802.16e Networks," http://www.ietf.org/internet-drafts/draft-ietf-mipshop-fh80216e-03.txt, August 2007.

[7] IEEE, "IEEE 802.20 – Mobile Broadband Wireless Access (MBWA)," 802.20 Working Group, 2005.

[8] J. Jee, S. Madanapalli, J. Mandin, G. Montenegro, S. D. Park, and M. Riegel, "IP over 802.16 Problems and Statements and Goals," August 2007. [Online]. Available: http://tools.ietf.org/id/draft-ietf-16ng-ps-goals-02.txt

[9] D.-H. Cho, J.-H. Song, M.-S. Kim, and K. J. Han, "Performance Analysis of the IEEE 802.16 Wireless Metropolitan Area Network," in *DFMA*, 2005, pp. 130–137. [Online]. Available: http://doi.ieeecomputersociety.org/10.1109/DFMA.2005.41

[10] C. Cicconetti, L. Lenzini, E. Mingozzi, and C. Eklund, "Quality of Service Support in IEEE 802.16 Networks," in *IEEE Network*, vol. 20, March/April 2006, pp. 50–55.

[11] F. Liu, Z. Zeng, J. Tao, Q. Li, and Z. Lin, "Achieving QoS for IEEE 802.16 in Mesh Mode," in *8th International Conference on Computer Science and Informatics*, vol. 5, July 2005, pp. 3102–3106.