WiMAX for Emergency Services: An Empirical Evaluation

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Abstract: WiMAX, as a Broadband Wireless Access technology for Metropolitan Area Networks, supporting fixed and mobile terminals, is very promising for Next Generation Networks. Emergency Services can also strongly benefit from WiMAX features, allowing the exploitation of novel application scenarios and business models. This paper presents a set of scenarios, such as Environmental Monitoring, Telemedicine and Fire Prevention, defined and implemented in several European testbeds, interconnected by the European research network GEANT 2, in the framework of the WEIRD project[1]. In particular, we focus our attention on the scenario implemented in the Portuguese testbed – Fire Prevention – providing a detailed description about the testbed planning, implementation and evaluation.

1. Introduction

Broadband Wireless Access (BWA) is becoming increasingly important as last mile access technology. Early precursors have been sensed by service providers, operators and manufacturers already few years ago. Consequently, the IEEE standardization body has developed the IEEE 802.16 MAN family [2, 3], the certainly most promising candidate published by today. Meanwhile manufacturers took on and first products have been released recently. In addition, an industry exclusive initiative, the WiMAX Forum, has been founded to promote products and ensure interoperability. Part of this work is the definition of a Network Reference Model (NRM), which is a complete "All IP End-to-End" infrastructure based on IEEE 802.16 as access technology [4, 6].

Although expected to be the BWA future, IEEE 802.16 deployment is yet in an early stage. Principal reason is its novelty and this matter recently has motivated an European research project called "WiMAX Extensions for Remote and Isolated Research Data Networks (WEIRD)" [5]. The aim of the WEIRD project is to deploy, evaluate and enhance WiMAX technology as access technology for a set of European research units with remote and impervious testbeds which are interconnected by the European research backbone network GEANT2 [1] and relevant National Research and Education Networks (NRENs), see Figure 1.

In brief, WEIRD defines an extended architecture based on the NRM and latest hardware, i.e. WiMAX Base, Subscriber and Mobile Stations (BS, SS, MS). To scrutinize WiMAX technology it defines a set of evaluation scenarios from which one is presented in great detail in this paper but the subject as a whole can be found in [7]. More precisely, the subject of this paper is our "early adopters" experience in setting up a WiMAX testbed for the WEIRD project. Mainly motivated by the fact that, at this moment, most of the scientific treatments are based on simulations, certainly mostly due to the novelty of WiMAX technology.

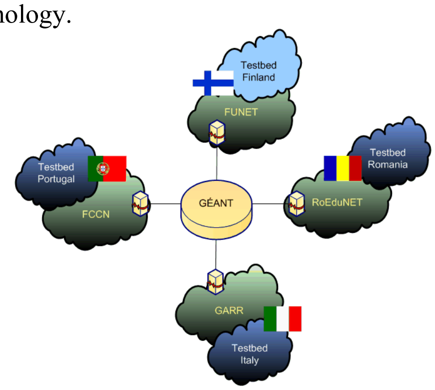

Figure 1: WEIRD project European testbeds interconnection through GEANT research network

The paper has been structured as follows. In Sec. 2 we present the WEIRD Fire Prevention Scenario in great detail. Thereafter, we present how this scenario has been deployed in Sec. 3. In Sec. 4 we present the results of a set of performance measurements from the real testbed. We conclude and close the paper with Sec. 5.

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2. WEIRD System Scenarios

WiMAX, as a BWA technology, is able to provide ubiquitous internet access for remotely connected users, contributing for the digital divide gap decrease and allowing the development of new business scenarios for the telecom operators. Several scenarios that can take advantage from both, the WiMAX technology and the architecture foreseen by the WEIRD project have been evaluated and defined: Environmental Monitoring, Telemedicine and Fire Prevention. In the following sub-sections, a brief overview of these scenarios will be presented, focusing on the Fire Prevention scenario, since this is the one implemented on the Portuguese testbed.

2.1. Environmental Monitoring

A reliable monitoring system should be implemented in impervious areas, such as seismic and volcanic zones, to preview and alert the population about the occurrence of natural catastrophes in these areas. This is one of the scenarios foreseen by the WEIRD project. Video cameras, as well as wireless sensor networks are installed in the surrounding area of the volcano. The collected data is transmitted to the aggregation point using a Mobile WiMAX link and then forwarded to the Monitoring Centre, where they will be analyzed, through the usage of a Fixed WiMAX connection, as depicted in Figure 2.

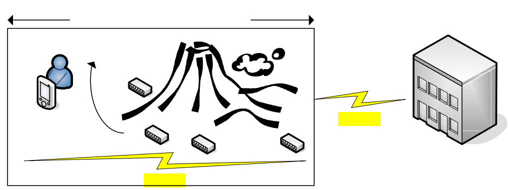

Figure 2: Volcano Scenario

Voice and video over IP communication services are used in this scenario, as well as regular data transfer. Furthermore, fast mobility is also mandatory allowing users, as shown in Figure 1, to keep their connection to the Monitoring Centre while moving in the impervious area.

2.2. Telemedicine

Nowadays, Telemedicine is one of the areas that can take high benefits from the WiMAX technology broadband and wireless capabilities. Figure 3 presents one of the possible applications for Telemedicine. In this case, an ambulance is carrying a patient to the hospital and meanwhile the doctor transmits, using a Mobile WiMAX channel, still and video images taken from the portable ultrasound device from the ambulance. Meanwhile, a video conference is also established between the hospital and the ambulance, allowing the surgery to be prepared based on the received images and information from the doctor in the ambulance.

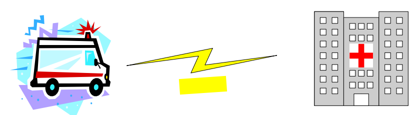

Figure 3: Telemedicine Scenario

2.3. Fire Prevention

Several pilot projects have shown how the use of technologies such as video and infrared cameras can help fire detection. The main obstacles to the implementation of such systems are the costs and image quality related to GSM/GPRS communications and the difficulty to implement radio links to transmit video in uninhabited mountainous regions. The abandonment of these remote or isolated areas, most times mountainous regions, is one of the main factors that leads to a poor early fire detection system.

2.3.1. FireStation Application

The *FireStation* application scenario is related to the transmission of images and text description taken from the Forest Fire Simulation System (*FireStation*) located and operated in the District Civil Protection Coordination Centre (DCPCC) to a mobile unit in the field (PDA/Laptop). Figure 2 depicts this scenario.

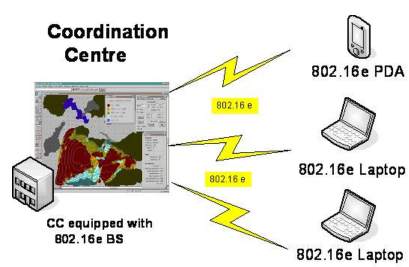

Figure 4: *FireStation* Application

Mobile WiMAX is used to transmit the images and the text from the DCPCC to a mobile unit in the field. In this case, real-time data collection and transmission, as well as voice and video over IP services will be utilized.

2.3.2. Fixed Video Surveillance

This scenario is related with fixed video surveillance. Fixed video cameras located near the mountains transmit video to the DCPCC associated with meteorological parameters. As presented in Figure 5, data is transmitted to a web server and is accessed in a web page where the user is able to control the movement of the cameras.

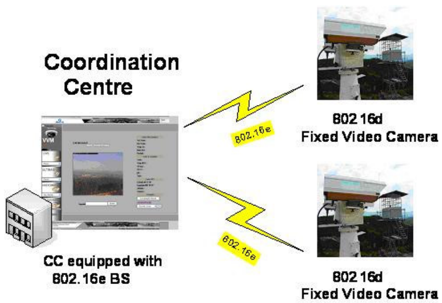

Figure 5: Fixed Video Surveillance Scenario

In this scenario, since fire detection and monitoring is still a human made process, as it implies the presence of a system operator, it is required to have real time video and camera control with the best possible resolution.

2.3.3. Mobile Video Surveillance

Besides fixed video surveillance, mobile video surveillance, as shown in Figure 6, is also very important. In this case, there is a mobile unit that works as a *mobile watch tower* and monitors the fire. It transmits text data, such as GPS position and meteorological parameters, as well as video data (similar to the fixed cameras) to the DCPCC.

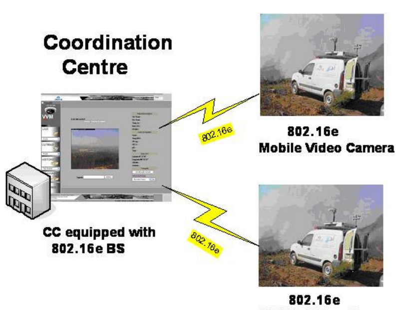

Figure 6: Mobile (Terrestrial) Video Surveillance Scenario

Mobile video Surveillance may also be performed over the air, allowing the helicopters from the fire fighter brigade to send voice and video communication to the DCPCC, see Figure 7. Helicopters can provide images from a different angle when compared with the ones provided by the fire fighter brigade cars provided on the ground. This scenario is very interesting because the helicopters are highly mobile, but it is also very challenging due to the high mobility.

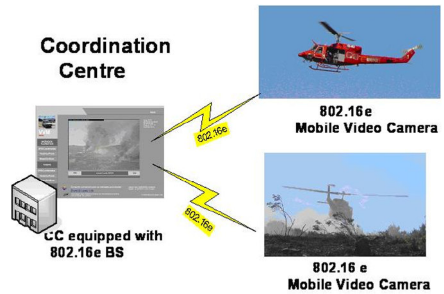

Figure 7: Mobile (Air) Video Surveillance Scenario

2.3.4. Wireless Sensor Networks in Fire Scenario

Another application is related with the distribution of a network of sensors near the mountains in order to facilitate the Civil Protection activities when forest fires reach populated areas. They could simply be temperature sensors that transmit text (time, position and temperature), or something more complex also transmitting video. The sensors will collect environment parameters and they will transmit them to a sink node with less memory and energy restrictions. As data gathered by the sensor network needs to be accessed through existing IP network infrastructures, the sink node will support a reliable interconnection between sensor networks and existing IP based network infrastructures through WiMAX technology.

3. Scenario Deployment

3.1. Site Planning

Taking into account that the system's main application is related with video surveillance of a forest scenario, several places were visited and the following constrains were regarded: high position with clear view over a large area, availability of electrical energy and the existence of an infrastructure to protect the equipment from adverse weather conditions or from vandalism acts. Three candidate sites were identified: *Lousã Mountain (LM)*, *Carvalho Mountain (CM)* and *University of Coimbra (UC)* regarding the constraints exposed above. Using simulation results and geographical data, the radio links between UC – LM (Link1), LM – CM (Link2) and UC – CM (Link3) were evaluated. Figure 8, Figure 9 and Figure 10 present the terrain profiles and the

Fresnel ellipsoids considering 66% and 90% of clearance.

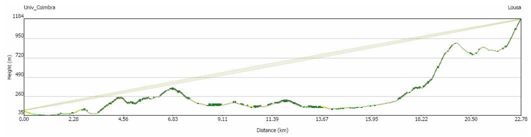

Figure 8: Terrain profile UC – LM (Link1)

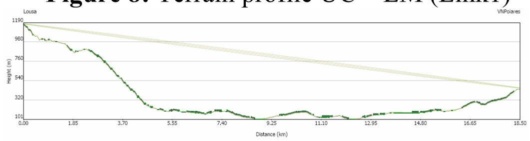

Figure 9: Terrain profile LM – CM (Link2)

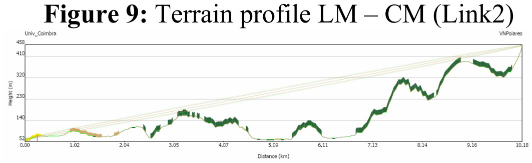

Figure 10: Terrain profile UC – CM (Link3)

Figure 11 presents the three antennas location.

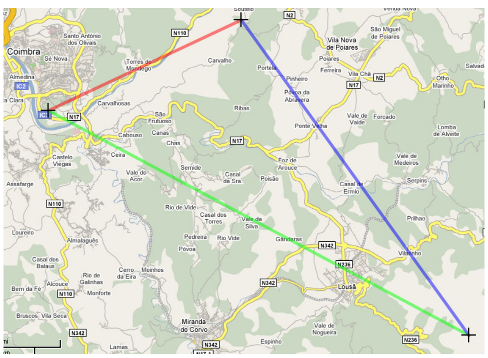

Figure 11: Site location

Due to very difficult propagation condition (NLOS in a forest environment without a terrain topological place, like a mountain, to be used as reflection surface), it is not expectable that a radio link CM – UC can be established. Therefore, the Point to Multipoint (PMP) network topology with the BS on UC and the SSs on CM and LM was abandoned. A new network topology, as shown in Figure 12, with two Point to Point (PtP) links between UC – LM (Link1) and LM – CM (Link2) has been implemented, using different frequencies on the radio link in order to minimize interference.
For the testbed implementation, WiMAX compliant equipments from a WiMAX certified vendor (Redline Communications [8]) have been used.
To estimate the throughput of both Link1 and Link2, the WiMAX BS and SS are configured with frame duration of 10 ms (milliseconds) and a CP (Cyclic Prefix, guard interval) of ¼. The remaining significant parameter values (BW, Tx Power and Antenna LF) are presented in Table 1.

Table 1: Equipment configuration

BS or SS, Location	**BW** (MHz)	**Power** (dbm)	**Antenna**
BS, UC	3.5 7 14	23	90º
SS, LM		16	15º
BS, LM		23	90º
SS, CM		16	15º

In order to evaluate the link performance, we have considered both the terrain profiles and related radio propagation conditions, shown in Figure 8, Figure 9 and Figure 10, as well as the equipment configuration and antenna characteristics, depicted on Table 1. The estimated maximum throughput on each direction is shown on Table 2, for a 7 MHz WiMAX channel bandwidth. The exactness of the results mainly depends on the accuracy of the terrain profile data and on implementation factors like a perfect antenna alignment.

Table 2: Maximum link throughput estimation (@7 MHz)

Link direction	**Distance** (Km)	**Propagation**	**Max** (Mb/s)
Link1: UC, LM	22,78	LOS	3.6
Link1: LM, UC			2.4
Link2: LM, CM	18,5	LOS	5.4
Link2: CM, LM			3.8
Link3: CM, UC	10,18	NLOS	--
Link3: UC, CM			--

3.2. Applications

For the first phase of deployment, the focus was on fixed surveillance (real-time video streaming and meteorological data). Mobile application scenarios will be addressed in a second phase.

3.2.1. The Remote Surveillance Application

The Remote Surveillance Application is composed of remote surveillance units, a central application server and web clients that can be installed in PCs or PDAs.
Each remote surveillance unit consists of one or several outdoor cameras controlled by an IP video server, IP compasses and an IP weather station (temperature, wind, humidity). The cameras automatically scan pre-defined sections of the forest and stream the video to the remote client. When the user detects a potential fire, he points the camera to the suspected location (performing remote rotation, tilt and zoom), in order to conduct a more detailed inspection. If the alarm is confirmed, the digital compass is used to determine the exact location of the fire and an early response fire brigade is sent to the location, by helicopter.

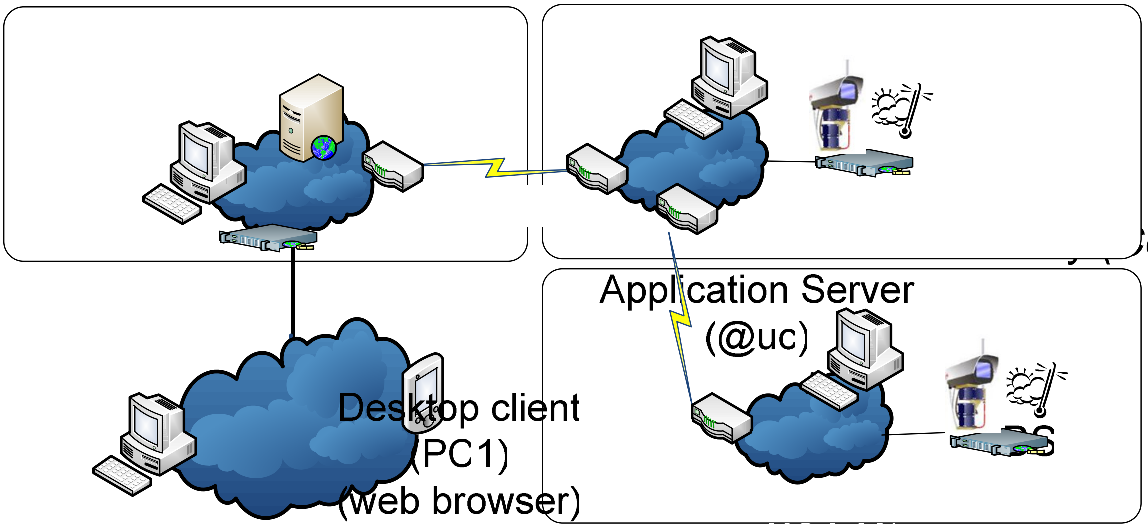

Figure 12: Testbed Layout

The central application functionality is threefold: it provides the web-based GUI interface that allows remote users to access the system; it enhances the usefulness of data collected from the remote surveillance units with geographical information system (GIS) information, so remote users can associate maps and GPS data with the received video streaming and pinpointed fire locations; and it stores collected data (video streams, meteorological data, pinpointed locations) for post-fire scientific research and criminal investigation (the majority of forest fires is caused by accidental and/or intentional human action).
The clients use a web-based interface – using PCs or PDAs – to access the information stored in the central server and the video streamed by the remote surveillance units.

3.2.2. Deployment of the Application

In the specific scenario described in this paper, one remote surveillance unit was deployed at LM and another at CM. Each of these units includes two cameras, providing effective coverage in a radius of approximately 10 km from LM and from CM.
The preliminary tests show that it is possible to support the video streaming from the four cameras without significant loss of quality or functionality.
The central server is located at UC, and client PCs can be located anywhere in the Internet. During the first phase, GPRS-based PDAs are used by on-field fire brigades, but network bandwidth and coverage are quite poor, limiting their usefulness. In the second phase, specific WiMAX-based mobile clients will be tested by the fire brigades, taking advantage of the installed network.

The surveillance units were installed in watch towers where the Civil Protection already keeps human watchers during the summer, equipped with binoculars. It will be possible, therefore, to directly compare the performance of classic fire detection mechanisms and remote surveillance. The key metric is the ability to early detect the fire, since the success of fire fighters greatly depends on the ability to reach the fire location within minutes from ignition, before it becomes uncontrollable. If the remote surveillance proves to be at least as effective as classic surveillance – in the early fire detection – it will be possible to reduce labour costs (a single operator can control several surveillance units) and to increase the number of surveillance posts, thus further increasing the probability of successful fire detection.

4. Performance Measurements

To evaluate the performance of the implemented testbed, a set of tests have been performed for both links – Link1 between the University of Coimbra (UC) and the Lousã Mountain (LM), and Link2 between the Lousã and Carvalho Mountains. The main goal of these tests was to verify if the WiMAX equipments were able to fulfill the bandwidth requirements defined by the applications, as defined in section 3.2. As a reminder, each camera will stream video with bit rate values between 512 Kbps and 2 Mbps.
Link1 and Link2 have important differences. Despite the propagation conditions for Link1 and Link2 are similar, since both links have Line of Sight (LOS) propagation mode, the distance is higher for Link1, as shown in Table 2. Besides this constraint, since Link1 is the "*aggregation link*"

from the testbed, it also has to carry live video streaming from both surveillance cameras: the camera installed in the LM and the one installed in CM. For Link2, since it only has to carry video streamed by the camera installed on the CM to the LM, the bandwidth requirements are lower.

The Iperf [9] tool has been used to load the WiMAX network with packets and measure the maximum available bandwidth. As shown in Figure 12, traffic generator/receiver PCs have been installed and connected to the WiMAX network in each one of the Mountains (Lousã and Carvalho), as well as in the UC, to generate and/or receive the packets sent by the Iperf measurement tool.

Using PC1 connected to the BS in UC and PC2 connected to the SS in the LM, we have measured the Link1 throughput in both uplink and downlink directions. The measured values are presented in Table 3 for different values of the WiMAX channel bandwidth (3.5 MHz, 7 MHz and 14 MHz) in order to check the variation in the obtained throughput for each case.

Table 3: Measured Bandwidth for Link 1

UC – LM Link1	Uplink (Mbps)	Downlink (Mbps)	Total (Mbps)
3.5 MHz	1.1	1.3	2.4
7 MHz	2.2	2.7	4.9
14 MHz	4.5	5.6	10.1

For the 3.5 MHz channel bandwidth test, the overall measured bandwidth is 2.4 Mbps, which is not affordable for the application requirements. This bandwidth must be shared between the downlink and the uplink channel, and for the uplink direction, only 1.1. Mbps are available. Therefore, it is not even possible to carry the video from both cameras (LM and CM cameras) using the minimum bit rate of 512 Kbps for each camera. For the 7 MHz case, 2.2 Mbps are available for the uplink direction, providing enough bandwidth for both cameras video streaming, but not with the maximum bit rate (2Mbps). To exploit the maximum bit rate from the video streaming, the 14 MHz WiMAX channel shall be used. This would provide 4.5 Mbps dedicated for the uplink direction, enabling the usage of the video streaming with the maximum video encoding bit rate.

Regarding the link between the Lousã and the Carvalho Mountains (Link2), the measured bandwidth is presented in Table 4.

Table 4: Measured Bandwidth for Link 2

LM – CM Link2	Uplink (Mbps)	Downlink (Mbps)	Total (Mbps)
3.5 MHz	2.0	2.4	4.4
7 MHz	4.1	4.8	8.9
14 MHz	7.8	9.6	17.4

As expected, the measured bandwidth in this case is higher when compared with the one obtained for Link1. This was expectable since the distance between the WiMAX BS and SS is lower (18 km). Since only the video streamed by the CM video camera had to be sent over this link, instead of the two videos streamed over Link1, the Link2 requirements are not so demanding as in the Link1. In this case, the 3.5 MHz channel provides 2 Mbps for uplink. This throughput might not ensure the video streaming using the highest bit rate mode (2Mbps) without packet losses. Therefore, to ensure that no packets are discarded, 7 MHz and 14 MHz WiMAX channels shall be used.

5. Conclusions

WiMAX is a great opportunity for both already existing application models and new, still unforeseen usage paradigms.

In this paper we present a number of innovative application scenarios – based on WiMAX technology – which are targeted by the WEIRD Project. In particular, the paper focuses in the usage of WiMAX to deploy surveillance units in remote forests, for early fire detection – a very relevant topic in Mediterranean countries. The testbed planning and implementation were described, and the early evaluation results were presented. The performance measurements and the initial user evaluation – already quite positive – will now be completed with more extensive evaluation studies, focusing on the effectiveness of the testbed for low-cost, early fire prevention.

6. References

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