Experimental characterisation of WiMAX propagation in different environments

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Abstract—**The aim of this work is to continue the cooperation on Fixed WiMAX experimental propagation characterization between Instituto de Telecomunicações – DEM of University of Beira Interior, Portugal, Fondazione Ugo Bordoni and the Department of Electronics and Information Systems of the University of Bologna, both from Italy. The field trials addressed different environments, i.e., suburban and open areas in a hilly terrain for the study of the propagation characteristics of WiMAX systems. The IEEE 802.16–2004 equipment operates at 3.5 GHz with a bandwidth of 3.5 MHz. Different antenna heights are considered. The measurements have been performed in outdoor, indoor and mixed environments, with omnidirectional and 120º sectored antennas. In the outdoor environment, results show an adequacy between the trend-curve for the experimental results with the modified Friis equation with propagation exponent 2.71.**

Keywords-WiMAX, measurements; propagation models

I. INTRODUCTION

Providing ubiquitous services is the main challenge driving the design of the next generation communication system. Wireless communications play an important role in giving wideband access in various urban contexts, such as schools, libraries, and airports and even open areas where a public access to the web is granted. Even if nowadays Broadband Wireless Access has worldwide diffusion, there are areas, generally remote and rural ones, where wired broadband connections are absent. Such areas are defined as Digital Divide ones. This term refers to the lack of high-speed access that in many cases is due to economic reasons.

Presently, telecommunications systems provide the opportunity to use Worldwide Interoperability for Microwave Access (WiMAX) based technologies, as IEEE 802.26–2004, since they support mobile broadband Internet services in outdoors and even in indoor scenarios with high coverage ranges and user mobility support. In the south of Europe, the introduction of WiMAX gains special interest for emergency and security public services. For example, in the summer time, forest fires are a persistent calamity, and authorities may lack access to real time fire information in order to coordinate fire brigades. As a demonstration, a network was deployed in the city of Covilhã, Portugal.

This paper presents the joint activities between Instituto de Telecomunicações/DEM of University of Beira Interior (IT-DEM/UBI), Portugal, and Fondazione Ugo Bordoni (FUB), Italy and the Department of Electronics and Information Systems (DEIS) of the University of Bologna (UniBO), Italy. This activity aimed at characterizing the WiMAX propagation phenomena in different operating situations. The first phase of the cooperation allowed for assessing the impact of WiMAX installations on the environment by means of field trials in the town of Bologna, as well as in an indoor environment [1]. The previous work enables to compare measurements with public available statistical models and with a proprietary ray-tracing tool. Results showed that ray-tracing provides a satisfactory agreement with the measurements, provided that the environment is modelled with sufficient accuracy. Although a few measurement campaigns have already been performed [2], statistical models proved themselves unsuitable to a detailed prediction. Key results arising from our experiments were published in the open literature [3].

The new measurement campaign in Covilhã addressed different environments, i.e., suburban and open areas in a hilly terrain. The measurements have been conducted both in an urban small cell (with both pedestrian and car-mounted receiver configurations) and in a suburban microcell, with base station (BS) mounted externally and measurements taken in an indoor environment, to evaluate such parameters as the impact of the internal building structure. Results are presented for various sets of measurements in different environments and in different situations (pure outdoor, pure indoor, outdoor to indoor pedestrian) with the aim of characterising the multi form propagation phenomena involved which include street-corner effect and the impact of internal building structure.

The remainder of this work is organized as follows. The WiMAX equipment is described in Section II. Section III addresses the methodology for the field trials, including a description of the outdoor, indoor and mixed measurements. Measurement results are analyzed in Section IV while Section V presents the conclusions and topics for further research.

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II. DESCRIPTION OF THE WIMAX NETWORK AND RECEIVER EQUIPMENT

A. *Transmission characteristics*

The installed WiMAX equipment is an Alvarion BreezeMAX 3000 micro-BS (µBS). The duplexing frequency range is 3499.5-3553.5 MHz and 3550-3600 MHz for downlink (DL), and 3399.5-3453.5 MHz, and 3450-3500 MHz for uplink (UL) [4]. The outdoor data unit (ODU) was operating at 3551.75 MHz (DL) and 3451.75 MHz (UL). The maximum transmitter power is 28 dBm. Initially, a 10 dBi omni antenna was installed at a 7 m pole for the set of measurements; later a 15.3 dBi 120º sectored antenna replaced the previous one, on other poles with different heights, Figure 1. The same equipment has been already used for previous COST 2100 Action measurement activities [5].

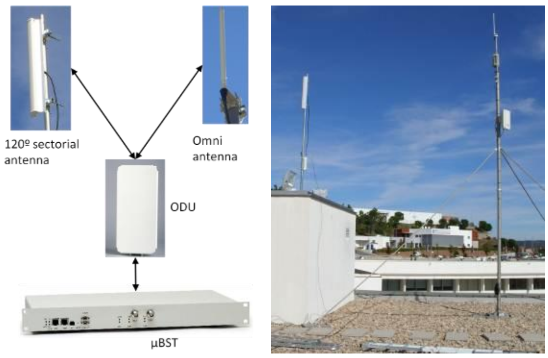

Figure 1. Alvarion BreezeMAX 3000 equipment with omnidirectional and sectored antennas

B. *Receiver equipment characteristics*

The receiver equipment used during the field trials is the Rohde&Schwarz FSH8 portable spectrum analyser. As in previous measurements, performed in Bologna, this new spectrum analyzer provides the received channel power from the WiMAX transmitter in the considered band using the channel power measurement approach. The configured sweep time of all data presented in this work was 0.02 seconds. Table I shows the list of spectrum analyzer characteristics. These parameters can be configured by the software installed in the laptop through a USB cable connection.

TABLE I. MAIN SPECTRUM ANALYSER CHARACTERISTICS [6]

Frequency range	9 kHz – 8 GHz
Sensitivity	< -163 dBm (1 Hz)
Low measurement uncertainty	<1 dB
Sweep time	200 µs to 100 s

III. FIELD TRIALS METHODOLOGY

A. *Outdoor measurements*

Outdoor measurements were performed in the city of Covilhã at pedestrian and vehicular speeds. Whenever possible, vehicular speed did not exceed 40 km/h. A 10 dBi gain omnidirectional antenna was installed on the rooftop of a car, approximately at a height of 1.6 m.

The geo-referencing during the campaign was provided by a GPS receiver, which was connected to the measurement equipment. The laptop runs two software applications. The first one, the R&S FSH4View® interface allows for visualizing, recording (every second on a text file) and analysing all spectrum analyser data. Besides, it is possible to synchronize the equipment with the laptop clock. The second application is GPS TrackMaker® [7] allows for recording all data provided by the GPS receiver into a text file. All files are processed by a Matlab® script that merges all data (*a posteriori*) into a single Excel™ file, for future analyses. For pedestrian measurements, the omnidirectional antenna was detached from the vehicle. The laptop and spectrum analyser were transported through a predetermined path.

The outdoor vehicular and pedestrian measurements were performed three times, for different transmitter antenna heights, repeating the same path. This allowed studying the impact of the antenna height change on the signal propagation. The BS was located on the roof top of the Health Science Faculty from University of Beira Interior, Covilhã, which has an approximate height of 14 m. For the first field trial, a 10 dBi omnidirectional antenna was used mounted on a 7 m pole; hence, the total antenna height was around 21 m, as shown in Figure 1, pole on the right.

Later, for the remaining measurements, given that the previous Tx antenna is sealed on its location and no other similar antenna was available to be connected to the BS at different heights, a 15.3 dBi, 120º sectored antenna was used. For the second field trial, the sectored antenna was mounted on a 0.89 m pole, placed on top of the roof technical housing, with 2.65 m height, 4 m away from the previous pole (on the left in Figure 1); at a total height of 17.54 m. Given the horizontal antenna aperture, trials were performed in two sets, as the antenna had to be directed twice to cover the entire trial area. The third field trial was performed with the previous antenna placed on top of the 2.89 m pole, reaching 19.54 m height above ground level in total.

B. *Indoor and mixed environment measurements*

Indoor and mixed environment measurements were performed at the IT/DEM/UBI. Firstly, for indoor measurements, the µBS, ODU and the 120º antenna were installed in a hall of the department, on a 1 m high pole, Figure 2. The R&S FS8 spectrum analyser and a laser meter were placed on a 0.75 m height trolley. The trolley was then pushed along the corridor. Measurements were taken every metre. For the mixed (outdoor to indoor) trials the transmitter equipment was transported outside, 10 m north from the building on the car park, and placed on a 0.44 m chair, as shown in Figure 2.

Figure 2. Indoor and outdoor-to-indoor installations with BS sectored antenna

The antenna was mechanically tilted by 4° to improve indoor coverage of the ground floor corridor. Between the car park and the building there is a 2.22 m drop, as can be seen in the figure. Measurements were then taken in the previous corridor and locations. The outdoor-to-indoor measurement parameters are shown in Table II.

TABLE II. PARAMETERS FOR THE OUTDOOR-TO-INDOOR MEASUREMENTS

Tx Antenna Type	Sectored 120°
Tx Antenna Gain	15.3 dBi
Rx Antenna Type	Omnidirectional
Rx Antenna Gain	10 dBi
Transmitter Power	28 dBm
Height Tx Antenna	3.6 m
Height Rx Antenna	1.4 m

IV. RESULTS

A. *Results for outdoor environment*

Figure 3 shows the measurements obtained with the omnidirectional antenna, previously presented at a height of 21.31 m. Different colours along the route represent the received field strength.

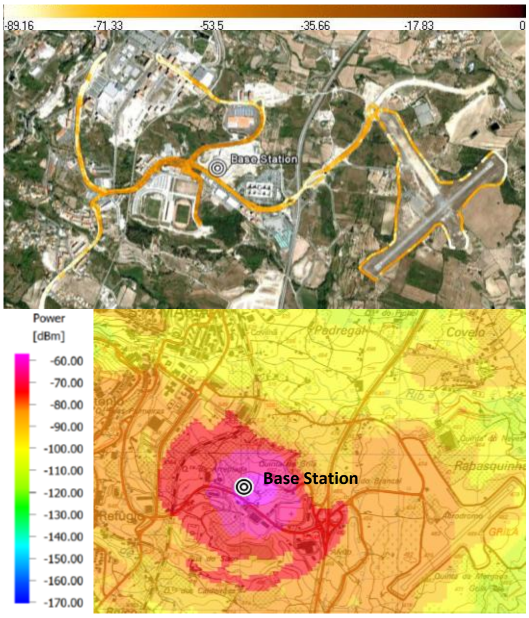

Figure 3. RSSI$_{[dBm]}$ for car measurements with omnidirectional antenna at 21.31 m

As could be expected, the field strength is lower in areas with a medium to high building density, on the left part of the figure. The northwest part of the city has a moderate to high density of buildings, whereas the remaining area has very few buildings and moderate vegetation. An airfield is also present. One important terrain characteristic that cannot be observed in Figure 3 is the city very pronounced topographic relief. The west area of the terrain has a much higher altitude then the east area. We can observe that coverage is rather poor in the built-up areas towards the urban centre, owing to the shadowing effect of buildings. We also note low received field in the area around the airfield: this is due to the effect of the hilly terrain.

Figure 4 presents the RSSI values as a function of the distance between transmitter and receiver. As the car roamed on the city streets, several measurements were obtained at equal distance from the BS; hence, for the similar distances, several values are presented for the RSSI. Saturation is verified at approximately -90 dBm for distances higher than 1.2 km.

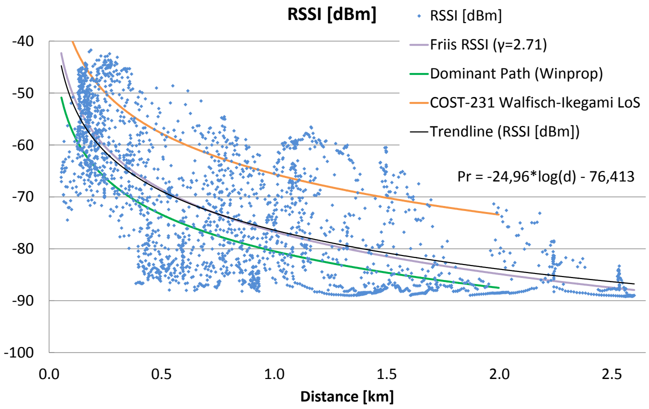

Figure 4. Comparison of the $RSSI_{[dBm]}$ with different propagation models (with omnidirectional antenna at 21.31 m)

Figure 4 also presents a comparison between the obtained data for the car omnidirectional antenna measurements and several well-known propagation models. By comparing the trend line for the measurements points and the curve for the modified Friis model with propagation exponent $\gamma = 2.71$, a mean square error of 0.6812 dB (and standard deviation of 9.31 dB) was obtained [8]. Winprop™ was used to determine line-of-sight regions and the simulation curves accounting for the terrain relief. These curves allowed for a comparison with the experimental results. The difference for the COST 231-Walfish-Ikegami Model curve is circa 10-12 dB, and needs to be further analyzed.

Other vehicular outdoor measurements were performed with a higher antenna height, i.e., 19.15 m. Higher values of the signal were acquired in the overall studied area (darker regions on the maps). As before, the saturation effect is present at distances around 400 m and above 1200 m. Figure 1 presents the corresponding RSSI values. In this case it can be verified that higher values of the RSSI were obtained at longer distances, whereas the maximum value of the RSSI remain approximately the same.

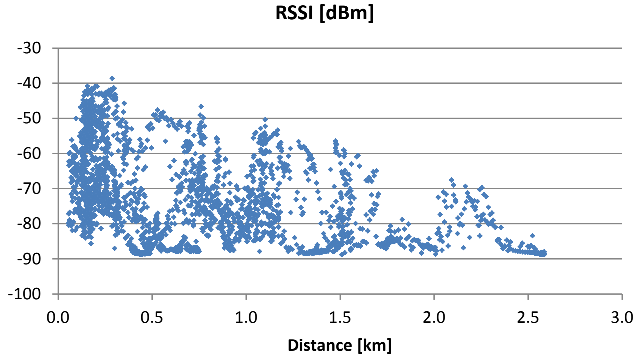

Figure 5. $RSSI_{[dBm]}$ versus distance for car measurements with 120° sectored antenna at 19.15 m

B. Resuslt for indoor and mixed environments

This section addresses the measurement results for indoor and mixed environments. The measurements were performed in IT/DEM/UBI, Covilhã, as shown in Figure 2. In the first case, the transmitter antenna was placed at the beginning of the corridor and the receiver moved away from the Tx antenna and then turned in a side corridor. In the second case the transmitter antenna was placed outside and the receiver followed the same path. In both cases the sectored 120° transmitter antenna was used in vertical position. The transmitter antenna inside the corridor was at 0.565 m height, while in second scenario it was at 2.067 m. The first measurement campaign was performed with the BTS and receiver in indoor locations, both Line-of-Sight and Non-Line-of-Sight conditions. Results are reported in Figure 6.

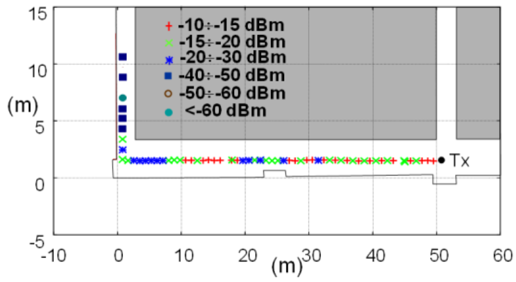

Figure 6. Indoor environment measurement results

The second measurements campaign was performed in what we named mixed environment, with the BTS outside and receiver inside the corridor. It has been performed to study the impact of internal building structure. In this case there were several windows between the transmitter and the receiver. The intention is to collect data to study indoor signal propagation, considering different walls dielectrics characteristics, because at the frequency of 3.5 GHz indoor coverage could be critical due to the high penetration loss. Figure 7 presents results obtained in indoor and mixed environments.

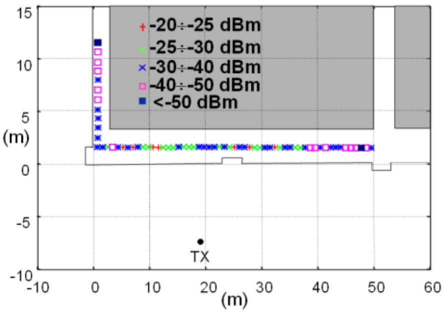

Figure 7. Mixed environment measurement results

Of course the received signal level is generally higher for the indoor-indoor case while lower signal levels are present for outdoor-indoor case due to building penetration loss.

V. CONCLUSIONS AND TOPICS FOR FUTURE WORK

In this paper we present a measurement activity that covered different environments, i.e., suburban and open areas in a hilly terrain, for the study of the propagation characteristics of fixed WiMAX systems. The measurements have been performed in outdoor, indoor and mixed environments, with omnidirectional and 120° sectored antennas. The equipment operated at 3.5 GHz with a bandwidth of 3.5 MHz. Different antenna heights have been used.

The collected data allow a comprehensive characterisation of WiMAX propagation at 3.5 GHz and will be used to fine-tune and improve existing propagation models and software tools. We have compared measurements with predictions obtained with different statistical models. One example is reported here, relating to car-mounted receiver, showing that the best approximation of measurements is obtained by the modified Friis equation with propagation exponent 2.71.

Further activity will comprise a thorough analysis of measured data for different environments. The results will also be compared with a proprietary ray-tracing tool [9] in order to have a better understanding of the propagation mechanisms in the 3.5 GHz band whose study still lacks empirical models as comprehensive as the ones available for lower radio frequency bands.

In the longer term, this comparison will help the research community in improving the existing statistical models and/or developing new models better suited to this frequency band. These new models will be more suitable for WiMAX planning and deployment than the existing ones. Moreover a comparison between measurements and simulations obtained with the ray-tracing tool [9] will be useful to validate and improve the accuracy of the ray-tracing algorithm.

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