Abstract—the paper explores the technical limits and possibilities to transmit live audiovisual contents in the uplink mode by means of IP networks based on WiMAX broadband system using a professional camera. A previous evaluation of the WiMAX link performances in real urban environments is tackled, and then, obtained results used to implement an Automatic Video Coding Rate Adjustment (AVCRA) algorithm that adaptively adjusts the video codec parameters to the experienced wireless channel capacity. The experimental network also contains a designed antenna small enough to be incorporated in the camera. Special considerations regarding the radiation diagram have been taken into account for not affecting the head of the proper cameraman. Obtained experimental WiMAX throughput in function of the signal to noise ratio, and the Peak signal to noise ratio (PSNR) levels demonstrated the feasibility of live video links over WiMAX networks in urban environment.

Keywords: Video Streaming, WiMAX, Throughput adaptation, AVC/264.

I. INTRODUCTION

The first Worldwide Inter-operability for Microwave Access (WiMAX) systems were based on the IEEE 802.16-2004 standard [1]. This targeted fixed broadband wireless applications via the installation of Customer Premises Equipment (CPE). In December 2005 the IEEE completed the 802.16e-2005 [2] amendment, which added new features to support mobile applications. The resulting standard is commonly referred as mobile WiMAX. Nowadays, a multitude of international companies as Alvarion, Airspan, Proxim, Motorola, Alcatel-Lucent, etc, are the worldwide leaders of such equipment that operates in both licensed and unlicensed bands. Many companies had wireless broadband equipment using proprietary technology since the 1990s and even before. Evidently these products were not interoperable.

With the arrival of the IEEE802.16 standard, many of these products claimed to be based on it. This was again not possible to verify as the WiMAX/802.16 interoperability tests started in 2006. These products were then known as pre-WiMAX products. The Pre-WiMAX equipment was proposed by manufacturers often specialised in broadband wireless. Many of them had important markets in South America, Central Europe, China, and elsewhere. The main objective of this proposal is to analyse by experimentation the possibilities and the limits of a wireless broadband Pre-WiMAX system as fixed broadband communication system to transmit standard definition (SD) video streams using a professional camera in the uplink mode.

The motivation comes from the fact that usually several audiovisual companies have a limited business area, such as local TV broadcasting stations, focusing on a reduced number of viewers and territory coverage. Therefore, it is considered strategic to have a transport support for live audiovisual transmissions over IP networks with broadband wireless systems like WiMAX, with an image quality, at least, similar to that offered by the conventional TV spread. Such a platform could be considered as an alternative to the actual video transmission infrastructures like the Coded Orthogonal Frequency Division Multiplexing (COFDM) or satellite transmission links, sometimes unsuitable for audiovisual business companies with a reduced budget or business area.

Therefore a prior analysis of the suitability of the proper WiMAX system within such context is required. As the experiment deals with transmitting video streaming in different urban environments, an important objective to achieve is the adaptive parameterisation of the AVC/H264 codec standard [3].

Therefore, demonstrating the viability of a WiMAX network for transmitting SD video streaming in urban environments as well as fixing adaptively the suitable compression parameters of the AVC/H264 codec in accordance to the radio channel variability is the main challenge to take up.

The rest of the paper is organized as follows: the experimental communication structure platform including designed and developed elements are defined and detailed in section II. The WiMAX experimental video throughput results and behaviours jointly with the adaptive video streaming coding over real urban environment are analyzed in section III. Finally, conclusions and further work are drawn in section IV.

II. EXPERIMENTAL PLATFORM STRUCTURES

The experimental platform is constituted by three parts; the first one consists of an experimental WiMAX network, the second is constituted by a reduced designed and experimental antenna for being integrated within the video camera, and the third part is related with the development of adaptive compression algorithms that directly react on the different parameters of the AVC/H264 codec standard based on the environment behaviour and variability of the radio channel to guarantee the required image quality.
The main goal of the experimental platform is first to evaluate the feasibility of using the pre-WiMAX system as a broadband system support to deliver SD video streaming in the uplink mode, and to guarantee a video streaming at the receiver side (base station in our case) with a throughput varying between 1.5 Mbps and 6 Mbps (required throughput). Different test measurement campaigns in different urban environments have been undertaken with the goal of defining/analyzing the uplink system throughput limitations. Such information will clarify the expectation and the limitations offered by the WiMAX system for SD video streaming applications.

### A. Experimental network platform description

The block diagram of the experimental platform is depicted in Figure 1. The camera transmits through a firewire cable the video streams to the laptop connected via Ethernet to the Subscriber Unit (SU). Within the laptop the device the video/audio codifications are carried out. After the codification process, the SU transmits the video signal via WiMAX connection to the Access Unit (AU), the AU forward the received signal using an Ethernet cable to the first Point to Point (PtP) station fixed at the top of the van’s telescopic mast used also for the experimental campaign (connection from the AU box to the PtP (mast) one depicted in Figure 1). The audiovisual content is then retransmitted on the top roof of a building and connected to the second laptop (at the reception side - in bottom right of Figure 1) by an Ethernet cable. The laptop at the reception side of the communication platform is used to decode and to visualize the transmitted SD video streams from the camera. The PtP connection constitutes the “transport network”, and the AU/SU connections constitute the “access network” (both highlighted in Figure 1 with dashed lines). The solid and dashed black lines mean fixed and wireless connection respectively.

The commercial pre-WiMAX equipment used in this platform are; the Alvarion’s BreezeNET B100 family (100Mbps) [4] for PtP stations which operates in both the 2.4 GHz and the 5 GHz unlicensed ISM bands and the Alvarion’s BreezeAccessVL family (54 Mbps Point-to-Multipoint) [5], for the AU/SU stations. This pre-WiMAX equipment allows 8 levels of modulation and coding schemes (BPSK (½, ¾), QPSK (½, ¾), 16-QAM (½, ¾) and 64-QAM (½, ¾)). The used system has two optional bandwidth (10 MHz and 20 MHz), and operates in the 5 GHz licence exempt band. The SU and the AU are mainly constituted by three differentiated parts; the Indoor Unit (IDU), the Outdoor Unit (ODU), and the antenna. The IDU is used to power the equipment and to connect the laptop (or a LAN) by an Ethernet port. The ODU contains the processing module and the radio modules.

The digital video camera captures and transmits the video signal with a data rate of 25 Mbps (RAW format) to the laptop. Within the laptop, the signal is coded using the AVC/H.264 and AAC standards [6]. Achieving a suitable coding rate based on the measured signal to noise ratio at the SU side (SNR-su) is one of the main goals of the platform. According to the measured SNR-su, the SU unit modulates the coded information using a predetermined constellation size (from BPSK up to 64-QAM).

![Figure 1. Experimental Pre-WiMAX network structure for uplink SD video streaming.](image)

### B. Designed antenna

The main objective behind the antenna elaboration is to design an antenna small enough for being incorporated within a professional camera device with some considerations/constraints regarding the radiation diagram. The antenna diagram must take into account and avoid the negative radiation effects on the head of the cameraman. A Planar Inverted “F” Antenna (PIFA) [7] has been designed, and implemented for its integration in the SD video camera (see Figure 2). An extra effort has been deployed to reduce to the maximum the ground plane without affecting the radiation pattern. Note that the S11 parameter gives a value for the reflected wave (in ratio to the direct wave). The S11 parameter is measured in dB at the antenna port (feed point). If the S11 value is below -10 dB means that the PIFA antenna is perfectly adapted to the frequency carrier of the used Alvarion’s equipment, the measured S11 value was -20dB.

![Figure 2. Designed PIFA antenna (ground plane: 40x40 mm)](image)

Figure 2 shows the implemented PIFA antenna with a bandwidth of 400 MHz within the frequency range 5.3 GHz to 5.9 GHz. As it can be seen in Figure 3, the PIFA antenna pattern radiation (obtained by the CST Studio Suite simulation tool) presents an “apple” radiation shape with a maximum radiation gain of 5.2 dB at all the corners. Note that this antenna has a null component orthogonal to the ground plane. It can be also observed that the designed antenna has a gain at both; vertical and horizontal polarizations. This characteristic is very useful in wireless communications which helps to receive the multipath reflections from several directions.

![Figure 3. Radiation diagram of the designed PIFA antenna.](image)
Note that other types of antennas have been also designed and investigated like the “patch” antenna [8], but due to the PIFA antenna omni-directional characteristics and radiation performances has been finally chosen for the final experimental test.

C. The Automatic Video Coding Rate Adjustment

A distributed audiovisual client-server application has been developed to deal with the radio channel variability. The software server is installed in the laptop connected to the digital video camera and sends UDP/IP packets with audiovisual contents to the client (see Figure 4a). The client software is composed by the H.264 and the AAC decoders. The main function of the client application usually located at the AU is to receive audiovisual stream content to decode and display it.

Figure 4. (a) Server and (b) client application block diagrams

Moreover, the choice of the server encoder parameters can be performed directly from the client terminal which simplifies drastically the parameter control operations at the camera. To achieve a good video quality reproduction a configurable streaming buffer (see block diagram in Figure 4b) is used at the client side, which implies a controlled time delay at the reception. The buffer allows the software decoder to be fed with a continuous audiovisual stream rate and to avoid video frame drops and audio cuts during the video reproduction.

As previously mentioned the bandwidth capacity is strongly related with the SNRs samples measured at the SU (SNR_{su})

\[
SNR_{su} = SNR_{AVG} = \frac{1}{N} \sum_{t=1}^{N} SNR_{i,su} (t-nT)
\]

SNR_{su} means the instantaneous measured SNR, N the total discrete time samples; T is the time delay between the measured SNR_{i,su} values; and the SNR_{AVG} the average SNR measured during the N time samples.

Therefore, the application includes an Automatic Video Coding Rate Adjustment (AVCRA) mechanism that is able to tune in an adaptive manner the maximum video coding rate by adapting the server to the throughput experienced by the client bandwidth capacity (see Figure 4b).

Figure 5 shows the finite state machine of the developed AVCRA algorithm. The AVCRA uses five video rate compression outputs (BRx) according to the instantaneous channel capacity status, directly related with the SNR and forwarded to the AU. The states transitions are performed based on a predefined hysteresis margin around the SNR measured levels. This will prevent those continuous switches between two adjacent states resulting in a reduction of frame drops at the client decompression/decoding process side. The T_i and T_j values depicted in Figure 5 mean the “lower” and “upper” hysteresis thresholds respectively both are determined experimentally and tested in the hereafter environments.

Figure 5: AVCRA state diagram; SNR_{su} is real acquired signal to noise ratio subscriber unit, BRx are possible output video coding rates, SNRx are signal to noise ratio thresholds. T_i is upper and T_j lower thresholds for hysteresis range.

Note that it is necessary to distinguish between a quick and a slow WiMAX channel variation. Quick variations are managed by the proper streaming buffer which maintains a constant throughput towards the decoder. Meanwhile low variations are processed by means of the finite state machine with the transition hysteresis comparator algorithm in the AVCRA algorithm.

III. EXPERIMENTAL PERFORMANCES RESULTS

Similar to big cities in Europe, the metropolitan area of Barcelona city is characterised by a very high density of urbanism with an average spaced distances between the buildings of 15m with a height of 20m, a relative weak vegetation density, and a high transport traffic level. Note that the effect of the multipath related with the topology of the environment could enhance or deteriorate the system performances (constructive or destructive effect of the signal at the receiver).

Figure 6a depicts the van used for the measurement campaign in urban environments, equipped with an Uninterruptible Power Supply (UPS) used for supplying the different measurements and communication devices (camera, laptops and pre-WiMAX equipment); also an automatic mast (see Figure 6b) of 6 meters height installed on the van was used. Figure 6c, shows the designed PIFA antenna incorporated in the video camera.

Two urban environments have been chosen for the test evaluation. The first one is the named “Pau Claris” zone (see Figure 7) located in the downtown zone of Barcelona.

This zone is characterized by its very high traffic activity, with very structured building mixed blocks with pedestrian streets. The average height of the adjacent buildings does not exceed 14m, and the width of the street is 10m. The WiMAX AU station is installed at a balcony facade at a height of 12m.
Figure 6. (a) Van unit used for the experimental urban network performance evaluation; (b) automatic mast; and (c) the PIFA antenna installed on the camera.

The second environment is in the named “22@” district of Barcelona city. This environment presents similar characteristics as those in “Pau Claris” zone with the difference that the streets are narrower (6m width), and the topology of the building height is very variant (from 10m up to 16m). In this zone the WiMAX AU is installed at a height of 4m, and the antenna pointed towards the crossroads.

Figure 7. “Pau Claris” zone of downtown Barcelona. The sharp zone indicates the evaluated zone using the experimental network in Figure 1. A 120° sectorial antenna was installed at the top roof of the indicated building.

An average among of the experiments done in each environment has been calculated to get the achieved performance results depicted in Figure 8. Two curves are depicted for each one of the tested environments showing the TCP/UDP traffic throughput behaviours.

The main difference between the TCP and UDP protocols is that the TCP is a connection oriented protocol. However, the UDP protocol has a simpler format frame than the TCP. For this reason by using UDP a higher throughput can be achieved for the same SNR value. As it can be seen in Figure 8 the “Pau Claris” zone presents better throughput possibilities. This could be explained by the fact that a better traffic condition has been experienced in this zone. The fact that the streets are more symmetric, with homogeneous buildings height, and more width than in “22@” zone helps to get a better signal reception or probability to receive a strength component of the signal at the AU in a non-line-of-sight (NLOS) environment.

Depicted results show a high UDP throughput of 45 Mbps at 35 dB in “Pau Claris” zone, and 34 Mbps in “22@” zone. Even at 15 dB of SNR a throughput of 10 Mbps is achieved in both tested environments at 450 meters from the AU. As a result it can be noted that at 35dB of SNR five video cameras can transmit simultaneously in the uplink with 6 Mbps encoded video streaming which means an excellent video quality at the receiver side. Note that the measured throughput values depicted in Figure 8 will be adapted (by selecting adaptively the appropriate jumping levels of the throughput in function of the SNR) and stored in a lookup table for being used as the basic parameters for adaptively managed the video streaming coding and the rate variability by the AVCRA algorithm.

TABLE I: Codec characteristics

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video Codec</td>
<td>AVC/H.264</td>
</tr>
<tr>
<td>Profile</td>
<td>Main-Baseline</td>
</tr>
<tr>
<td>Bit rate</td>
<td>1500 – 5000 Kbps</td>
</tr>
<tr>
<td>Level</td>
<td>3.0</td>
</tr>
<tr>
<td>Resolution</td>
<td>720x576</td>
</tr>
<tr>
<td>Audio Codec</td>
<td>AAC</td>
</tr>
<tr>
<td>Bit rate</td>
<td>1600kbps (2 channels)</td>
</tr>
</tbody>
</table>

The distance between the two PtP stations (transport network) was about 300 meters and the distance between the SU and the AU (access network) was 22 meters. In the selected tested point different types and segments of vehicles were crossing constantly, which is ideal to really evaluate the experimental network with all the developed elements.

The tests have been performed using different live video streams; the features of the video and the audio codec are exposed in TABLE I. The AVCRA algorithm operates within a rate range from 500 kbps up to 6000 kbps.

Also based on the obtained throughput performances in the tested urban environments (see Figure 8) a video coding
rate curve was pulled out for being used by the AVCRA algorithm in the final test. Figure 9, shows the used coding rate (CR) step curve in function of the experienced SNRs at the SU side. Five different levels of codification were fixed at the output of the camera before the final transmission (transmitter side) to achieve an appropriate video/audio quality at the receiver.

![Figure 9. Coding rates versus the measured SNRs at the SU side (fixed step adaptation)](image)

Thanks to the AVCRA algorithm (detailed in section II) and the step fixed video coding rate curve, the data flow from the camera was constantly adapted to the radio channel variability and the measured SNRs.

The metric used for analyzing the quality of the received video is the Peak signal to noise ratio (PSNR), defined in (2), which is used as a metric coefficient to quantify the quality of the received video.

\[
PSNR = 10 \cdot \log_{10} \left( \frac{\text{Max}_i^2}{\text{MSE}} \right) = 20 \cdot \log_{10} \left( \frac{\text{Max}_i}{\sqrt{\text{MSE}}} \right)
\]

(2)

\(\text{MAX}_i\) is the maximum value that can reach a pixel in an image and is defined as \(2^B-1\) where \(B\) is the number of bits per sample. The Mean Squared Error (MSE) for two monochrome images \(F\) and \(R\) of size \(m \times n\) is defined as follows:

\[
\text{MSE} = \frac{1}{mn} \sum_{i=1}^{m} \sum_{j=1}^{n} \left( F(i,j) - R(i,j) \right)^2
\]

(3)

One of the main obtained results depicted in Figure 10 is that using the “Main” profile best PSNRs values are achieved using different types of video contents. An average value of 24.82 dB was obtained for the “Baseline” profile, and a value of 29.69 dB for the “Main” profile. Moreover, there is a trade-off between the “Main” and the “Baseline” profile; the “Main” profile guarantees a better codification and a value of 29.69 dB for the “Main” profile. Moreover, there is a trade-off between the “Main” and the “Baseline” profile. The “Main” profile guarantees a better codification but introduces more delay than the “Baseline” profile. Therefore, depending on the audiovisual content and the real situation on the terrain one of them has to be chosen. For instance, a war correspondent transmission requires the “Baseline” profile as a maximum image quality due to the extreme situation of the transmission environment. However, a simple interview in a crowded street needs to use the “Main” profile as minimum demanded image quality.

The tested video sequences were composed by different obstacles (vehicles, people, etc.) in movement and dynamic backgrounds. Obtained results also demonstrated the system feasibility. The whole connection time was stable and the audiovisual streams were transmitted smoothly with minimal latency due to the implemented buffer for keeping continuous audiovisual stream flow at the reception.

![Figure 10. Experimental video sequence, the PSNR (in dB) behaviour for the “Baseline” and the “Main” profiles.](image)

In the final test environment the “Main” profile achieves better image quality impression than the “Baseline” one. At the same time, a higher jitter and delay were observed due to the higher complexity and computational cost of the decompressing/decoding process. Very limited drops have been experienced; this could be explained by the fact that the AVCRA algorithm was able to switch in a smooth manner to the appropriate compression parameters of the AVC/H264 codec and rates based on the channel radio variability.

IV. CONCLUSION

Obtained experimental results have demonstrated the feasibility of live video links in the uplink transmission mode over a WiMAX network. Nevertheless the need of higher bandwidth and very low delay/jitter for high definition video streams still imposes an important challenge to many broadcasters, especially with the growing interest in the use of broadband wireless systems such WiMAX system for transporting live streams not only with standard video definition with 720×576 pixels, but also with high definition using 1920×1080 pixels.

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REFERENCES