Evaluation of Multimedia Services in Mobile WiMAX

Bruno Sousa
Laboratory of Communications and Telematics, Center for Informatics and Systems of the University of Coimbra,
Polo II, Pinhal de Marrocos
3030-290, Coimbra, Portugal
bmsousa@dei.uc.pt

Kostas Pentikousis
VTT
Technical Research Centre of Finland
Kaitovayla 1
FI-90571 Oulu, Finland
kostas.pentikousis@vtt.fi

Marilia Curado
Laboratory of Communications and Telematics, Center for Informatics and Systems of the University of Coimbra,
Polo II, Pinhal de Marrocos
3030-290, Coimbra, Portugal
marilia@dei.uc.pt

ABSTRACT

Mobile WiMAX defines an architecture for metropolitan area broadband wireless access networks based on IEEE 802.16e. One of the most important characteristics of WiMAX is support of applications with different QoS requirements in terms of delay, jitter and bandwidth. We briefly review IEEE 802.16 and the mobile WiMAX network reference model and discuss how IEEE 802.21 can enhance mobility management. Mobile WiMAX is often cited as an important 4G contender. We evaluate via simulation its capacity to support real time applications in high-speed vehicular scenarios and assess the potential of using cross-layer information made available by IEEE 802.21/MIH. Our results indicate that using MIH information allows for the fulfillment of multimedia application requirements. On the other hand, the requirements of such applications are far from being fulfilled when MIH assistant information is not employed.

Categories and Subject Descriptors

C.2.5 [**Computer-Communication Networks**]: Local and Wide-Area Networks; C.4 [**Performance of Systems**]: Measurement Techniques

General Terms

Experimentation, Measurement, Performance, Verification

Keywords

WiMAX, IEEE 802.16, VoIP, Video Streaming

1. INTRODUCTION

Network services such as Video on Demand (VoD), triple play and IPTV [1] deliver multimedia content to the end user while placing considerable demands on the infrastructure. In this diversity of multimedia applications, voice and video applications are the most popular. To address the requirements of such applications, the current specification of the Worldwide Interoperability Microwave Access (WiMAX) technology [2] defines different traffic models according to the requirements of the applications [3] in terms of bandwidth, latency and jitter requirements.

IEEE 802.16 is a wireless broadband access family of standards that includes two main specifications: IEEE 802.16-2004 [4] for fixed scenarios and IEEE 802.16e [5], which adds mobility support. One of the novelties introduced by IEEE 802.16 is the native support for Quality of Service (QoS). To enable such support, the standard specifies different scheduling services optimized for different kinds of applications. The QoS model includes service flows to characterize the traffic that can be transported over different connections. Moreover, connections between the Mobile Station (MS) and the Base Station (BS) are identified by Connection IDentifiers (CIDs) and not by MAC addresses as in other IEEE 802 standards.

Mobile WiMAX is based [6] on IEEE 802.16 and on the ETSI HiperMAN [7] standards. WiMAX completes the specification of IEEE 802.16 by defining a complete network architecture including the access and the connectivity segments. The access service network includes the MS, the BS and the gateway that is responsible for the network access. The connectivity service network includes functionalities related with IP services. This network reference model [8, 9] also includes support for mobility.

The IEEE 802.21 standard [10] aims at enabling handovers between heterogeneous networks, by defining a network model which includes different entities with specific roles and supporting several services. IEEE 802.21, also known as Media Independent Handover (MIH) standard, defines the Media Independent Event Service for the propagation of events, the Media Independent Command Service which allows the MIH user to issue specific actions on lower layers, and the Media Independent Information Service to provide network details.

The main goal of this paper is to evaluate the performance of multimedia applications over mobile WiMAX networks. Our evaluation is based on simulations performed with ns-2 [11] and the WiMAX mobility package from NIST [12]. We consider several test cases and experiment with different parameters, including MIH support; the type of MIH information, if predictive or only from generated events, such as Link UP.

Our simulation results reveal good support of mobile Wi-

MUM' 2008 , December 3-5, Umeå, Sweden

MAX for multimedia applications when employing MIH services. On the other hand, the results indicate that with no MIH services performance is very poor, inflicted by high packet loss when handovers occur.

This paper is organized as follows. Section 2 provides the necessary background by introducing the IEEE 802.16 standard, the WiMAX reference architecture model, and the MIH standard. Section 3 overviews related work and Section 4 describes the multimedia applications under study and the evaluation process to assess the performance of the mobile WiMAX. Finally, Section 5 presents the main conclusions and highlights issues to be addressed in future work.

2. BACKGROUND

This section introduces the functionalities of the IEEE 802.16 standard, the network architecture of mobile WiMAX, and the MIH specifications.

2.1 An Overview of IEEE 802.16

The IEEE 802.16 standard, often cited as the last-mile wireless broadband access standard, includes a set of features such as native QoS and mobility support. The IEEE 802.16-2004 [4] (also known as IEEE 802.16d), IEEE 802.16e [5] both addressing the data plane and IEEE 802.16g [10], specifying the management plane, represent the major versions of the standard. They define different functionalities, such as, operation in line of sight (LOS) and in non line of sight (NLOS) conditions, inherent support for different scheduling services, mobility, and extended coverage. The scheduling services include support that addresses requirements from web browsing applications till VoIP applications with silence suppression features.

In the IEEE 802.16 QoS model, each service flow is a unidirectional flow of packets with a particular set of QoS parameters, such as, traffic priority, maximum sustained traffic rate, maximum traffic burst, minimum reserved traffic rate, among others. The standard specifies different types of service flows: Provisioned, Admitted and Active, which are the only ones that are allowed to forward packets. The functional entities introduced in the standard are the Subscriber Station (SS), or Mobile Station (MS) in IEEE 802.16e, and the Base Station (BS). The BS is responsible for the centralized QoS scheduling inside its cell based on QoS parameters configured by the management system and the active bandwidth requests received from the SS. The SS or MS must identify a BS, acquire physical synchronization, obtain MAC parameters, and attach to the network.

The mobility support introduced in IEEE 802.16e includes power-saving specifications and handover procedures. The Sleep and Idle modes are two power-saving modes specified. The Idle mode is more power conservative, when compared to the Sleep mode, since the MS can completely turn off and become periodically available for downlink broadcast messages without being registered with any particular BS. Although three different handover modes are described in the standard Hard Handover (HHO), Fast Base Station Switching (FBSS) and Macro Diversity Handover (MDHO) all handover procedures are specified for the HHO mode only. Critically, the HHO mode has a major disadvantage as it implies an abrupt transfer of connection from one BS to another when compared to the other two, optional modes. The handover decision can be made by the BS, the MS or by a network entity. The MS learns about existing neighbors in management messages sent periodically by the BSs. Using such information, the MS can scan and associate with a BS. Once the handover decision is made, the MS initiates the synchronization process with the target BS.

The 16ng working group [13] is specifying the operations of IP over IEEE 802.16 networks. The transmission of IPv6 packets is specified in RFC 2151 [14]. This RFC, among other items, recommends the IP Convergence Sublayer using IPv6 classifiers for the transmission of IPv6 packets over IEEE 802.16 networks. Also, this RFC, overrides router discovery mechanisms specified in the Neighbor Discovery Protocol (NDP) [15], such as the Router Advertisement (RA) interval, which is set to the range between 4 and 21600 seconds and with a default value of 10800 seconds. Such values are specified for power-saving, for example in order to avoid to wake up mobile nodes that can be on the idle mode specified in the IEEE 802.16e standard.

2.2 WiMAX Description

The WiMAX Forum [2] aims at defining an architecture within which different vendor equipment can interoperate flawlessly while conforming to IEEE 802.16 and ETSI HiperMAN standards. Fixed WiMAX is based on [4, 7] and supports fixed and nomadic access in LOS and NLOS conditions. Mobile WiMAX is based on [5] and, among others, adds mobility support in WiMAX networks. In short, the WiMAX Forum specifies an end-to-end architecture [8, 9], instead of only focusing on the radio access segment of the network.

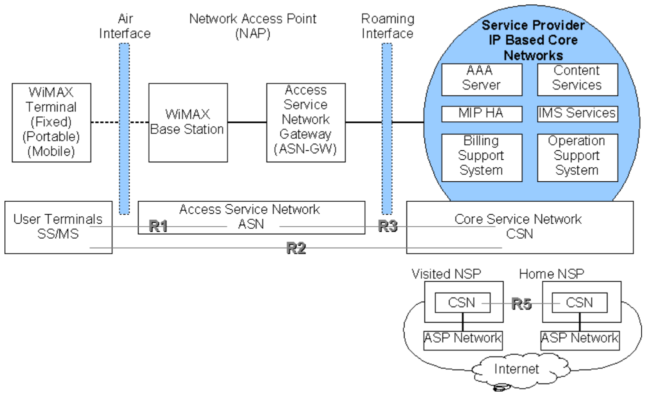

Figure 1: WiMAX Network Architecture

Fig. 1 illustratres the entities of the WiMAX network architecture. The Network Access Provider is a business entity providing WiMAX radio resources to one or more WiMAX Network Service Providers and controls the Access Service Network (ASN). The Network Service Provider is possibly a different business entity that provides IP connectivity and WiMAX services to WiMAX subscribers and manages the Connectivity Service Network (CSN). The Access Service Network includes network elements such as the BS and the ASN Gateway (ASN-GW), providing network access to the MSs. The ASN contains the network functions needed to provide radio access to a WiMAX subscriber.

Communication between the different elements of the network architecture is based on reference points, which form the foundation for seamless interoperability (see Fig. 1). For instance, reference point R1 describes the protocols and procedures between MS and ASN, as detailed in [4,5,10]. Since the ASN concentrates on network access functionality, different profiles define how the ASN-GW and the BSs are implemented in the ASN network. Besides the IP connectivity assured by the CSN, IP address allocation, Internet access, billing operations and IP Multimedia Services (IMS) are also managed by the CSN.

The mobility management considered by the WiMAX Forum for Mobile WiMAX supports IPv4 [11] and IPv6 [12] mobility management protocols as well as mechanisms for reducing packet loss and handover delay. Two types of mobility are considered: ASN-anchored mobility and the CSN-anchored mobility. ASN-anchored mobility, or micro-mobility, is devoted to the mobility procedures that occur without the need for a MS Care-of-Address update, since the MS moves its point of attachment between BSs of the same ASN. CSN-anchored mobility, or macro-mobility, considers IP mobility between ASN and CSN. Different types of Mobile IP (MIP) implementations are considered to support macro-mobility. The first one is aimed for MIP-enabled clients and the second for those nodes that do not support MIP, and therefore need assistance from the network to perform handovers. This last approach is based on Proxy Mobile IP (PMIP) [16]. With the MIP-aware approach, the MS is compliant with MIPv4 if deployed in IPv4 networks, or MIPv6 if deployed in IPv6 networks, respectively.

2.3 An Overview of IEEE 802.21

IEEE 802.21 [10], often referred to as Media Independent Handover (MIH) standard, aims at enabling handovers between heterogeneous networks. IEEE 802.21 is still under standardization and, when deployed, it aims at improving a series of aspects that affect handover performance. These operations include the support for multihomed nodes, for layer 3 mobility protocols and the support of structured layer 2 information. Figure 2 depicts the MIH network model, which includes several entities communicating with each other via well defined reference points, for instance between Home AAA servers (H-AAA) and Visited (V-AAA) servers, or between Foreign Agents (FA) placed in the access network and the Home Agent (HA) located in the home network. The mobile nodes connect to points of attachment located in the access network and MIH points of service (PoS) located on the network side provide the different MIH services.

The MIH Function is a logical layer in the mobility management protocol stack offering MIH services to upper layers. These services include the Media Independent Event Service (MIES) which is related with event classification and event reporting reflecting changes in link availability and characteristics (status, quality and so on); the Media Independent Command Service (MICS) which enables MIH users (for example, layer 3 protocols) to control and manage link behavior associated with handovers and mobility; and the Media Independent Information Service (MIIS) which provides details of network characteristics and supported services of available target networks.

The configuration of the MIH entities, before using the MIH services, is done through the MIH capability discovery mechanisms that allow the MS to discover MIH entities supporting different MIH services. MIH registration allows a MIH entity to become aware of the presence of an MIH entity peer and the MIH event subscription allows a MIH user to subscribe to a set of events, say, for instance, Link Up and Link Down events.

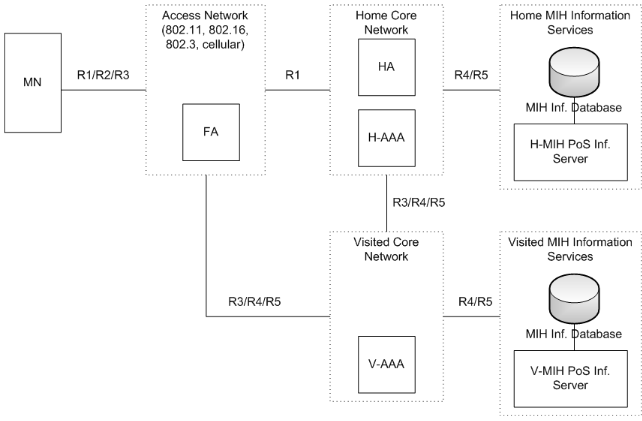

Figure 2: MIH Network Reference Model

The MIH standard also defines a protocol to transport MIH messages in the data and management planes of the different IEEE and 3GPP standards, including reliable transport. IEEE 802.16g includes support to transport MIH messages in the data/control plane using the MOB_MIH_MSG management messages.

The complete MIH framework relies also on discovery mechanisms, which go beyond the MIH standard specification. Therefore, the MIPSHOP working group [17] is specifying a Mobility Services Framework Design (MSFD) [18] to accomplish the mobility services discovery and the reliable transport of MIH messages.

3. RELATED WORK

Several works evaluate the performance of IEEE 802.16 networks to assess the support of WiMAX to transport different types of traffic or simply to measure new algorithms for the functionalities specified in the standard. Sivchenko et al. [19] evaluate different applications in IEEE 802.16 networks, considering different number of users and specific requirements for the wireless channels. Despite the focus of this evaluation in point to multipoint topology, the work addresses IEEE 802.16a features, therefore without mobility capabilities. Sayenko et al. [20] evaluate a scheduling algorithm, exploring different scheduling services. Lakkakorpi et el. [21] also employ simulation to evaluate active queue management mechanisms in WiMAX networks. Nevertheless, both papers deal only with fixed WiMAX.

Carlberg [22] provides a study of IEEE 802.16e mobility, addressing the different handover modes and the network entry process specified in the standard, however, the evaluation is limited to the MAC layer, and does not assess the performance of applications when operating in mobile WiMAX networks.

Rouil and Glomie [23] study an algorithm for channel scanning in IEEE 802.16e networks. The study contemplates the performance of video and audio applications in IEEE 802.16e. Despite assessing the performance of multimedia applications in mobile WiMAX, the work does not include the handover impact on such applications. Finally, Melia et al. [24] evaluate MIH services for heterogeneous handovers between 3G/UMTS and WLAN, but do not con-

Table 1: PSNR and Mean Opinion Score for Video

PSNR	MOS	Impairment/Description
>37	5	Imperceptible / Excellent
31-37	4	Perceptible but not annoying / Good
25-31	3	Perceptible and slightly annoying / Fair
20-25	2	Annoying but not objectionable / Poor
<20	1	Very annoying and objectionable / Bad

sider WiMAX. To the best of our knowledge, current literature does not integrate a complete framework for WiMAX mobility evaluation which includes simultaneously the use of cross-layer information, let alone the analysis of handover impact on multimedia applications. Besides evaluating these scenarios, this paper explores MIH functionalities in vehicular mobility scenarios. All simulations are done with ns-2 patched with the NIST mobility package [12] and should be easily repeated by other researchers interested in this area.

4. EVALUATION

VoIP applications require assured bandwidth and specific bounds of delay and jitter strictly related with the configured codec, which codes human voice into samples that can be transported in IP packets. Different codecs are specified in the ITU-T recommendations, such as the G.711 [25]. Although most VoIP applications support G.711 [25], this codec is not the best performing in terms of bandwidth conservation, since it does not compress data. Despite this, G.711 provides features for bandwidth conservation such as voice activity detection, which avoids sending full packets in periods of silence. G.726 [26] performs better than G.711 with respect to bandwidth conservation, since it only requires 32 kbit/s which is half the rate required by G.711, while G.729 [27] is used for VoIP applications with low bandwidth requirements since it operates at 8 kbit/s.

Video applications, on the other hand, have different QoS requirements, which are determined by the data representation format (e.g. MPEG-4), resolution, frame rate, compression rate, color spaces and stream type. Buffering mechanisms are used by voice and video applications mitigate the jitter and delay effects. The Common Intermediate Format (CIF) and the Quarter Common Intermediate Format (QCIF) are the most representative picture scanning formats of H.261 and H.263 video codecs. For instance, CIF defines a resolution of 352 x 288 pixels, and approximately 30 frames per second. The YUV model is the preferred video color space since it models the human perception of color better than other color spaces like RGB. The YUV model defines the color space in terms of one lumma component (brightness) and two chrominance (color) components.

The user perceived video quality can be measured by calculating the Peak Signal Noise to Ratio (PSNR). PSNR is determined by comparing each pixel in the original frame with the received (and possibly distorted) frame, thus allowing the evaluation of the distortion introduced by the propagation in the network. Table 1 presents the relation between PSNR and the Mean Opinion Score 5-point scale.

4.1 Tests Description

Different tests were performed in order to evaluate the mobile WiMAX support for multimedia applications. Each test included 10 runs, therefore the results, presented correspond to the average of such runs. The different simulation parameters include the velocity, the MIH usage information and the confidence level of the MIH predictive events. The velocity of the MS is configured according to the ITU vehicular A profile [28] with the velocities of 30 and 120 km/h. The distance between the base stations corresponds to the cell size, which is configured both for urban macrocells (2.8 km) and for urban microcells (1 km). The MIH information is employed in three distinct modes: 1- No events, no facilities of MIH exist; 2- Events, the Link Down event is used to trigger the handover process; 3- Predictive triggers, the Link Going Down trigger is employed to start the handover process. The last one, namely the predictive triggers, have a confidence level associated, in our case 60% and 80%, which conduct to different test cases. Such confidence level determines the instant when the event information is replicated to the MIH user, so when the Link Going Down event starts to occur it is only propagated when it reaches 60% or 80% of probability. The Router Advertisement (RA) interval is configured according to the recommendation in RFC 5121 [14].

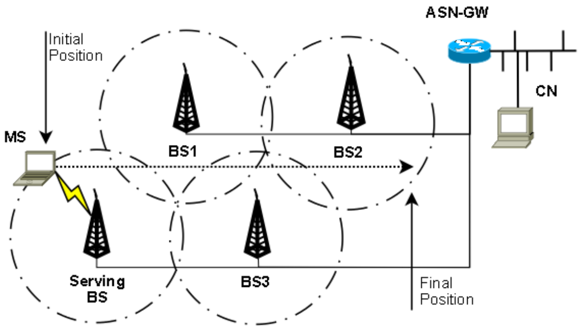

Figure 3: Simulation Scenario

Voice traffic is simulated with Constant Bit Rate (CBR) streams with packetization intervals according to the G.711, G.726 and G.729 recommendations. The packet size includes IP, UDP, and RTP headers and the generic MAC header of WiMAX. The configurations according to the G.711 recommendation do not include voice activity detection mechanism. The video traffic is based on the highway video file encoded in the H.264 format and converted into the MPEG-4 format in order to be used in ns-2 [11] simulations. We use evalvid [29], a video transmission evaluation framework, which accounts for first order network performance metrics, such as delay, jitter and packet loss, and video quality metrics, i.e. PSNR and MOS.

The mobility scenario is based on the network reference model of the WiMAX Forum and is depicted in Figure 3. The MS moves rectilinear and not randomly in order to guarantee that it connects, at least, to two BSs, this means to perform a successful handover. Each BS is configured with a particular network prefix and they are connected to a router, acting as an ASN-GW. The distance between the base stations defines the macrocell or microcell scenarios. The simulation time is configured accordingly to the type of scenario, macrocell or microcell, in order to assure that the MS performs HO more than once during the simulation.

The physical parameters, although not an object of study, considered for evaluation were the following: frequency of 3.5 GHz, channel bandwidth of 7MHz, OFDM with 16QAM with 3/4 cyclic prefix.

4.2 Results

This section presents the results obtained from our simulation study. The metrics evaluated consist on packet loss and one way delay which is determined according to RFC 2679 [16]. Additionally, MOS is used to evaluate video quality. The tests are identified by MS velocity (30 or 120 km/h) and by the MIH information used. The NoEvents cases do not employ MIH facilities, while the LinkDown cases correspond to the test cases using Link Down triggers, and the LinkGDown cases comprise test cases using predictive information, such as Link Going Down trigger. The test cases with LinkGDown, are also associated with different confidence levels, namely 60% and 80%.

4.2.1 VoIP

Table 2 presents packet loss of the G.729 voice codec for the urban macro- and microcell scenarios configured with different velocities. The NoEvents test cases present high packet loss, also the increased velocities tend to present higher packet loss ratios. The best performant cases are represented by the LinkDown cases, since in these cases the mobile node detects a new link immediately after handover and sends a Router Solicitation message to obtain the network prefix of the new link. The predictive test cases have high packets loss ratios and, in general a higher confidence level (80%) introduces less packet loss, since with the lowest confidence level (60%) the mobile node tries to perform HO too early (e.g. the radio link of the new BS may not be optimized). Despite Table 2 presents only the results of G.729 voice codec, the others, namely G.711 and G.726 voice codecs have the same approximated values for the respective test cases.

Table 2: Packet Loss (G.729 codec)

Velocity	Cell Size	MIH Case	Packet Loss (%)
30km	micro	NoEvents	91.29
		LDown	1.56
		LGDown 60%	43.23
		LGDown 80%	38.30
120km	micro	NoEvents	97.60
		LDown	4.62
		LGDown 60%	63.20
		LGDown 80%	34.71
30km	macro	NoEvents	88.08
		LDown	0.60
		LGDown 60%	79.57
		LGDown 80%	20.93
120km	macro	NoEvents	91.37
		LDown	2.66
		LGDown 60%	50.67
		LGDown 80%	56.08

Notably, and perhaps surprisingly, the performance of LinkDown cases is better than in the LinkGDown cases. In the latter, predictive information is associated with a level of confidence expressing that within a certain amount of time the link will go down. The ns-2 NIST add-on fakes a link down when the confidence level is achieved, causing a variation in the delay, since the mobile node is scanning the network to determine neighbors and a possible target BS. The

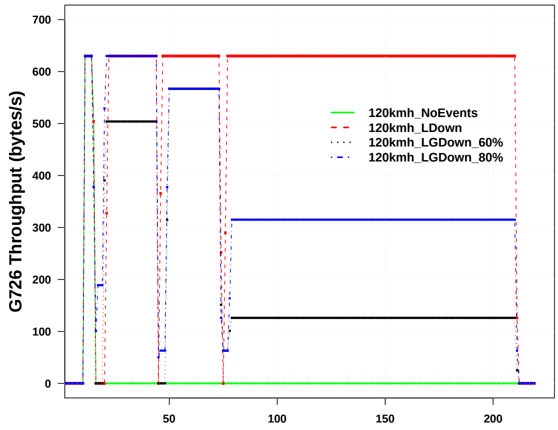

Figure 4: Throughput Micro Cell (120km/h)

mobile node only performs the handover when it receives a reply to the scans performed. While scanning, packets are buffered at the serving BS (configured a maximum of 50 packets). However, if the scan takes too long, packets are lost due to buffer overflows. The one-way delay during non handover instants, when connected to a BS without service disruption, is around 4ms for the three voice codecs testes.

Another difference between the several test cases and the voice codecs under evaluation is the throughput achieved by the mobile node. For instance Figure 4 depicts the throughput of the G.726 voice codec measured on the mobile node. The LinkDown case has an higher throughput when compared with the remaining test cases. During the HO moments (throughput = 0), the LinkDown case performs better than the LinkGDown cases, since they get to the original throughput sooner (e.g. reduced time with throughput = 0).

The performance of voice applications does not strictly follow ITU G.114 [30] and ITU Y.1541 [28] recommendations. The one way delay, in some test cases, exceeds the 150 ms threshold recommended in ITU G.114 (HO moments), while the packet loss is high, exceeding 0.1% for the classes 0 and 1 of ITU Y.1541, intended for voice. All the voice codecs under evaluation have the same performance since no bandwidth restrictions were introduced in the tests.

4.2.2 Video Streaming

The MOS classification for the urban macro- and microcell scenarios, depicted in Table 3, summarizes the objective quality of the video under the different test conditions. As with voice, the test with MIH facilities and tests with higher velocities present the worst performance, mainly due to the packet loss which correlates with MOS. There is no excellent video quality (e.g. MOS=5), nonetheless the LinkDown cases present a good video quality (e.g. MOS=4), which decreases with higher vehicular speeds.

One way delay in the evalvid framework is based on the probabilistic distribution function (PDF), which determines the probability of a given delay. Figure 5 depicts the delay in the urban microcell with velocities of 30km/h. The value of 0 ms, actually corresponds to packet loss, thus the curve in the graphic presents a variation of delay in the range of 0.003

Table 3: MOS

Velocity	Cell Size	MIH Case	MOS
30km	micro	NoEvents	1.63
		LDown	3.98
		LGDown 60%	3.06
		LGDown 80%	3.02
120km	micro	NoEvents	1.36
		LDown	3.38
		LGDown 60%	2.07
		LGDown 80%	2.02
30km	macro	NoEvents	2.30
		LDown	4.11
		LGDown 60%	3.54
		LGDown 80%	3.95
120km	macro	NoEvents	1.73
		LDown	3.57
		LGDown 60%	3.59
		LGDown 80%	3.50

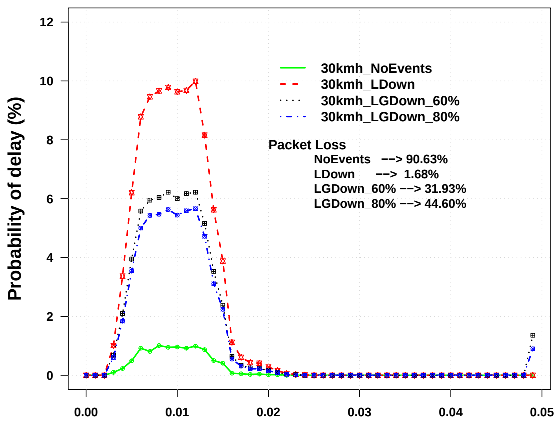

Figure 5: PDF Delay of urban micro cell

and 0.018s, on which the LinkDown case have the highest probability values for the delay in this range.

The performance of video applications also does not rigorously follow the ITU G.114 and ITU Y.1541 recommendations. Packet loss in the general test cases exceeds the 0.1% limit specified for the classes 0 and 1 of ITU Y.1541. The one way delay is inside the bounds of ITU G.114 in normal operation (non handover).

5. CONCLUSION AND FUTURE WORK

The mobile WiMAX capability to support multimedia applications, namely voice and video, was evaluated by simulation. The results showed that handover has high impact in the performance of multimedia applications, introducing high packet loss and intolerable delay. However, use of cross-layer information through MIH improves handover performance and significantly decreases the packet loss ratio. The comparison of MIPv6 with Neighbor Discovery Protocol shows that if the former is used, packet loss is reduced, as the mobile node detects the new links faster.

The experiments conducted put in evidence a good support of Mobile WiMAX for multimedia applications when assited by MIH information. However, the results are far away from being complete, since they do not include several mobile nodes and handover issues between heterogeneous networks, for instance from Wi-Fi to WiMAX.

Our next steps will concentrate efforts on mobile WiMAX networks with several mobile nodes and on handover performance between heterogenous networks.

6. ACKNOWLEDGMENTS

This work was conducted within the framework of the IST Sixth Framework Programme Integrated Project WEIRD (IST-034622), which is partially funded by the Commission of the European Union. Study sponsors had no role in study design, data collection and analysis, interpretation, or writing the report. The views expressed do not necessarily represent the views of their employers, the WEIRD project, or the Commission of the European Union. We thank the anonymous reviewers for their comments and suggestions; they greatly improved the quality of this paper.

7. REFERENCES

[1] Xang Xiao, Kiaojiang Du, Jingyuan Zhang, Fei Hu, and Sghaier Guizani. Internet Protocol Television (IPTV): The Killer Application for the Next Generation Internet. *IEEE Communications Magazine*, November 2007.

[2] WiMAX Forum. http://www.wimaxforum.org.

[3] WiMAX Forum. System Evaluation Methodology, 2001.

[4] 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.

[5] 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.

[6] J. Pinola and K. Pentikousis. Mobile WiMAX. *The Internet Protocol Journal*, 11(2):19–35, 2008.

[7] ETSI. Broadband Radio Access Networks (BRAN); HiperMAN; Data Link Control (DLC) layer, 2006.

[8] WiMAX Forum. Network Architecture (Stage 2): Architecture Tenets, Reference Model and Reference Points, 2007.

[9] WiMAX Forum. WiMAX Forum Network Architecture (Stage 3): Detailed Protocols and Procedures, 2007.

[10] IEEE. IEEE 802.16g/D9 Draft IEEE standard for Local and Metropolitan Area Networks Part 16: Air Interface to fixed and Mobile Broadband Wireless Access Systems, 2007.

[11] Charles Perkins. IP Mobility Support for IPv4, RFC 3344, 2002.

[12] David B. Johnson, Charles Perkins, and Jari Arkko. Mobility Support in IPv6, RFC 3775, 2004.

[13] 16ng. IP over IEEE 802.16 Networks (16ng). http://www.ietf.org/html.charters/16ng-charter.html, 2008.

[14] B. Patil and F. Xia and B. Sarikaya and JH. Choi and S. Madanapalli. Transmission of IPv6 via the IPv6 Convergence Sublayer over IEEE 802.16 Networks, RFC5121, February 2008.

[15] T. Narten and E. Nordmark and W. Simpson and H. Soliman. Neighbor Discovery Protocol, RFC4861, September 2007.

[16] S. Gundavelli and K. Leung and V. Devarapalli and K. Chowdhury and B. Patil. Proxy Mobile IPv6, Internet Draft, May 2008.

[17] mipshop. Mobility for IP: Performance, Signaling and Handoff Optimization (mipshop). "http://www.ietf.org/html.charters/mipshop-charter.html", 2008.

[18] T. Melia and G. Bajko and S. Das and N. Golmie and JC. Zuniga. Mobility Services Framework Design (MSFD), Internet Draft, September 2008.

[19] Dmitry Sivchenko, Nico Bayer, Bangan Xu, Veselin Rakocevic, Joachim Habermann. Internet Traffic Performance in IEEE 802.16 Networks.

[20] Alexander Sayenko, Olli Alanen, Juha Karhula, Timo Hamalainen. Ensuring the QoS requirements in 802.16 Scheduling. *MSWiM 06*, October 2006.

[21] J. Lakkakorpi, A. Sayenko, J. Karhula, O. Alanen and J. Moilanen. Active Queue Management for Reducing Downlink Delays in WiMAX. *Proceedings of IEEE VTC2007-Fall, Baltimore, MD, USA*, October 2007.

[22] Michael Carlberg. WiMAX A Study of Mobility and a MAC-layer Implementation in GloMoSim. Master Thesis, April 2006.

[23] Richard Rouil and Nada Glomie. Adaptive channel scanning for IEEE802.16e. *Proceeding of Military Communications Conference, MILCOM 2006*, October 2006.

[24] Telemaco Melia, D. Corujo, A. de la Oliva, A. Vidal, R. Aguiar, I. Soto. Impact of heterogeneous network controlled handovers on multimode mobile device design. *Proceedings IEEE WCNC 2007*, 2007.

[25] Intel. Overcoming barriers to High-quality voice over IP deployments, 2003.

[26] ITU-T. ITU-T Recommendation G.726, Series G: Transmission systems and media digital systems and networks, Digital terminal equipments - Coding of analogue signals by methods other than PCM, 40, 32, 24, 16 kbit/s Adaptative Differential Pulse Code Modulation (ADPCM), , May 2005.

[27] ITU-T. ITU-T Recommendation G.729, Series G: Coding of speech at 8 kbit/s using conjugate-structure algebraic-code-excited linear prediction (CS-ACELP), , January 2007.

[28] ITU-T. ITU-T Recommendation Y.1541, 2006.

[29] Jirka Klaue, Berthold Rathke, and Adam Wolisz. EvalVid - A Framework for Video Transmission and Quality Evaluation. *In 13th International Conference on Modelling Techniques and Tools for Computer Performance Evaluation, Urbana, Illinois, USA*, September 2003.

[30] ITU-T. ITU-T Recommendation G.114, 2003.