Path Loss Measurements at 3.5 GHz:
A Trial Test WiMAX Based in Rural Environment

Pasquale Imperatore, Elio Salvadori, Imrich Chlamtac
CREATE-NET
Via dei Solteri 38, 38100 Trento, Italy
name.surname@create-net.org

Abstract— **This paper addresses the dimensioning of the emerging wireless broadband networks operating in 3.5 GHz band by focusing on the key problem of propagation loss. The characteristics of the path loss in the 3.5 GHz band measured in a rural macro-cellular environment are presented. The existing empirical prediction models are compared with the measured data and a comparative analysis is carried out. The measurements are performed within the experimental activities developed on a WiMAX based platform located in an Italian rural area.**

Keywords-component - Path loss, 3.5 GHz, measurements, WiMAX, propagation model

I. INTRODUCTION

Wide area wireless broadband systems are expected to play a significant role in providing the future high-rate services and bridging the digital divide, especially with the advent of technologies such WiMAX (802.16 standards). Broadband wireless technologies operating at 3.5 GHz can be used for LOS and NLOS communications and have the potential to provide high performance fixed and nomadic access with extensive geographical coverage. Therefore they are of particular interest in regions not covered by cabled broadband.

The expected dramatic increase in the number of broadband wireless accesses in this frequency range poses a difficult challenge when designing a wireless network. In fact, system designers must fulfill several objectives to dimension large scale broadband wireless networks: an efficient determination of the spatial variation of field signal strength levels, a sufficiently high percentage of covered location in the intended service area, a proper selection of base station locations, and an estimation of the interference power. A realistic and reliable estimation of the propagation losses as well as an accurate understanding of the power levels statistical variation are therefore fundamental.

In the simulation of radio propagation two main approaches have been effectively adopted in the last decades; the first one is based on deterministic methods, the second relies on empirical methods [1-7]. In general, the available methods differ in the type of approximation made, in the characterization of the environment and in the applicability to different frequency regimes. As a matter of fact, while in urban scenario it is possible to achieve an accurate deterministic description of the scene and advanced techniques for site-specific propagation prediction are feasible [8-11], it is much more difficult to perform a detailed description of the obstacles in rural environment (foliage, tree density, seasonal variability, etc.). On the other hand, to cope with dimensioning broadband wireless systems, empirical models offer simple and no *site-specific* (i.e. without the need for detailed propagation environment database) prediction methods. Although a plethora of theoretical models have been developed to deal with the path loss prediction in different bands [1,2,4,12-16], the knowledge of the propagation loss in 3.5GHz band is firmly less advanced with respect to the one accumulated for the frequencies used in cellular application. Furthermore, publications related to the *Broadband Fixed Wireless Access* (BFWA) channel modeling at 3.5GHz are still very limited. Generally speaking, as far as the authors know, the applicability of the current propagation models is yet to be properly validated at this frequency. Specifically, the available empirical prediction models [12-16] focus on different frequency ranges and it is not clear their extendibility for the 3.5 GHz range. Even though appropriateness of some existing model has not been fully established, experimental path loss studies in this band has gained new consideration only recently, with the advent of emerging broadband wireless technologies operating in 3.5 GHz band like WiMAX [17-21]. In [17] *Walden et al.* have conducted path loss measurement in urban environment up to 1 km of range; in [18] *Abhayawardhana et al.* have presented measurement results in different regions essentially within a range of 2 km. However, the few available experimental path loss studies in the 3.5 GHz band analyze limited scenarios or are restricted to limited coverage range, so that the macro cellular rural environment is not completely characterized at 3.5 GHz yet. Nevertheless, mathematical tools for accurate prediction of the electromagnetic signal characteristics in this scenario are becoming of critical importance.

This work addresses the dimensioning of a wireless broadband network operating in 3.5 GHz band by focusing on the key problem of path loss behavior. The study refers to measurements carried out in a WiMAX-based (IEEE 802.16-2004) testbed deployed in *Canavese*, a rural area in North-East district of Turin (Fig.1). A data set of radio propagation measurements at 3.5 GHz is analyzed to derive a path loss model over wide ranges (up to 10 km) and a comparative analysis is also provided. The obtained results are of

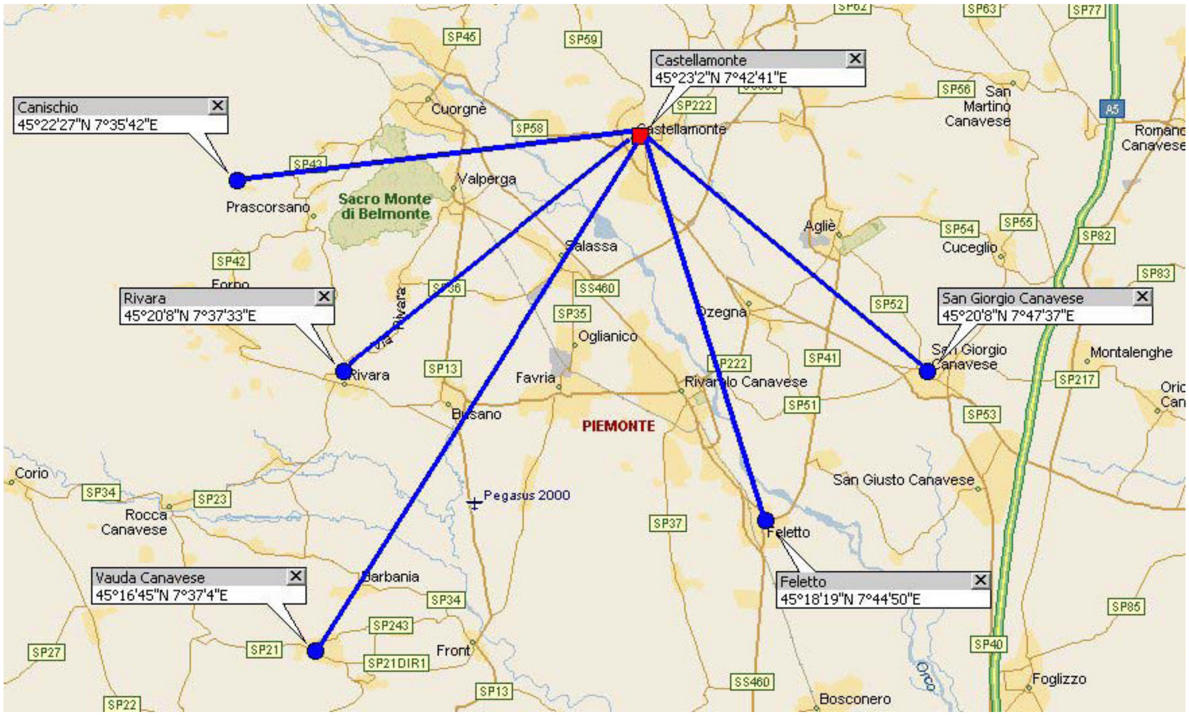

Figure 1. Installed WiMAX-based testbed architecture.

considerable interest since they provide a useful knowledge for dimensioning broadband wireless networks operating in this frequency range.

The paper is organized as follows. Section II describes the framework of the measurement activity and the testbed architecture as well as the characteristics of the involved environment. Section III describes the hardware and the technique used to perform the measurements. Section IV shows the measurement results. In Section V, the available path loss models suitable for 3.5 GHz propagation prediction in rural scenario are analyzed. Section VI is devoted to the analysis of empirical data and it furnishes a careful evaluation and comparison with the considered prediction models. Conclusions are drawn in Section VII.

II. PLATFORM AND MEASUREMENT AREA

The general aims of our project were to investigate which factors must be tuned to perform an optimal design of a wireless broadband system in the 3.5 GHz band and to develop dedicated planning methodologies for WiMAX deployment.

For this purpose, it is crucial to acquire knowledge of radio propagation characteristics in the 3.5 GHz band. A radio propagation measurement program was conducted in *Piemonte* region (Italy) within three test settings, which were carefully chosen in urban, suburban, and rural areas. In each environment, an experimental platform based on the emerging WiMAX technology was installed using commercial equipments (*802.16-2004* compliant). The deployed architectures implement Point-to-Multipoint (P-MP) configurations, with a number of terminals or *Customer Premises Equipments* (CPE) communicating with a single base station or access point (AP). The CPEs in a BFWA network typically have narrow-beam antennas, pointing directly to the AP, but the AP antennas may have wider beamwidths. A wide range of experimental activities on all the different layers of the installed WiMAX infrastructure (PHY, MAC, Application) has been performed so far, in [22] some initial results are provided. In particular, a detailed program of link and system monitoring and data measurements has been carried out in the physical layer. Here we focus only on the propagation loss experimental activities that were carried out within *Canavese* (Turin) rural area.

A. *Canavese WiMAX Testbed Infrastructure*

The deployed WiMAX network consists of one Base Station (BS) and five CPEs and has been operational since January 2006. The network operates within the 3.5 GHz band, with channel bandwidths of 3.5 MHz. The BS site is located on a tower (*Torre Civica di Castellamonte*) and employs two Access Points (AP), each having a vertical polarized antenna with beamwidth of 90° and 8° in azimuth and elevation, respectively. The AP2 covers two CPEs located in *Feletto* (CPE1) and *San Giorgio Canavese* (CPE2) respectively. The other one, AP1, covers three CPEs located in *Canischio* (CPE3), *Rivara* (CPE4) and *Vauda Canavese* (CPE5) respectively. All CPE antennas are vertical polarized, have beamwidths of 15° in azimuth, 18 dBi gain, are mounted at rooftop level and are aligned to receive maximum signal power. Fig.1 shows the network architecture. The BS antennas are elevated above any local scatters, and all the CPE locations within the sectors are in line of sight conditions.

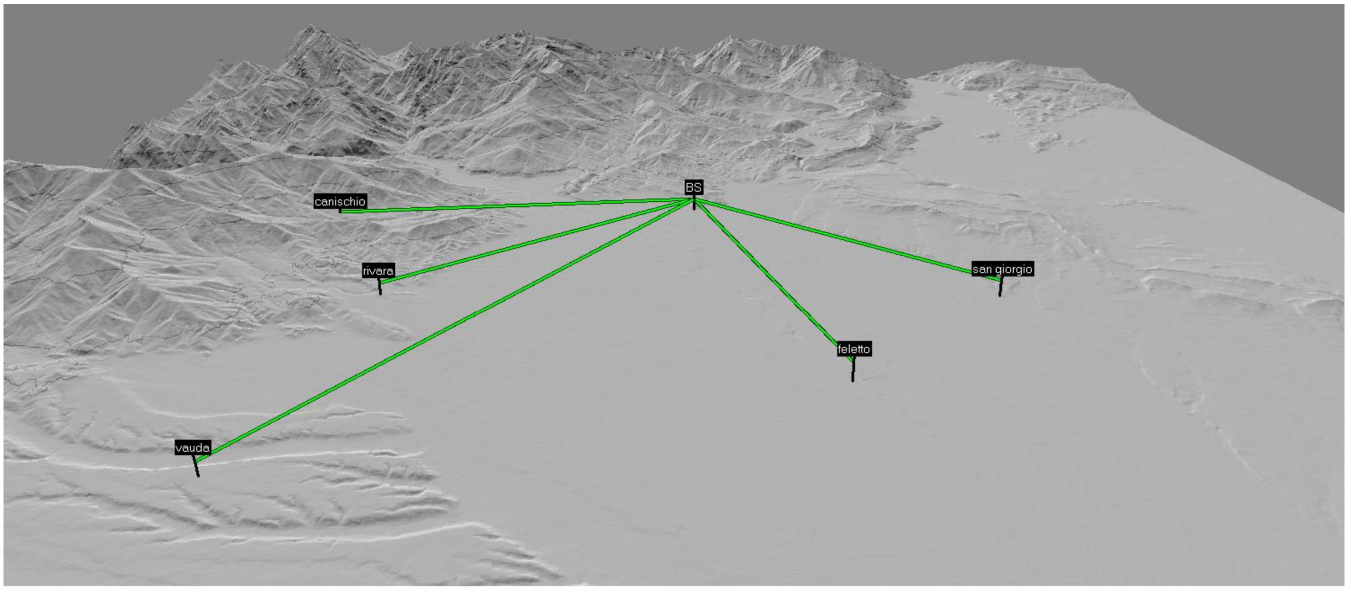

Figure 2. Canavese rural area: measurement environment and testbed architecture .

B. *Area Morphology*

The region in which the measurements were carried out appears as a flat open area surrounded by large mountains (Fig.2). The BS is located in the middle of a suburban area, which is limited within a range of a few hundred meters. As a result, *Canavese* area can be categorized as a rural environment characterized by sparse amount of low height buildings and light tree density. All the considered measurement scenarios are characterized as outdoor cases.

III. MEASUREMENT EQUIPMENT AND METHOD

The propagation measurements have been performed by transmitting from a sectored stationary BS and sampling the received signal in the equipped mobile receiving vehicle. The transmitting antenna is vertical polarized and exhibits a gain of 14 dBi, a beamwidth of 90° and 8° in azimuth and elevation, respectively. The acquisitions were conducted along different routes and in several fixed points where the receiving antenna height was varied to ensure that measurement were taken both above and below typical rooftop heights. The propagation measurements were taken using a survey vehicle equipped with receiver and position location equipment (GPS). The mobile vehicle is furnished with a DC/AC inverter to supply all the equipments, and it is fitted with a *10 m* telescopic mast to give an adaptable antenna height from 2 to 10 m above ground level (Fig.3). This permits to acquire measurements at different antenna heights in a fixed location. A vertically polarized receiving antenna (*3360 Fibreglass Omni*) is mounted on the top of the mast. Its radiation pattern is omni-directional in the azimuth plane with gain of 13 dBi. The mobile receiver comprises an appropriate band pass filters (3.4-3.5 GHz) and a low noise amplifier connected to a spectrum analyzer.

Figure 3. Equipped mobile vehicle with telescopic mast.

A PC-based data acquisition software was developed in order to periodically read the output from a GPS receiver, used to obtain the vehicle position data in terms of latitude and longitude. In addition, it obtains inputs from the spectrum

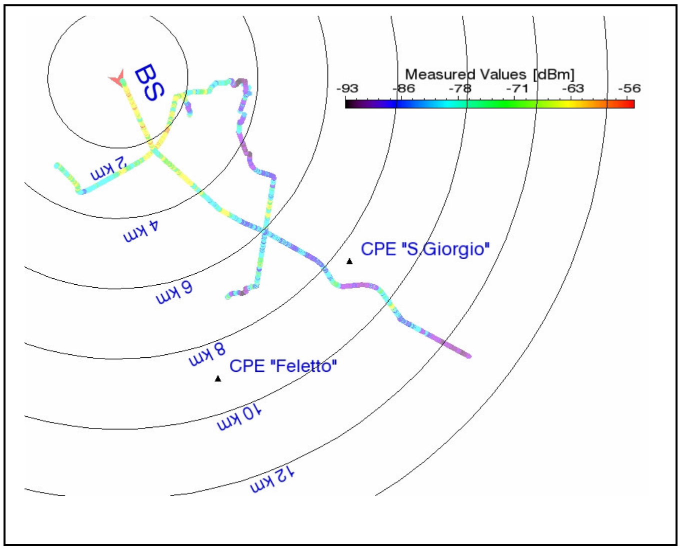

Figure 4. Test area map: BS location and Measurement Routes.

analyzer and stores raw survey data (including GPS time and coordinates) for later processing. Therefore, the geo-referenced received power, recorded in every measurement location, was used to determine the radial distance from the BS associated with each power measurement and to generate path loss map for the sites coverage area. The spectrum of the received signal is acquired every 2 seconds while the vehicle is traveling. The local received signal strength is calculated by integrating the measured spectra in the frequency domain.

Once the transmitted power is known (fixed), the antenna gains, the cable loss and insertion losses are carefully measured and removed from the propagation chain in order to measure the attenuation in the communication path only due to propagation in environment.

IV. EXPERIMENTAL RESULTS

The signal strength measurements were made by monitoring and recording the power signal received by the mobile unit as it moves along predefined routes at constant speed, driving field test vehicle as slowly as possible. The measurement locations in the *Canavese area* were concentrated in the AP2 coverage area (toward Feletto and San Giorgio, see Fig.2) transmitting at 3566.75 MHz (downlink).

The measured data are recorded in geo-referenced manner and are used to evaluate propagation-path loss within the considered area. Locations included both line of sight (LOS) conditions as well as obstructed locations (NLOS). Within the extension of the area covered by the sectored BS antenna two acquisitions were conducted: a continuous one obtained with a receiver height of 2m as well as a non-continuous one performed in several fixed location, at different receiver antenna heights, up to 10m. In Fig.4 a multi-colored line is displayed to represent the processed field-strength levels (continuous acquisition).

V. EXISTING EMPIRICAL MODELS

In this section the existing empirical approaches are discussed. First, we present a basic empirical model, since all the other ones here considered are based on a similar structure. After, we consider the *SUI model* and *Cost 231-Hata model*. While the latter is an extension of the Hata model and is widely accepted for cellular deployments up to 2.0 GHz, the first was proposed specifically for fixed wireless applications, even though it was basically based on experimental results at 1.9 GHz. Both the considered models are suitable for the rural scenario case.

The path loss, which is a measure of the RF attenuation suffered by a transmitted signal when it arrives at the receiver, can be defined as:

$$Pathloss\,[dB] = EIRP + G_R - P_R \qquad (1)$$

where EIRP (Effective Isotropic Radiated Power) is measured in dBm, G_R is the receiver antenna gain in dB, and P_R is the local mean received power in dBm at the receiver antenna terminals.

A. General model

It is common practice to represent propagation loss using an inverse power law of the distance to the transmitter as follows:

$$Pathloss\,[dB] = A + 10\gamma \log_{10}(d/d_0) + \chi_\sigma \quad d > d_0 \qquad (2)$$

where γ denotes the *path loss exponent*, d is the distance between the transmitter (BS) and receiver station, d_0 is the reference distance, A is the path loss at range d_0, and χ_σ is the variable representing uncertainty of the model which reflects the variation of the average received power that naturally occurs when a model of type as in (2) is used. The shadow fading χ_σ is typically modeled with a log-normal distributed random variable [1, 4, 7].

B. IEEE 802.16 SUI Model

The model included by the IEEE working group 802.16, informally known as Stanford University Interim (SUI), was derived from [13] and can be found in [14]:

$$Pathloss[dB] = A + 10\gamma \log_{10}(d/d_0) + \chi_h + \chi_f + \chi_\sigma \quad d > d_0 \qquad (3)$$

$$A = 20\log_{10}(4\pi d_0/\lambda) \qquad (4)$$

being λ the wavelength, $d_0 = 100m$, and γ the *path loss exponent* given by:

$$\gamma = a - bh_b + c/h_b \qquad (5)$$

where h_b is the BS antenna height above the ground that should be between 10m and 80m, and a, b, c are constants dependent on the category of the environment considered by the model, which are given in Tab. I. *Category A* is associated with hilly terrain with moderate to heavy tree density (maximum path loss), *Category C* with mostly flat terrain with light tree density (minimum path loss), and *Category B* captures intermediate conditions. Additional correction terms are defined as follows:

$$\chi_f = 6.0 \log_{10}(f/2000) \tag{6}$$

$$\chi_h = \begin{cases} -10.8\log_{10}(h_m/2) & type \quad A,B \\ -20.0\log_{10}(h_m/2) & type \quad C \end{cases} \tag{7}$$

where f is the frequency in MHz and h_m is the receiver antenna height between *2m* and *10m*. The typical value for the standard deviation σ of the shadow fading χ_σ is between 8.2 and 10.6, depending on terrain/tree density type.

TABLE I. SUI MODEL PARAMETERS

Model parameter	***Terrain type A***	***Terrain type B***	***Terrain type C***
a	4.6	4	3.6
b	0.0075	0.0065	0.005
c	12.6	17.1	20

SUI model should perform adequately in the 2-4 GHz range. However, its performance, in the European 3.5 GHz band, has not been evaluated and the applicability is yet to be properly validated. It is important to note that there is no systematic method for selecting which terrain type category (*A, B, C*) to apply for any specific scenario.

C. Cost 231- Hata model

The COST-231 Hata model [15] was devised as an extension of the Okumura-Hata model [12]. Okumura-Hata is the most widely used empirical path loss model for prediction and system dimensioning in cellular environment. This model was developed for the 500-1550 MHz frequency range and for base station antenna heights greater then *30 m* and receiver distance greater than 1km from the BS. The COST-231 model extends Okumura-Hata model to frequency range up to 2 GHz and also has corrections for urban, suburban, and open areas. The basic path loss equation is [1]:

$$\begin{aligned} Pathloss[dB] = 46.3 + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d) + \\ -13.82\log_{10}(h_b) - ah_m + c_m + 33.9\log_{10}(f) \end{aligned} \tag{8}$$

where d is the distance from the base station to the receiver in kilometers, f is the frequency in MHz, h_b and h_m are the height of the base station and the receiver above ground in meters, respectively. The correction term c_m, is defined as 0 dB in open or suburban environments and as 3 dB for urban environments. For suburban (medium–small city) or open (rural) areas the term ah_m is defined as follows:

$$ah_m = (1.1\log_{10} f - 0.7)h_m - (1.56\log_{10} f - 0.8) \tag{9}$$

For the sake of unitary formalism, in the rural case, equation (8) can be rewritten as:

$$Pathloss\ [dB] = A + 10\gamma\log_{10}(d/d_0) + \chi_c \tag{10}$$

where A = 46.3, d is the distance from the base station to the receiver in meters, $d_0 = 1000\ m$, and where

$$\gamma = (44.9 - 6.55\log_{10}(h_b))/10 \tag{11}$$

$$\chi_c = -13.82\log_{10} h_b - (1.1\log_{10} f - 0.7)h_m + 35.46\log_{10} f - 0.8 \tag{12}$$

VI. ANALYSIS OF MEASUREMENT DATA

In this section, a method for analyzing the collected empirical data is outlined and the results from the analysis of the measurements are presented. Furthermore, in order to assess the relation between the empirical results and the existing models analyzed in Section V, the characteristics obtained from the measured data are compared with those estimated by empirical prediction models. Finally, the applicability of the existing models for path loss prediction in wide rural areas in 3.5GHz band is discussed.

The measurement points corresponding to the locations less than 1 km from the base station have been excluded from the analysis for two reasons. First, the environment characteristics change from rural to suburban when approaching the 1 km circle. In addition, these locations experience varying antenna gains due to the nulls and side lobes in the antenna (vertical) pattern. Furthermore, as the signal level approached the receiver noise floor, the collected data have been excluded.

Given the data set $\{d_i; y_i\}$, where d_i is the distance to the BS and y_i is the local average power measured from the i-th measurement segment, a curve fitting is needed in order to estimate quantitatively the trend of the propagation loss. For this purpose, assuming a path loss model defined as in (2), the best-fitting (BF) curve *Pathloss(d)* can be obtained by the method of least squares:

$$E = \sum_{i=1}^{n}\left[y_i - Pathloss\,(d_i)\right]^2 \tag{13}$$

such that the root mean square (*rms*) deviation of points about this curve is minimized. Consequently, the parameters A and γ can be obtained as the least square estimate from the measurements. First, we consider measurements based on data acquired along the radial route: a scatter plot of measured local power versus distance is pictured in Fig.5. Moreover, a linear regression curve is superimposed on the scatter points. Our regression analysis on the experimental data has led to a simple one-slope characterization for decibel path loss versus decibel-distance. For the radial route the slope γ was 30 dB per decade (or γ= 3.0 in linear scale).

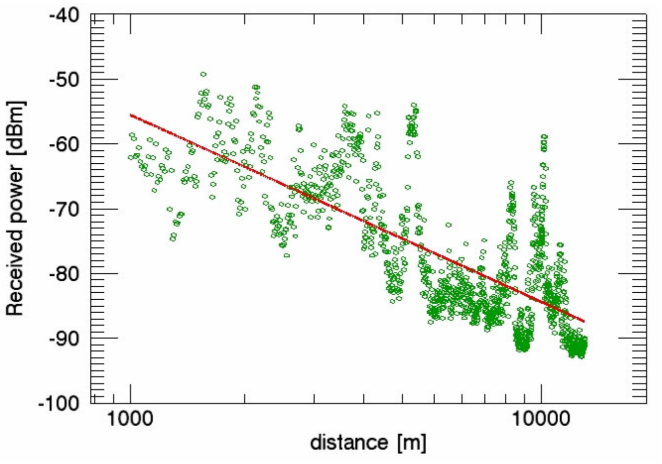

Figure 5. Scatter plot of the local received power versus distance (radial route). The straight line represents the least-square linear regression fit.

Under the assumption that the deterministic long term distance dependent path loss can be expressed in decibel as in (2), the large scale spatial fading, also known as shadow fading component [1,4], can be extracted from the measured data. For instance, the channel's shadow fading component isolated from each measurement value along the radial route is shown in Fig.6. As we can see, the local average power signal changes much more slowly with distance compared to the typical small-scale fluctuations, and it is caused by large scale variation in terrain profile along the path to the transmitter and by changes in the local topography.

In Fig.7 a scatter plot of measured path loss versus distance over all routes (at h_m = 2m) is pictured, with the least-square linear regression fit curve superimposed on the scatter points (A = 116.0 dB and γ= 2.5, σ= 8.9 dB). We find that χ_σ appears to be Gaussian (in dB) in shape with standard deviation σ= 8.9 dB. This observation is in coherence with several other studies available in literature [1, 2, 4, 17], in which the large-scale fading characteristics are accurately modeled by a log-normal distribution. With reference to the measurements acquired in fixed locations at (h_m =) 10 m receiver antenna height, Fig.8 shows the scatter plot of measured path loss versus distance. The straight line represents the least-square linear regression fit with A = 103.3 dB and γ= 2.5, σ= 9.4 dB.

To quantitatively assess the prediction capability of the models analyzed in Section V, we perform the comparison between the trends deducted from our regression analysis (BF) and the predictions obtainable from the empirical models specialized to the analyzed case. For the purpose, we have used the category *terrain type C* (see Tab I) for the *SUI*, and the category open (rural) areas for *COST 231-Hata*. The assessment is performed for two different receiver heights (2 and 10 m). Fig. 9 shows the different trends of the obtained path loss. To perform a uniform comparison, the *path loss exponent* γ and the path loss (*PL*) evaluated at *1km* exhibited by the different cases (BF, SUI and COST 231-Hata) are provided in Tab. II. It should be noted that the predictions provided by SUI and COST 231-Hata models differ significantly, even though the difference is more reduced at receiver height of *10m*. As we can see, the *COST 231-Hata* model as well as the *SUI* model overestimates the amount of the propagation loss for both the receiver heights.

TABLE II. TABLE MODEL PARAMETERS COMPARISON

MODEL	***BF***		***COST 231 - HATA***		***SUI***	
h_m	***10m***	***2m***	***10m***	***2m***	***10m***	***2m***
γ	2.5	2.5	3.6	3.6	4.5	4.5
PL(d=1km)	103.3	116.0	118.5	144.1	115.8	129.8

Overestimation of propagation loss affects not only the prediction of the service radius of the cell. In fact, in high density systems, where the overall performance is interference limited, this aspect can be detrimental especially during the network planning phase since it leads to underestimate the total external interference levels. Consequently, the designer can fall into frequency reuse distance miscalculation. The above discussion highlights the relevance of an accurate prediction of the propagation loss and, at the same time, the fact that available empirical modeling can turn out to be inadequately in the 3.5 GHz frequency band, as far as a rural scenario is considered. Concerning our specific case, we stress that SUI model, which however performs better than Cost 231-Hata model at h_m = 2 *m*, exhibits a path loss exponent of 4.5. On the other hand, the path loss exponent values found out experimentally in [18], within a range of 2 km in rural environment at 3.5 GHz, ranges from 2.13 to 2.70. In [21], the seasonal variation in path loss at 3.7 GHz associated with tree foliage is studied in a range up to 6 km; the estimated path loss

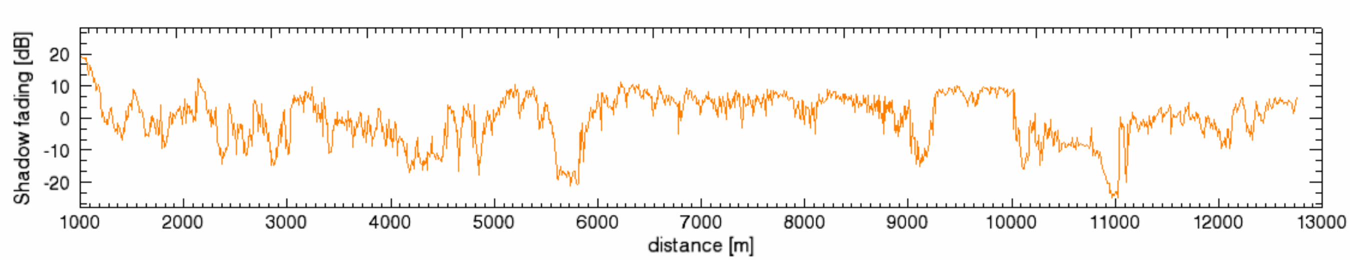

Figure 6. Shadow fading component along the radial route.

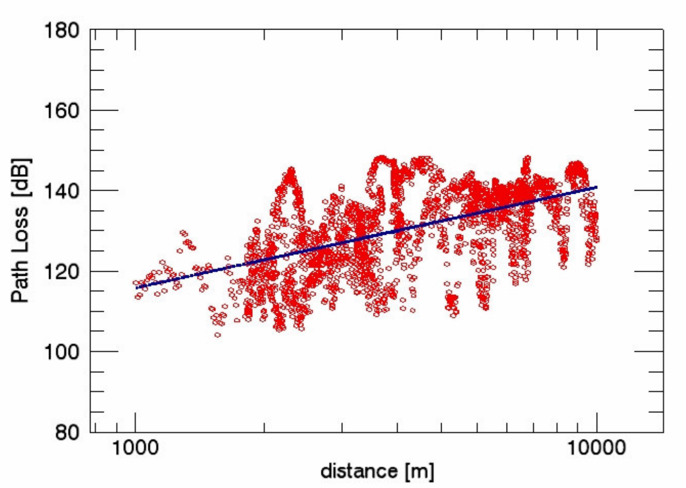

Figure 7. Scatter plot of path loss over all routes versus distance in rural environment, with hm = 2 m. The straight line represents the least-square linear regression fit with A = 116.0 dB and $\gamma = 2.5$, $\sigma = 8.9$ dB.

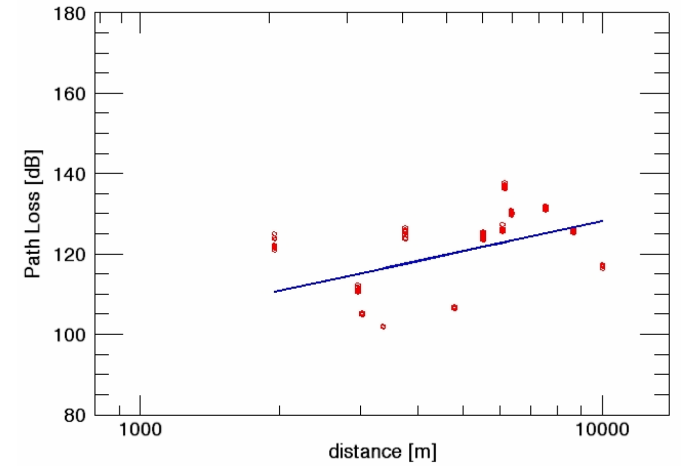

Figure 8. Scatter plot of path loss versus distance, with $h_m = 10$ m. The straight line represents the least-square linear regression fit with A = 103.3 dB and $\gamma = 2.5$, $\sigma = 9.4$ dB.

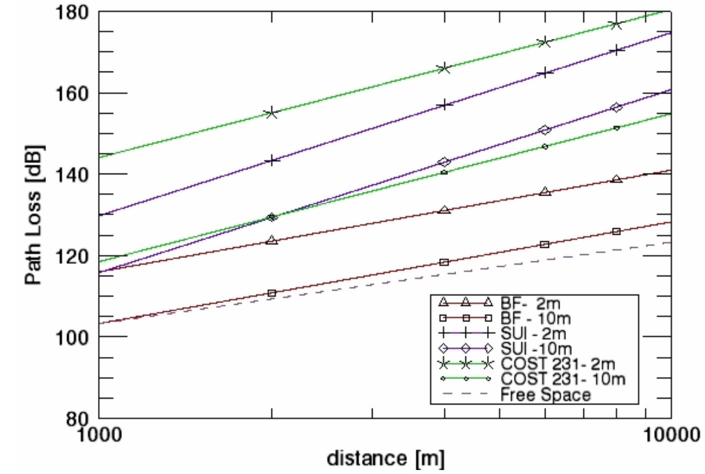

Figure 9. Comparision of the fitted measured data (BF) with the existing empirical models for a rural scenario with $h_b = 20\ m$ and for $h_m = 2m, 10m$.

exponent is to be around 3. Therefore, our results, taking into account also the experimental outcomes obtained in [18, 21], suggest that in rural scenario a good choice for the *path loss exponent* γ can be within the 2.5-3 interval.

VII. CONCLUSIONS

We have presented results of propagation loss measurements from a WiMAX based trial test deployed in a rural environment. A comparison between our results and the predictions obtained by applying available empirical models (SUI and COST231-Hata) shows that existing models can be inadequate in rural scenarios since they could lead to overestimate the propagation loss. Therefore our outcomes are of considerable interest since they provide a useful knowledge for dimensioning BFWA networks operating at 3.5 GHz. Wider measurement campaigns have been already planned in the testbed to propose further theoretical analysis. All this measurements will provide a basis for defining planning methodologies that will be a matter of further publication.

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