WiMAX TV: Possibilities and Challenges

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Abstract. WiMAX is an emerging wireless access network offering high data rates and good coverage range. This makes it an appealing last-mile delivery network for IPTV and video applications. However, TV/video delivery must be designed with respect to WiMAX characteristics in different environmental conditions. This paper studies the possibility of providing TV and video over the downlink and uplink of a Fixed WiMAX network without compromising the user perceived video quality. Measurements were taken using professional IPTV and video streaming equipments on commercial IEEE 802.16d equipment. Analysis was done for different video settings and network configurations. A key outcome of this analysis was the feasibility of TV/video delivery over WiMAX with good quality of user experience provided that system limitations are respected.

Keywords: WiMAX, IPTV, High-Definition and Standard-Definition Video Quality Assessment, Quality of Experience (QoE).

1 Introduction

Broadband wireless access has undergone a fundamental change in recent years. WiMAX is a typical example of an emerging wireless access system. At a fraction of the costs of wired access networks, it is currently being deployed across the world; for example, developing countries deploy it as their main network infrastructure while more developed countries exploit it as an alternative to cable and DSL lines in rural and underserved areas.

There are two types of WiMAX systems called Fixed and Mobile. The Fixed WiMAX (IEEE 802.16d) [1] provides point-to-point links to stationary and nomadic (with limited mobility) users. The Mobile WiMAX (IEEE 802.16e) offers full mobile cellular type access. The fixed type represents most of nowadays deployments and is the one studied in this paper.

While WiMAX is being increasingly deployed, the delivery of high resolution video over IP network (i.e. SD/HD IPTV) is becoming a reality thanks to advanced compression technologies. The compression efficiency, in addition to the affordable broadband access and high data rates offered by WiMAX, may make different scenarios of TV applications possible. One featured application is the delivery of IPTV over WiMAX downlinks. Another one might be video live broadcast or video surveillance on the uplink. Figure 1 shows an overview of these scenarios.

P. Daras and O. Mayora (Eds.): UCMedia 2009, LNICST 40, pp. 127–136, 2010.

Little or no published material was found on the expected performance and quality of TV and video applications over real WiMAX links. Some studies examined the possibility of delivering H.264 scalable video with small resolution over simulated WiMAX links, such as in [2,3]. Others were limited to analyzing the protocol structure in case of video/IPTV delivery [4-6]. Few papers reported results from trials on real WiMAX links; however, they were limited to throughput and signal strength measurements [7-10].

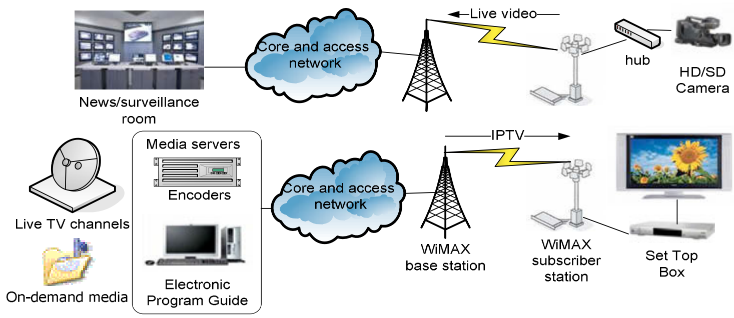


Fig. 1. Scenarios of TV applications over WiMAX

Therefore, there is still work to be done on understanding and analyzing how this broadband wireless access technology can accommodate commercial video and IPTV services, especially when taking advantage of the compression efficiency offered by H.264. The focus of this paper is to study the feasibility of exploiting this technology in different scenarios involving high and standard definition video and TV applications.

The paper is organized as follows. Section 2 describes the testbed design including video and WiMAX network settings. Section 3 covers the characterization of the experimented network in terms of QoS parameters (e.g. packet loss, delay and jitter). Results for downlink and uplink scenarios are analyzed in sections 4 and 5 respectively. Discussion of results and a summary of expected quality and recommended scenarios are presented in section 6. Finally section 7 concludes the paper and gives directions for future work.

2 System Design

A testbed was developed for assessing video quality over WiMAX link in different conditions. The testbed, as shown in Fig. 2, had two main components: an IPTV section and a WiMAX network. The IPTV component consisted of a video server feeding raw video to a professional live encoder. The encoded video is transmitted via the WiMAX network to a professional decoder, emulating a customer set-top box. The decoded video is recorded and stored for post analysis.

The WiMAX network consisted of a base station (BS) and a Customer Premises Equipment (CPE) connected by attenuators, emulating a fixed over-the-air media. The tests were basically done with one subscriber (one CPE) in order to assess single user quality of experience.

WiMAX Network: A real 3.5 GHz Fixed WiMAX network was provided by the WISELAB group [11], within CRC, in order to test the feasibility of TV delivery on WiMAX links. Table 1 gives the important network characteristics. The network provides several FEC code rates. Since video applications require higher bandwidth relative to other multimedia services such as voice and data, we chose a FEC code rate that maximizes the offered throughput within each modulation scheme. ¾-rate FEC setting was used for 64QAM, 16QAM and QPSK. The only code rate available for BPSK is ½.

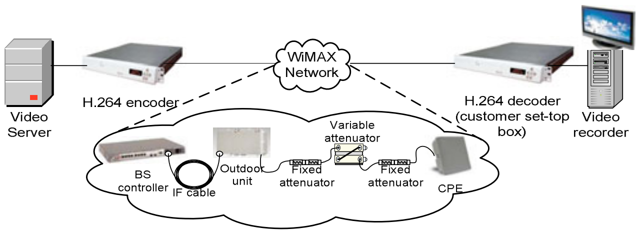


Fig. 2. Testbed overview

Table 1. Network Characteristics

Standard compliance	IEEE 802.16d
Duplex mode	TDD, Full Duplex
Channel size	7 MHz
FFT size / Frame size	256 / 10 ms
Supported modulations	64QAM, 16QAM, QPSK, and BPSK
Transmission powers of BS/CPE	36 dBm / 20 dBm
Total fixed attenuation signal loss	82.6 dB

The WiMAX equipment uses Time-Division Duplex (TDD), which offers the ability to adjust the downlink to uplink bit rate ratio (DL/UL ratio). In the downlink scenarios, the DL/UL ratio was set to 85/15 while a ratio of 25/75 was chosen for testing uplink scenarios.

The maximum throughput on the WiMAX link was measured on both uplink and downlink for different modulations. As shown in Table 2, the throughput depended on the modulation scheme. QAM schemes gave higher bit rates than PSK schemes.

Table 2. WiMAX Link Throughput

Modulation	**Throughput (Mbps)**			
	DL/UL ratio = 85/15		DL/UL ratio = 25/75	
	DL	*UL*	*DL*	*UL*
64QAM 3/4	19.0	3.2	5.0	17.0
16QAM 3/4	12.7	2.1	3.5	11.5
QPSK 3/4	6.4	1.0	1.6	5.7
BPSK 1/2	2.0	0.3	0.4	1.9

IPTV Settings: The input to the encoder is either a high definition (HD) or standard definition (SD) video. The HD video has 1080i format (1920 x 1080 pixels) at a frame rate of 29.97 fps while the SD video is a 480i (720 x 480 pixels) format at the same frame rate. The video material is a 4-minute sequence. The sequence consisted of 24 10-second clips covering a wide range of picture content and complexity. The encoder is a professional MPEG-4 AVC/H.264 encoder with IP output. Table 3 shows the encoder settings used for HD and SD applications. The GOP length was 32 frames with an IBBBP structure for both definitions. The encoding bit rates were selected to match the maximum throughput we can get on the WiMAX link using different modulation schemes. The lowest bit rates recommended for satisfactory quality of experience of MPEG-4 AVC encoded SD and HD TV services are 1 and 8 Mbps respectively [12]. However, it was decided to lower the HD encoded bit rate to 5 Mbps because the preliminary tests showed that the quality could remain acceptable at that rate. The same test cases were evaluated on both uplink and downlink.

Table 3. Test-cases (Video encoding – modulation)

Definition	**H.264 settings**			**Encoding quality**	**Corresponding modulation**
	Profile	Level	Bit rate (Mbps)	PSNR (dB)	
SD	Main	3	1	33	BPSK 1/2
			4	36	QPSK 3/4
HD	High	4	5	33.62	QPSK 3/4
			8	35.18	16QAM 3/4
			15	37.3	64QAM 3/4

The encoded stream was packetized in 188-byte MPEG2-TS packets before being transmitted in chunks of seven TS packets over RTP/UDP/IP. The protocol overhead is around 3% of the encoded stream bit rate.

The video was decoded by a professional HD/SD MPEG-4 AVC/H.264 decoder. For error concealment, the decoder was configured to replace missing frames (if any occurs due to packet loss) by copying the last decoded frame.

The video quality in each test case was evaluated for different link conditions. The link condition was changed by varying the attenuation. Each test-case was repeated several times (20). We then measured the average quality computed over all decoded samples. The video quality of the received video sequence was measured with the full-reference metric: the PSNR. We also evaluated the quality of encoded sequence (without network transmission) for each test-case, as shown in Table 3, capturing the sole effect of resolution and encoding bit rate.

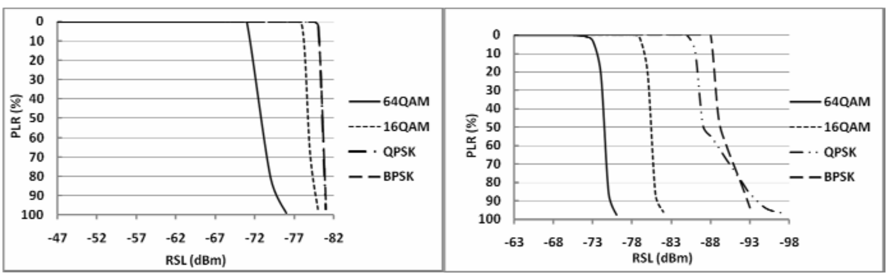
3 Network Characterization

This section presents a characterization of the network under test in terms of QoS parameters (e.g. packet loss, delay and jitter). The jitter and packet loss were measured for each run. We then computed the average over 20 runs. The same process was done for different channel conditions. The channel condition is reflected in the signal strength, based on which the BS decides to pursue or drop the connection. Thus, the channel condition is represented thereafter by the received signal level (RSL). Note that the accuracy of RSL values is +/-1 dB.

It can be seen in Fig. 3 that the channel had almost no packet loss until the signal strength drops to the threshold of operation, below which packet loss increased dramatically and the signal was rapidly lost. This threshold depended on the modulation scheme.

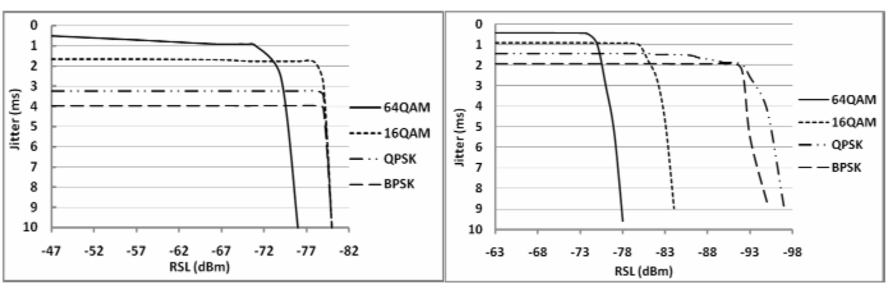
Thereafter, the signal strength level, below which packet loss rate started to increase, is called signal strength threshold or threshold of operation. Based on results of data loss rate, it was at -71 and -78 dBm for 64QAM and 16QAM schemes respectively on both downlink and uplink. For uplink QPSK and BPSK, the thresholds were -85 and -89 dBm respectively. The downlink test cases of 4 and 1 Mbps, corresponding to QPSK and BPSK schemes respectively, lost the connection at -81 dBm because of the uplink signal loss due to the asymmetric transmission power.

In all the downlink test cases, except the cases where connection was lost abruptly because of uplink signal loss, the packet loss rate on the downlink was in the order of 10^{-4} at 2 dB and of 10^{-3} at 1 dB above the threshold of operation. However, on the uplink, a packet loss rate in the order of 10^{-4} was observed at 4 dB before the signal strength threshold was reached. The next sections present the video quality with respect to these thresholds.



(a) (b)

Fig. 3. Packet loss rate on downlink (a) and uplink (b) in function of the channel condition for different test cases



(a) (b)

Fig. 4. Jitter measurements on downlink (a) and uplink (b) in function of the channel condition for different test cases

Depending on the modulation scheme and, hence, on the bit rate, the jitter varies from 0.5 to 4 ms on downlink and from 0.5 to 2 ms on uplink as illustrated in Fig. 4. This represents an ideal condition for video applications that are sensitive to delay variations.

Concerning the delay (latency) on the WiMAX link between BS and CPE, it was observed to be 35 ms +/-5 ms. In general, reasonable end-to-end delay and jitter values are not problematic due to STB de-jitter buffers, provided the de-jitter buffer size is provisioned to match network and video delay variation.

4 Downlink Scenarios

The video quality for HD test-cases on downlink is shown in Fig.5. The highest HD video quality was observed with 64QAM modulated signal because of the high encoding bit rate of 15 Mbps. However, the PSNR of 37 dB at high RSL fell to 27 dB at a RSL of -70 dBm (1 dB above the threshold). The 8Mbps test-case on 16QAM channel resulted in slightly lower quality than that of 64QAM, with a PSNR of 35 dB. This quality was observed until the RSL was 3 dB above the threshold.

The 5Mbps QPSK test-case showed the lowest quality with a PSNR of 33 dB until the connection is lost at RSL of -81 dBm. However, this quality remains acceptable for most of scene types, according to the subjective study in [13]. The 5 Mbps might not be sufficient to encode some complex HD scenes. Fortunately, these complex scenes represent only a small portion of the types generally broadcast for TV [14].

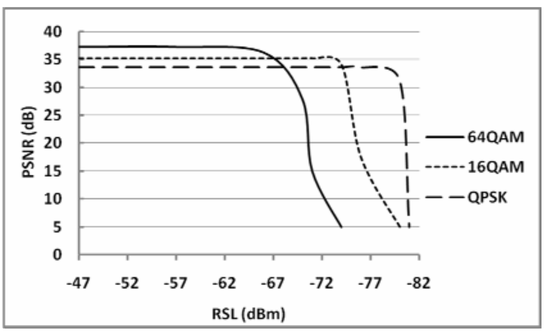


Fig. 5. Quality of HDTV in function of the channel condition for different test cases

The SDTV test-cases gave constant video quality until the connection was lost because of power asymmetry. The 4 Mbps on QPSK modulated channel resulted in a very good quality (PSNR of 36 dB). The 1 Mbps, the only bit rate that can fit a BPSK channel, showed an acceptable quality as well with a PSNR of 33.1 dB.

In general, when the channel had acceptable conditions, the difference in video quality between test-cases was mainly attributed to the change of encoding bit rate to suit the modulation scheme.

It is worth noting that, above signal strength thresholds, the perceived video quality in the entire test cases was almost the same as the encoded video (coded at the same bit rate and then decoded without transmission on network). This means that the WiMAX channel might have minimal effect on video quality if channel limits are respected and suitable modulation scheme is selected accordingly.

When QPSK and BPSK modulation schemes were selected on downlink, the video quality remained stable until the connection was lost. However, the video quality started decreasing before the signal strength threshold was reached when the 64QAM and 16QAM schemes were used. Thus, it is advised to operate the network 2-3 dB above the threshold of operation to guarantee a good video quality when these QAM modulation schemes are selected.

5 Uplink Scenarios

The video quality on uplink was measured for scenarios such as Electronic News Gathering, up to news room, etc. The same HD and SD video test-cases were evaluated for different conditions. Recall that the uplink was not affected by the transmission power asymmetry.

The HD quality is shown in Fig. 6(a) for the three HD test-cases. The highest HD video quality with PSNR of 37 dB, observed for 64QAM modulation, only lasted over a narrow range of high RSL. Although an uplink 64QAM channel can be maintained around a RSL of -71 dBm, the 15 Mbps video quality starts to drop at -67 dBm.

The same observation can be reported for the 8 and 5 Mbps HD test-cases, except that the video quality showed more steep water fall region. The best video quality achievable for each test-case was observed when the RSL was 3 dBm above the signal strength threshold of each corresponding modulation. Even if an uplink signal continued to be transmitted near the threshold the video was not watchable.

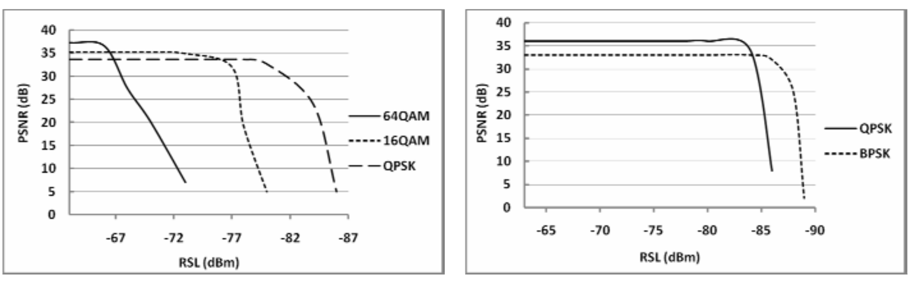


Fig. 6. Quality of HDTV (a) and SDTV (b) in function of the channel condition for different test cases

Fig. 6(b) shows the video quality results for SD test-cases. The 4 Mbps test-case can maintain a very good SD video quality (PSNR of 36 dB) up to an RSL of -84 dBm, which is only 1 dBm apart from the threshold. This is very close to the signal threshold above which QPSK modulation is supported. However, the 5 Mbps HD test-case, that used the same QPSK modulation, required larger distance from the threshold (3 dBm and higher) to preserve the same quality. This means that SD video was more tolerant than HD video to higher packet loss rates, experienced just above the signal strength threshold.

The 1 Mbps SD test-case showed a constant acceptable quality (PSNR of 33 dB) that started to degrade when RSL was 2 dB above the threshold (-89 dBm).

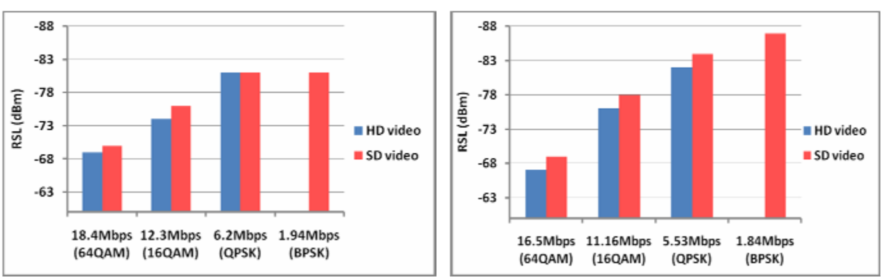
In general, in best conditions, when the RSL was above enough the threshold in each test-case, video quality was the same on both uplink and downlink. However, on uplink, if HD video service is to be provided, it is recommended to design the link budget in such a way to maintain the RSL at 3-4 dB above the thresholds of operation. The recommendation can be relaxed to 1-2 dB in case of SD video service on uplink.

6 Discussions

After we evaluated the expected video quality perceived by individual users at different link conditions and network settings, we discuss in this section factors that can influence the business case of TV/video over WiMAX.

In fact, video resolution and quality that can be offered to customers mainly depend on the bit rate allocated to the TV/video service. The bit rate per WiMAX user is controlled by several factors: the modulation scheme, the DL/UL ratio and the BS load of CPEs. As seen before, the supported modulation depends on the link condition, which is reflected in RSL and is resulting from signal strength gains (transmission power, antenna gain) and attenuation (i.e. path loss, interference).

Based on previous analysis, we can estimate the aggregated video bit rate available for all CPEs per BS with respect to RSL. Recall also that the value of RSL above which a good video quality can be sustained, depended on the video resolution and bit rate. Fig. 7 summarizes the aggregated throughput (excluding protocol overhead) that can be allocated to IPTV/video applications in downlink and uplink scenarios in each modulation scheme. The figure shows also the recommended RSL values for high and standard definition services in each case on both uplink and downlink.



(a) (b)

Fig. 7. Total video throughput with respect to RSL on (a) downlink and (b) uplink

The signal strength depends on the BS location. Basically, RSL of a line-of-sight (LOS) channel is above -70 dBm and most of the time below -70 dBm in non line-of-sight (NLOS) cases [9, 10]. So according to the received signal strength measured in the area of deployment, engineers can know a priori what video service may be supported and the perceived quality that can be expected.

When all users agreed on the same service (i.e. same rate setting of the same QoS class), throughput is equally divided on them. Another plausible scenario would be users having different service agreements. In this case, throughput will be attributed using different bit rate settings of QoS classes and, hence, some users may have SD service while others may get HDTV with the same BS.

Nevertheless, despite the capacity to deliver a good TV/video quality, WiMAX link is quite different from a classic broadcasting cable (ATSC or DVB). The WiMAX link can only support a limited number of TV channels at once. This means that fewer video streams (or one stream in some cases) would be sent from the IPTV local office to each subscriber due to the limited bandwidth. When a user changes the TV channel on his STB, it does not tune a channel like a cable system, but it switches to another stream. This way, only channels that are currently being watched are actually sent from the local office to users and so, the WiMAX available bandwidth may be enough for delivering IPTV services.

Even so, a distinguishing capability from traditional broadcast networks is that WiMAX equipments offer an adaptive modulation feature. This feature enables the transmitter and receiver to negotiate the highest mutually sustainable modulation (data rate), then dynamically changes the modulation scheme to adapt to RF conditions.

The adaptive modulation feature can help in sustaining TV delivery in most of link conditions. That is, when the radio channel is good, the 64QAM, 16QAM or QPSK provides a very good TV quality. However, when BPSK is the only supported modulation due to channel conditions, clients can still get a standard definition TV or video service with acceptable perceived quality.

The adaptive modulation feature must be coupled with H.264 encoders capable of dynamically changing the encoding bit rate to match the rate change of the channel. Such encoders already exist on the market; they are able to vary the encoding bit rate transparently while keeping the same definition. Thus, the adaptive modulation backed by these featured H.264 encoders can guarantee a continuous good service delivery. Scalable video coding may also be a good solution in case of software encoders. Video base layer can be transmitted in low bit rate cases while both base and enhanced layers can be sent when higher bit rate channel can be afforded.

7 Conclusions

This paper presented a study on possibilities and limitations to provide high and standard definition TV/video services on WiMAX technology in different scenarios. The expected video quality was analyzed with respect to channel condition, traffic direction, encoding bit rate and resolution of video service. Results have shown a potential of providing a good video quality, satisfying IPTV/video QoE requirements, when signal strength limits are respected. These limits were identified with respect to modulation scheme, scenario and service type. Service adaptation and factors affecting user perceived quality were also discussed in order to give better options of service provisioning.

Acknowledgments

The authors would like to thank the CRC WISELAB, in particular, Simon Perras and Philippe-André Bonneau, for providing the WiMAX system used for the testing, as well as the technical involvement and support in implementing the WiMAX testbed. Also, the authors gratefully acknowledge the contributions of Ron Renaud from CRC for providing video sequence and helping in setting the video testbed.

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