A MODEL FOR WIMAX COVERAGE & CAPACITY PERFORMANCE ESTIMATION

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Abstract: A new model for WiMAX coverage and capacity performances evaluation is presented in this paper. This model is capable to simply estimate performances on downlink radio channel (from base station to user terminal equipment), assuming that all users generate the same amount of traffic and that they are uniformly spread over the cell area.
This paper presents also results from a WiMAX trial carried out in 3.5 GHz band. One of the trial objectives was to assess Erceg propagation model reliability in this frequency band. The result is that Erceg model can be used for performance evaluation at this stage.
Simulation results using the proposed model, with Erceg propagation model, show good performances for a WiMAX system. This standard is capable to deliver a high spectral efficiency in very different propagation scenarios, with a cell radius ranging from 1 km (dense urban indoor reception) to 6 km (rural outdoor reception).

Keywords: WiMAX, Erceg, 3.5 GHz band, Performances, Coverage, Capacity

1. INTRODUCTION

WiMAX, as a future microwave access system, shall increase the capacity without reducing coverage in order to have a low initial deployment costs. One of the best and rapid solutions for increasing the expected capacity is to implement adaptive modulation and coding in order to improve channel spectral efficiency for those users who experience a good channel condition. This solution allows of maintaining the coverage of the most robust physical layer, therefore without reducing system coverage and without increasing initial deployment costs.

At this point a new model for capacity and coverage estimation is needed for system design and deployment. In this paper a new capacity and coverage prediction model is presented; this model is only valid for downlink channel and it does not consider the traffic generated by each user terminal, but it just supposes that each user terminal generates the same amount of traffic. Another approximation of the model is to consider a uniform distribution of user terminals in the area covered by each base station. However it should be considered that downlink capacity evaluation typically represents the most critical item in a system evaluation.

In this paper the model is applied using Erceg path loss prediction model which is the model chosen by IEEE 802.16 as reference propagation model for WiMAX system evaluation, but it should be noted that the model described in this paper can be generalized for any path loss prediction model to be used as reference.

In this paper a WiMAX field trial carried out in the urban area of Milan is also described and the results obtained regarding coverage measurement. The scope of this trial was to get a first feedback on Erceg path loss model accuracy and to evaluate the actual performances of an 802.16d (IEEE 802.16-2004) WiMAX system (IEEE802.16-2004, July 2004; ETSI TS 102 177, November 2004).

Finally, this paper provides coverage and capacity performances expected for a WiMAX system in different environments. These performances have been evaluated using Erceg path loss model and radio characteristics of a WiMAX system currently on the market.

2. PATH LOSS MODEL

The outdoor path loss model is the Erceg one (V. Erceg et al, 2001), which has been chosen by IEEE 802.16 as reference propagation model for WiMAX system evaluation (V. Erceg et al, 1999). The proposed Erceg model can be applied to systems operating in frequency bands up to 6 GHz and it has been derived by the Erceg model created for mobile applications at 2 GHz. This model can be applied in three different environments, Type A, B and C.

By using this model the total attenuation $PL_s(d)$ is given by:

$$PL_s(d) = PL_{s0}(d) + s = 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right) + 10\gamma\log_{10}\left(\frac{d}{d_0}\right) + X_f + X_h + s \qquad (1)$$

Table 1: Erceg Model Parameters

Model Parameters	Terrain Category		
	Type A	Type B	Type C
d_0	100 m	100 m	100 m
a	4.6	4.0	3.6
b	0.0075 m^{-1}	0.0065 m^{-1}	0.0050 m^{-1}
c	12.6 m	17.1 m	20.0 m
σ_s	10.6 dB	9.6 dB	8.2 dB

where:
$PL_{s0}(d)$ is the fixed part of the path loss attenuation;
s is a zero-mean random Gaussian variable with standard deviation;
σ_s which represents the shadowing effect and it depends on terrain category (see Table 1);
d is the distance between transmitter and receiver;
d_0 represents the intercept distance and it is the maximum distance from the base stations for which the free space loss is valid (see Table 1);
λ is the wavelength;
γ represents the path loss exponent;
X_f is the frequency correction term;
X_h is the user antenna height correction term.

The path loss exponent γ depends on terrain category and on the base station height and it is equal to:

$$\gamma = a - b \cdot h_b + \frac{c}{h_b} \qquad (2)$$

where
a, b, c are data-derived constants for each terrain category (see Table 1);
h_b is the base station antenna height in meters ($10 \le h_b \le 80$ m).
The frequency correction term X_f depends on the carrier frequency f and it is equal to:

$$X_f = 6 \cdot \log_{10}\left(\frac{f}{2000}\right) \qquad (3)$$

The user antenna height correction term X_h will depend on user antenna height hr ($2 \le h_r \le 10$ m) and on the terrain category and it is equal to:

$$X_h = \begin{cases} -10.8 \cdot \log_{10}\left(\frac{h_r}{2}\right) & \text{Type A and B} \\ -20 \cdot \log_{10}\left(\frac{h_r}{2}\right) & \text{Type C} \end{cases} \qquad (4)$$

The indoor reception provides additional path loss (usually called penetration loss) that can be modelled with a Gaussian random variable w with the following parameters:

- mean value $\mu_W = 12$ dB
- standard deviation $\sigma_W = 8$ dB

So, in case of indoor reception the total attenuation (outdoor + penetration loss) is given by:

$$PL_z(d) = PL_s(d) + w = PL_{s0}(d) + s + w = PL_{s0}(d) + z \qquad (5)$$

where z is a random variable which is the sum of the two Gaussian random variables s and w. Due to the property of the Gaussian random variables, the random variable z is still a Gaussian random variables with the following parameters:

- mean value $\mu_z = \mu_w$
- standard deviation $\sigma_z = \sqrt{\sigma_s^2 + \sigma_w^2}$

Figure 1 shows the path loss curves for Erceg model A, B, C considering 3.5 GHz band, a BS height of 30 meters and a CPE height of 6 meters. These curves will be used for calculating the WiMAX performances in section 6.

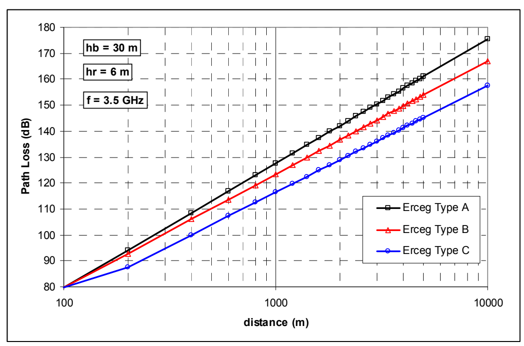

Fig. 1: Pathloss for Erceg model.

3. COVERAGE AND CAPACITY MODEL

In this section a model for coverage and capacity evaluation of a WiMAX system using several physical modes (combinations of modulation and coding) for a single isolated cell is presented. This is because the purpose of this paper is to compare this model (used with the above mentioned path loss model) with a field trial measurements where a single cell has been installed. A similar, but more complex model, has been defined in order to evaluate coverage and capacity in a cellular environment taking into consideration interference and cell overlapping (multiple coverage from different base stations).

In this model we consider a system which employs adaptive coding and modulation and so it has different physical layers (i=1…N), where the first physical layer (i=1, BPSK for WiMAX) is the most robust one and the last physical layer (i=N, 64 QAM 3/4) is the most spectral efficient one. So the probability of using a certain physical layer i, if it is the only one, in a cell with a radius R (see Fig. 2) is given by:

$$P_i = \frac{2}{R^2}\int_0^R p\left(P_r(x) > P_{s,i}\right)\cdot x\,\mathrm{d}x \qquad (6)$$

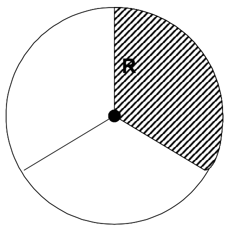

Fig. 2: Single cell scheme with a 3 sectors base station

where $P_r(x)$ is the received power and $P_{s,i}$ is the threshold received power of the physical layer i at BER=10^{-6}. The received power $P_r(x)$ is given by the following relationship:

$$P_r(x) = P_t + G_t + G_r + G_a - PL_t(x) = P_{r0}(x) - q \qquad (7)$$

where

- P_t is the transmitted power;
- G_t is the transmitter antenna gain;
- G_r is receiver antenna gain;
- G_a represents the gain due to different techniques, such as diversity receiver, Space Time Coding, etc.
- $PL_t(x)$ is the space loss and it is equal to $PL_s(x)$ in case of outdoor reception and to $PL_z(x)$ in case of indoor reception;
- $P_{r0}(x)$ is the fixed part of the receiver power;
- q is a random Gaussian variable and it is equal to s in case of outdoor reception and to z in case of indoor reception.

For a system employing adaptive modulation and coding the effective utilization of a physical layer (i) is given by the difference between the probability of using that physical layer and the probability of using the less robust one ($i+1$). So, considering that each physical layer i provides a capacity C_i, the average capacity C in the cell can be expressed by:

$$Capacity = C = \frac{\sum_{i=1}^{N-1}(P_i - P_{i+1})\cdot C_i + P_N \cdot C_N}{P_c} \qquad (8)$$

where P_c is the coverage probability of the cell with radius R and it is given by the probability of the most robust physical layer, so:

$$Coverage = P_c = P_1 \qquad (9)$$

4. TRIAL DESCRIPTION

The trial layout set up in Milan (urban area) during first half of year 2006 is depicted in Fig. 3 and it was composed by:

- Frequency band 3.5 GHz, channel size 3.5 MHz
- 1 Base Station (BS): antennas installed 47 meters above ground level
- 2 sectors (for 120 degrees sector coverage) on 2 different 3.5 MHz channels
- 5 portable CPE's[1] with several antenna types (see Table 2).

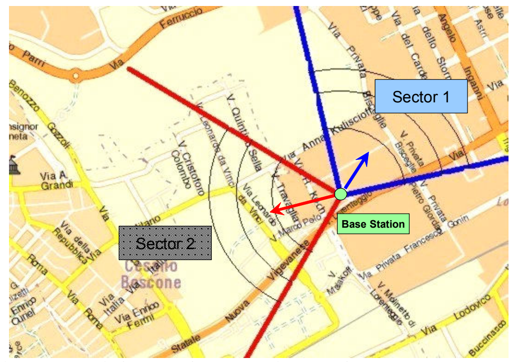

Fig. 3: Trial map: base station and sector coverage.

Table 2: CPE antennas type and characteristics

Parameter	Outdoor	Desktop	PCMCIA
Gain [dBi]	18	9.5	2
Beamwidth [deg]	20°x20°	65°x55°	360°x80°

Exploiting the advantages of portable CPE's coverage measurements were carried out in:

- about 100 indoor locations in 8 different buildings, at different floors and up to 1.5 km away from BS
- about 230 outdoor locations at ground level, mainly in a range up to 2.5 km away form BS as depicted in Fig. 4.

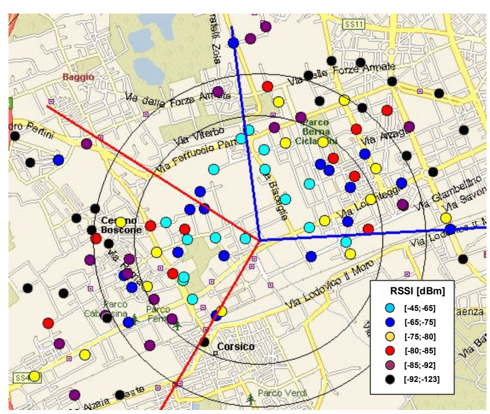

Fig. 4: Outdoor coverage measurements.

[1] Customer Premises Equipment

5. TRIAL RESULTS FOR PATH LOSS MODEL

All the above mentioned measurements have been compared with expected path loss Erceg models A, B and C. Most of the comparisons have revealed that measurements collected during this trial were closer to model B on average. Therefore, Figure 5 and 6 report the comparison between Erceg B model curves (average and standard deviation range) and measurements points collected outdoor, with CPE receiver 2 meters above ground level.

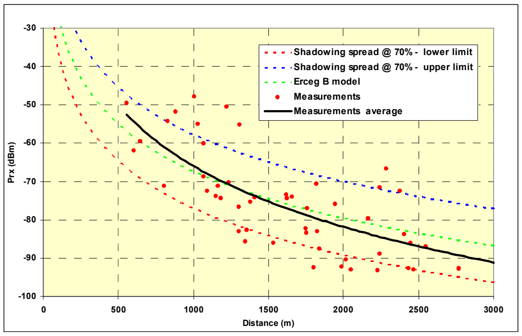

Fig. 5: Erceg B vs outdoor measurements, sector 1.

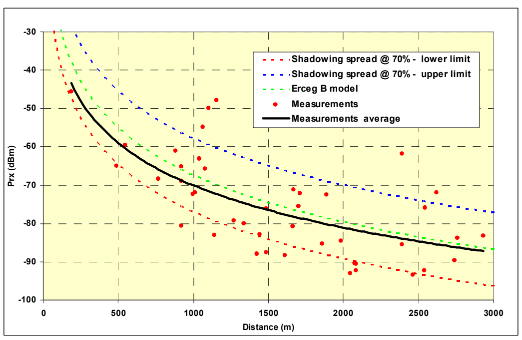

Fig. 6: Erceg B vs outdoor measurements, sector 2.

Comparisons in Figure 5 and 6 both show that most of measurement points are inside the shadowing effect range indicated, where 70% of measurements are expected to be. This means that propagation in the area trial is well described by Erceg B model. This fact is confirmed by trend lines that are quite close to average path loss model (green dashed line in the middle). It is also interesting to compare trend lines with average path loss model because it is different for two sectors. For sector 1 trend line tend to be lower than path loss model for distances above 1.5 km, and reaching 5 dB difference at 3 km. On contrary, for sector 2, you can see that trend line tend to be much closer to path loss model as long as distance increases. These two different trends can be simply explained considering the fact that two sectors cover two different areas with different building density; sector 1 is towards city centre direction and more similar to dense urban environment (Erceg A), while sector 2 is in the sub urban area of Milan (Erceg B).

The same kind of comparison has been carried out for indoor measurements and Figures 7, 8 and 9 show the results for different building heights. We have grouped measurements in these 3 sets in order to compare with a unique path loss model that can be valid for CPE heights range. Therefore, we have considered path loss models with CPE height 3, 10 and 20 meters, that differ approximately 5 dB one from the other.

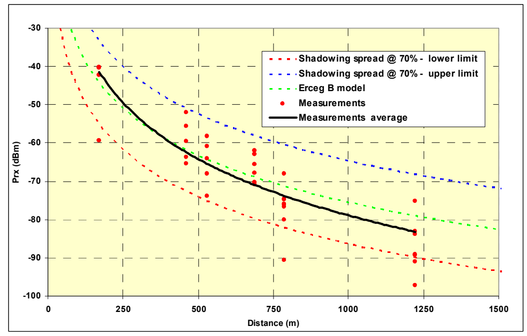

Fig. 7: Erceg B vs indoor measurements, CPE height between 1.5 and 4 meters.

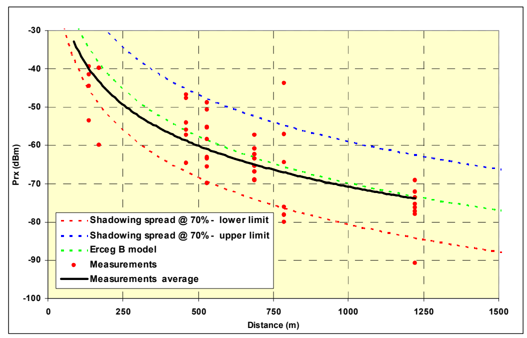

Fig. 8: Erceg B vs indoor measurements, CPE height between 5 and 15 meters.

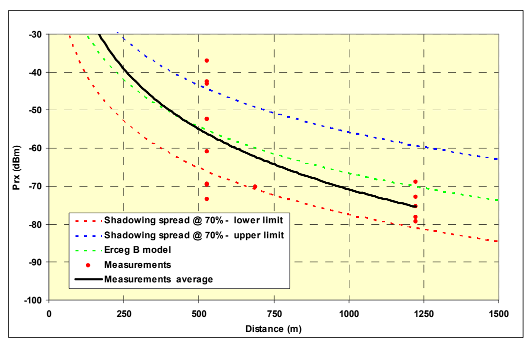

Fig. 9: Erceg B vs indoor measurements, CPE height between 16 and 25 meters.

Also for indoor measurements, Erceg B path loss model is a good representation of propagation conditions in the trial areas. This is especially true in Figure 7 and 8, while comparison in Figure 9 is not much meaningful because we collected few measures. By comparing results in Figure 7 and 8, it is possible to see that measurements tend to be closer (or even better) than path loss model as long as the CPE height is increasing.

From trial measurements we also discovered the following facts regarding WiMAX urban application in 3.5 GHz band.

- CPE antennas: high directional antennas (18 dBi) can only be used in LOS or near LOS links; in non LOS conditions it is also difficult to take advantage from low directional antennas (9.5 dBi) due to difficult antenna pointing; in several measurement this antenna is equivalent to a 5 dBi antenna.
- Using an OFDM symbol guard time of 1/16 it is not sufficient to counteract multipath channel distortion; most of measurement points revealed a reduction (3 – 7 dB) of the expected C/I ratio. It is suggested to use a 1/8 guard time in order to avoid a throughput reduction of about 20%.

6. WIMAX COVERAGE AND CAPACITY

Having verified Erceg propagation model in 3.5 GHz band, it is now possible to evaluate coverage and capacity performances of a WiMAX system according to our model described in section 3.
We have considered downlink system gain of the equipment used during this trial and described in Table 3 for downlink. It has to be noted that we assume to use a small CPE antenna with a little directivity (desktop antenna in Table 2).

Table 3: WiMAX system gain characteristics

Parameter	Value
Frequency band [GHz]	3.5
Channel spacing [MHz]	3.5
Output power [dBm]	35
BS antenna gain [dBi]	17
CPE antenna gain [dBi]	9
Receiver sensitivity @ BPSK [dBm]	-98.8
Feeder Losses [dB]	1
System gain [dB] =	158.8

For the evaluation of an average throughput we also used receiver sensitivity and capacity of 7 physical modes (combination of modulation and coding) described in Table 4. Moreover, net average throughput has been calculated from physical average throughput assuming a 75% MAC efficiency.

Table 4: WiMAX physical layer characteristics

Modulation	Coding Rate	Capacity [Mbits/s]	P_{rx} CPE [dBm]
BPSK	1/2	1.33	-98.8
QPSK	1/2	2.67	-94.8
QPSK	3/4	4.00	-92.1
16 QAM	1/2	5.33	-89.4
16 QAM	3/4	8.00	-86.0
64 QAM	2/3	10.67	-82.2
64 QAM	3/4	12.00	-80.6

Using system parameters described in Table 3 and 4 we have calculated system performances considering a fixed CPE installed:

- outdoor at 6 meters above ground; it could be a full outdoor CPE or an indoor CPE with an external antennas
- indoor at 6 meters above ground; it is the classical desktop CPE.

Results are reported in Figure 10 and 11 respectively for outdoor and indoor CPE.

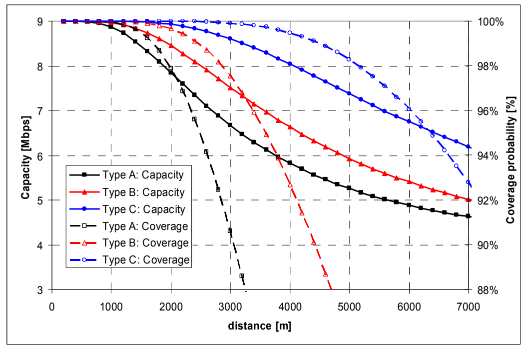

Fig. 10: Downlink net capacity and coverage probability for outdoor CPE

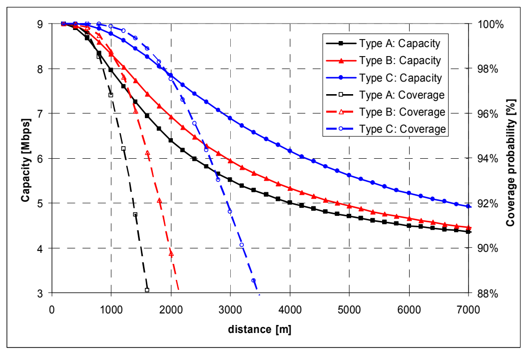

Fig. 11: Downlink net capacity and coverage probability for indoor CPE

In case of outdoor CPE', considering a coverage objective of 95%, it is possible to reach a distance (cell radius) of 2.4, 3.6 and 6.2 km for different terrain categories. Average net throughput per cell, considering also a MAC efficiency of 75%, is about 7 Mbit/s for Type A and B and it is slightly less (6.6 Mbit/s) for Type C. This means that a WiMAX system is capable to provide a net spectral efficiency of about 2 bit/s/Hz over the entire cell area.
In case of indoor CPE the coverage radius at 95% is reduced to 1.2, 1.5 and 2.5 km due to wall penetration extra path loss, while average net throughput is about 7.5 Mbit/s.
Comparing outdoor and indoor results it is possible to note that WiMAX system can provide high spectrum efficiency (similar average throughput per cell) in very different propagation scenarios, from rural (type C) outdoor CPE's down to dense urban (type A) indoor CPE's.

7. CONCLUSIONS

In this paper a new simplified model for WiMAX performances evaluation has been proposed. This model has been used for providing some coverage and capacity figures; these figures has been obtained using Erceg propagation model.

Erceg pathloss model in the 3.5 GHz band has been verified during a trial in Milan (Italy). Trial results in terms of propagation path loss model show that Erceg model can reasonably be used for performances assessment.

Simulation results show that a WiMAX system is capable to provide a high spectral efficiency (2 bit/s/Hz) over the entire cell area in very different propagation scenarios. Coverage radius is strictly dependent to propagation conditions (terrain categories, indoor/outdoor CPE). But, in all scenarios, an average net throughput of about 7 Mbit/s can be provided using 3.5 MHz radio channel.

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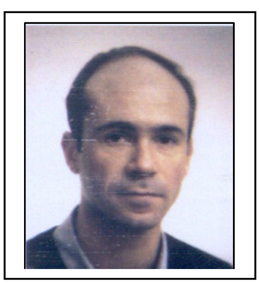
BIOGRAPHY



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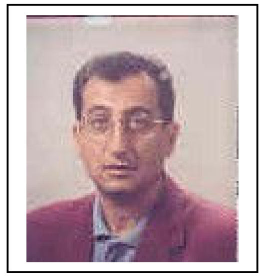

Bruno Cornaglia received the Degree in Electronic Engineering at “Politecnico di Torino” in 1990. He enjoyed CSELT, the research centre of Telecom Italia Group, in 1990. He was initially involved in millimetric radio relay links, both point-to-point and point-to-multipoint, and then in the introduction of Synchronous Digital Hierarchy (SDH). In 1994 he became Project Head of “Fixed Wireless Access” for studying and trialing new opportunities of using PMP networks for delivering basic services and new multimedia services. In the meantime he participated actively to various standardization bodies. In 1999 he enjoyed OMNITEL Pronto Italia SpA, now VODAFONE OMNITEL NV, a private cellular operator, where he became responsible of “Point-MultiPoint Project” in 2000 for the deployment of a PMP network at 26 GHz in the major urban areas in order to backhaul 2G and 3G sites. In the meantime he also became the coordinator for BWA technologies in the Vodafone Group. In June 2005 he became responsible of New Product Development for Access Transmission under the Global Network organization of Vodafone Group. The main goals were to develop the right technology access transmission strategy and to drive the vendors to implement the right access transmission strategy. In August 2006 he became responsible of “Fixed Mobile Convergence” Team in the Transmission Group under the Global Network. The main responsibility is to develop a common strategy in the transmission area for delivering fixed mobile convergence services and to drive the operational companies to implement it. He is author or co-author of about 20 papers.

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