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The Study of Radio Propagation Models for Urban Areas Prediction

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Abstract – The development of the mobile communications and the integrated services provided using the cellular networks has exploded in the last years, and the expansion keep an asceding slope, due to continuous request of new services on the mobile communications market. Although the radio cellular networks already exist, new technologies evolve, and that imply the usage of new frequncy bands and new propagation models to caracterise the propagation problems that can appear.

Keywords: prediction, propagation model, Longley-Rice

I. INTRODUCTION

The explosive growth of both the wireless industry and the Internet is creating a huge market opportunity for wireless data access. Until today, Internet access at very low speed is already available in the existing 2G cellular systems, but those systems are designed to provide voice services and short messaging, but not fast data transfers. Third-generation (3G) mobile wireless systems, currently under development is designed to provide, theoretically, user data rates as high as 2 Mbps, although the studies shown that approaching those rates might only be feasible in certain extremely favorable conditions.

The 3G services cannot be implemented on existing cellular networks because do not meet the extremely demanding requirements for providing high speed and mobile data. The new services must coexist (at least) a wile with the old ones, and that added with other spectrum requirements, go to the usage of higher frequency spectrum resources, like 2,5 GHz and 3,5 GHz bands. One problem related to the usage of these bands is that coverage estimation cannot be done with the existing propagation models [1]. The well known models, used for GSM coverage has the limitation to quantify the phenomenon that can appear at frequencies beyond 2 GHz.

This paper present a study related to prediction models in 3,5 GHz band used by a Wi-MAX network.

II. PROPAGATION MODELS

Propagation models are used extensively in network planning, particularly for conducting feasibility studies and during initial project and development. They are also very useful for performing interference studies as the deployment proceeds. These models can be broadly categorised into three types: empirical, deterministic and stochastic.

The deterministic models make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location. Deterministic models often require a complete 3-D map of the propagation environment. An example of a deterministic model is a ray-tracing model. All deterministic scenarios suppose the knowledge of a real of fictive digital terrain and the use of a deterministic propagation model. To study that type of scenario, simulation is the only available method. However, the spectrum management process efficiency cannot be estimated. The compromise between the accepted jamming probability and the spectrum need for a given telecommunication traffic cannot be optimise on a single run. This solution is expensive and time consuming, but in some applications can be a good compromise.

Stochastic models, on the other hand, model the environment as a series of random variables. These models are the least accurate but require the least information about the environment and use much less processing power to generate predictions. The real world is neither totally random nor deterministic. A parameter can be described as a random process only if its value is influenced by many independent inputs. This type

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of simulation is very difficult and needs to be carefully tested on generic cases. A drastic parameters number reduction is necessary for reduce simulation complexity and allow analysis of the results.

The empirical models are those based on observations and measurements alone. These models are mainly used to predict the path loss, but models that predict rain-fade and multipath have also been proposed. Empirical models can be split into two subcategories namely, time dispersive and non-time dispersive. The former type is designed to provide information relating to the time dispersive characteristics of the channel i.e., the multipath delay spread of the channel. An example of this type is the Stanford University Interim (SUI) channel models developed under the Institute of Electrical and Electronic Engineers. Examples of non-time dispersive empirical models are ITU-R, Hata and the COST-231 Hata model. All these models predict mean path loss as a function of various parameters, for example distance, antenna heights etc. [2]

The advantages of using this last type of propagation models are related to the simplicity of the implementation, the low cost and the low time requested to run the software that implement the model. The main disadvantage is that the model output data is a mean value for the attenuation, taking into account the terrain influences, the diffraction, etc. In the situations where the wave resulted by destructive recombination of multiple reflections or/and diffraction waves [3], the results of the measurements are far from the predicted attenuation, and the model usually give an optimistic prediction of the attenuation. The same situation appear when the cannoning effect is recorded in different points of the streets oriented radial towards the transmitter, but in this case the prediction is pessimistic.

III. THE PREMISES OF THE STUDY

The worldwide experience purchased in previous stages of mobile communication network development and signal coverage designs, shown that a complex model is not necessarily the most used or the best propagation model. For instance, although there appears to be a huge potential for improved prediction methods based on deterministic or semideterministic processes through the availability of improved databases of various kinds and the ready availability of small, powerful computers, the fact remains that the most used model for macrocells was *Okumura-Hata* model, with all its variations and improvements, despite its simplicity.

On the other hand, for propagation in built-up areas, another model used was *Walfisch - Bertoni* and *COST-Walfisch-Ikegami* model.

In this approach the density of the buildings, distance between the buildings and the angle of arrival relative to orientation of the street for the incident wave is taken into account (fig.1). The diffraction loss is calculated by numerical methods [4].

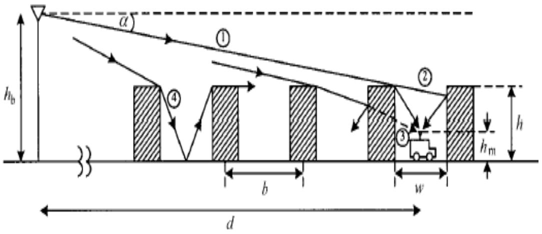

Fig. 1 Propagation scenario for built-up areas in Walfisch – Bertoni approach

Both *Okumura-Hata* and *Walfisch - Bertoni* models, unfortunately stops with expertise at 2000 MHz.

The interest for 2,5 GHz and 3,5 GHz increased lately and new methods for prediction are necessarily. Considering the previous studies of the authors related to propagation for broadcast service [5], like Longley-Rice model, the idea of testing this model for mobile services in the new trends was provocative.

The Longley-Rice model has the following input data [6]:

- carrier frequency ranges between 20 MHz and 40 GHz, but it is recommended the upper limit to be 20 GHz;
- distance: 1 km – 2000 km;
- antenna heights: 0,5 m – 3000 m;
- vertical or horizontal polarization.

Beside the mentioned parameters, the model uses:

- terrain irregularity parameter,
- electric ground constants,
- climatic region influences.
- surface refractivity.

The models, for point-to-point analysis take into account the relief between the transmitter and receiver extracted from a database. Also, the software that implement the model calculate the effective antenna heights above the ground and eventually the diffraction loss due to relief obstruction of the propagation path.

In addition, the model has three statistic variables by which, one can choose the confidence level for the estimation of propagation attenuation for the different conditions.

According to [7], from the original model, developed initially for broadcast propagation, subsequently has been added a supplementary correction, for prediction in urban areas. This urban factor (UF) has been derived comparing prediction from the original model with a curve given by Okumura, for urban areas:

$$UF[dB] = 16{,}5 + 15 \cdot \lg(f/_{100}) - 0{,}12d \qquad (1)$$

In the (1) formula, f is in megahertz and d is in kilometers.

IV. PRESENTATION OF THE EXPERIMENTAL DATA

The study started from a set of experimental data obtained from a measurement campaign deployed for signal coverage in 3,5 GHz band, in a metropolitan area. Due to privacy restriction of the project owner, the complete report with the location name and the coordinate of the measurements points cannot be displayed.

From the entire set of measurements, it was take a number of 37 measured points, around the base station (fig. 2). The measured value represents an average value of several measurements points, whose mutual distance was equal to 40 lambda (f = 3427 MHz). This operation is necessary to compensate the fast (Rayleigh) fading.

For every measurement point was added, beside the coordinates, distance from transmitter and the altitude above the sea information, the type of clutter of the area around the measured point, and was also established the average heights for every type of clutter (marked with different type of gray on the map in fig. 2).

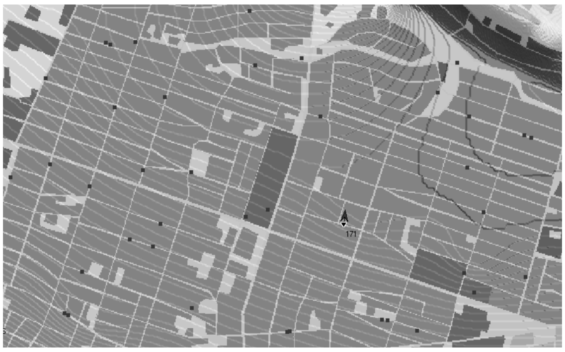

Fig. 2 The measurements points around the transmitter

In the coverage area, for this city, 4 types of clutter were described: parks, industrial-commercial, residential-low and open-in-urban.

Analyzing the (1) formula it is obvious that the correction for the urban environment loses is a function of two variables: frequency and distance, whatever type of clutter and building density exist around the estimation point. This is not necessarily a wrong approach (*Okumura-Hata* model is a good example), but loses the facilities of the latest mapping technology that in the past was something almost impossible.

Starting from these observations and inspiring from *Walfisch – Bertoni* model, it starts the idea of introducing a new urban correction to the Longley-Rice model. Having the digital terrain map, the Longley-Rice model calculates all the parameters related to ground influences.

Because the model give medium space attenuation, the new correction must have more generality in the characterization of the build-up area loses. Analyzing the propagation scenario, it can be seen that in a very large number of cities, the base station antenna being placed on a highest building in the neighborhood, and it is a large probability that, at street level, somewhere in the cell, to be only one knife-edge diffraction (fig. 3).

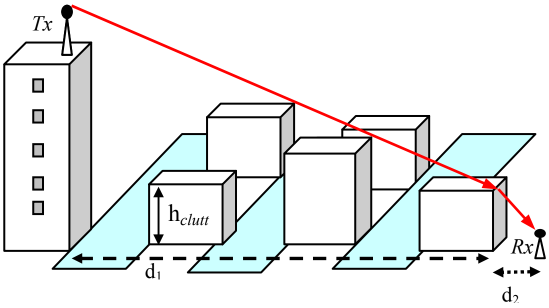

Fig.3 The propagation scenario for a medium city

The new correction coefficient keeps the frequency and distance as variables, but adds a new variable, the knife-edge diffraction loss.

For the calculus of the diffraction loss it needs to establish the distances from the diffraction point to receiver and transmitter. The distance from receiver to diffraction building was considered to be an average d_2 =10 m, for the case of the receiver placed at street level. The building penetration ray(s) or multiple reflections were not taken into account.

Generic mathematic formula for the correction is:

$$C = k_1 \cdot \lg(d) + k_2 \cdot L(\nu) + k_3 \cdot \lg(f) \qquad (2)$$

where:

d-distance from transmitter to receiver in meters;

$L(v)$ – diffraction loss in dB, calculated with Lee formulas, starting from Fresnel integral;

f – frequency in megahertz.

In the next step we establish the values for the weight coefficients k_1, k_2 and k_3. Starting from the measured values and the median attenuation predicted by Longley –Rice model, by quantify the differences between the predicted attenuation and the measured values, the resulted coefficients are presented in table 1:

Table 1 – the values of weight coefficients

k_1	k_2	k_3
8,628	-0,0166	2,6

The study results are presented in table 2 and the power diagrams, for the analyzed points are presented in fig. 4.

Table 2. The experimental results and the power calculated with Longley Rice model and the two corrections for the calibration set of measurements

Id	Clutter	Clutter Height (m)	Dist. (m)	M[dB]	A_LR [dB]	Pr_LR_UF [dB]	M- Pr_LR_UF [dB]	Pr_cor [dB]	M- Pr_cor [dB]
1	openinurban	10	741	-107	101.3	-117.22	10.22	-111.66	-4.66
2	openinurban	10	1363	-122	105.7	-121.56	-0.44	-118.34	3.66
3	openinurban	10	985	-118	103.6	-119.50	1.50	-115.03	2.97
4	openinurban	10	1254	-119	105.4	-121.27	2.27	-117.73	1.27
5	openinurban	10	1521	-116	106.5	-122.35	6.35	-119.55	-3.55
6	openinurban	10	772	-118	98.7	-114.65	-3.35	-109.21	8.79
7	openinurban	10	755	-110	100.2	-116.14	6.14	-110.63	-0.63
8	openinurban	10	1007	-122	103.5	-119.40	-2.60	-115.01	6.99
9	openinurban	10	767	-117	98.6	-114.55	-2.45	-109.09	7.91
10	openinurban	10	977	-120	103.3	-119.20	-0.80	-114.70	5.30
11	openinurban	10	745	-108	101.5	-117.42	9.42	-111.88	-3.88
12	openinurban	10	1509	-114	106.5	-122.35	8.35	-119.52	-5.52
13	openinurban	10	955	-115	104.4	-120.29	5.29	-115.71	-0.71
14	openinurban	10	1457	-122	106.8	-122.64	0.64	-119.69	2.31
15	parks	12	639	-107	101.7	-117.62	10.62	-111.48	-4.48
16	parks	12	677	-109	101.3	-117.23	8.23	-111.29	-2.29
17	parks	12	847	-107	103	-118.91	11.91	-113.83	-6.83
18	residlow	4	918	-104	102.5	-118.41	14.41	-113.82	-9.82
19	residlow	4	1085	-118	103.8	-119.69	1.69	-115.75	2.25
20	residlow	4	985	-112	102.9	-118.81	6.81	-114.48	-2.48
21	residlow	4	1358	-123	106.7	-122.54	-0.46	-119.49	3.51
22	residlow	4	969	-112	104	-119.89	7.89	-115.52	-3.52
23	residlow	4	713	-112	102.3	-118.22	6.22	-112.67	-0.67
24	residlow	4	1235	-115	106	-121.86	6.86	-118.43	-3.43
25	residlow	4	958	-120	101.9	-117.82	-2.18	-113.38	6.62
26	residlow	4	706	-115	97.2	-113.16	-1.84	-107.54	7.46
27	residlow	4	662	-102	99.8	-115.74	13.74	-109.89	-7.89
28	residlow	4	720	-117	97.5	-113.46	-3.54	-107.91	9.09
29	residlow	4	339	-106	97.9	-113.86	7.86	-105.49	0.51
30	residlow	4	1058	-110	103.2	-119.11	9.11	-115.05	-5.05
31	residlow	4	1230	-124	104.4	-120.28	-3.72	-116.82	7.18
32	residlow	4	1187	-116	105.4	-121.27	5.27	-117.68	-1.68
33	residlow	4	1337	-122	106.5	-122.35	0.35	-119.23	2.77
34	Induscom	9	779	-116	99.4	-115.35	-0.65	-109.96	6.04
35	Induscom	9	876	-111	100.5	-116.44	5.44	-111.50	-0.50
36	Induscom	9	377	-100	95	-110.98	10.98	-102.84	-2.84
37	induscom	9	492	-106	97.1	-113.06	7.06	-105.94	0.06

Table legend: openinurban – open space surounded by bulildings with an average height around 10 m;
residlow – residential area with houses, average height around 4m;
industcom – industrial/ commercial areas, average buildings around 9 m.

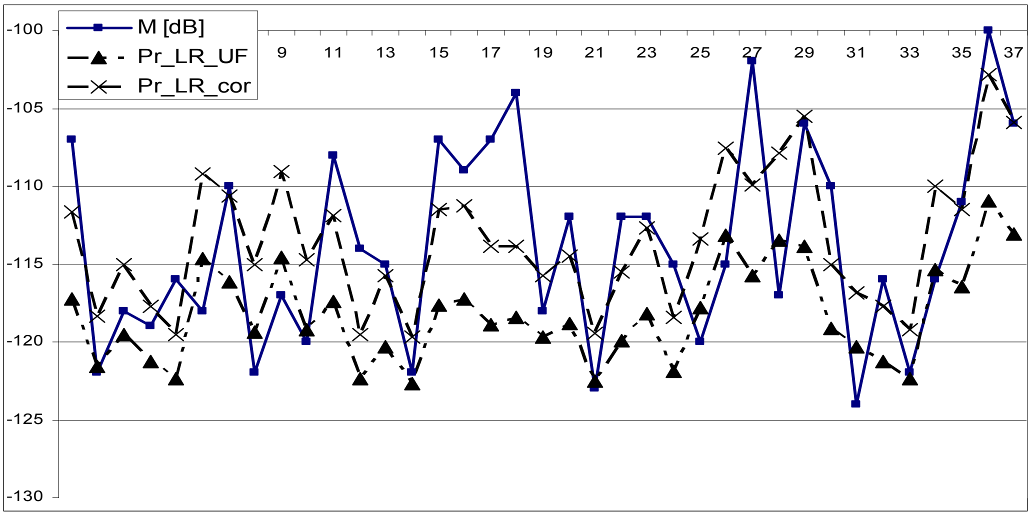

Fig. 4 Characteristics for the measured power and the predicted power with Longley-Rice + urban factor respectively with Longley-Rice + new correction

Diagram legend: M[dB] – power corresponding to measured points, in dB;
Pr_LR_UF – predicted power, in dB, using Longley-Rice model by adding UF;
Pr_LR_cor – predicted power, in dB, using Longley-Rice model by adding new correction.

Table 3. The experimental results and the power calculated with Longley Rice model and the two corrections for the testing set of measurements

Id	Clutter	Clutter Height (m)	Dist. (m)	M[dB]	A_LR [dB]	Pr_LR_UF [dB]	M- Pr_LR_UF [dB]	Pr_cor [dB]	M- Pr_cor [dB]
1	openinurban	10	284	-104	96,6	-113,09	9,09	-103,36	0,64
2	openinurban	10	944	-114	103,3	-119,71	5,71	-114,57	-0,57
3	openinurban	10	1.812	-121	108,4	-124,71	3,71	-122,11	-1,11
4	openinurban	10	1.084	-108	103,7	-120,09	12,09	-115,48	-7,48
5	openinurban	10	746	-106	102	-118,43	12,43	-112,38	-6,38
6	openinurban	10	1.005	-120	104,7	-121,10	1,10	-116,20	3,80
7	openinurban	10	1.418	-113	107,1	-123,45	10,45	-119,89	-6,89
8	openinurban	10	1.581	-123	107,2	-123,53	0,53	-120,40	2,60
9	openinurban	10	860	-110	100,2	-116,62	6,62	-111,12	-1,12
10	openinurban	10	807	-110	102,7	-119,13	9,13	-113,38	-3,38
11	openinurban	10	1.110	-118	102,9	-119,29	1,29	-114,77	3,23
12	openinurban	10	1.405	-112	107	-123,36	11,36	-119,76	-7,76
13	openinurban	10	464	-102	98,7	-115,17	13,17	-107,30	-5,30
14	parks	12	391	-106	98,6	-115,08	9,08	-106,53	-0,53
15	parks	12	553	-109	96,8	-113,26	4,26	-106,03	2,97
16	residlow	4	1.144	-132	103,9	-120,29	-11,71	-116,05	15,95
17	residlow	4	1.546	-117	106,9	-123,24	6,24	-120,17	-3,17
18	residlow	4	1.378	-110	106,2	-122,56	12,56	-119,04	-9,04
19	residlow	4	1.163	-118	104,9	-121,28	3,28	-117,11	0,89
20	residlow	4	1.213	-120	104,2	-120,58	0,58	-116,56	3,44
21	residlow	4	491	-103	96	-112,46	9,46	-104,97	-1,97
22	residlow	4	711	-120	100,7	-117,14	-2,86	-111,06	8,94
23	residlow	4	750	-111	99,5	-115,93	4,93	-110,06	0,94
24	residlow	4	1.151	-106	104,1	-120,49	14,49	-116,27	-10,27
25	residlow	4	1.031	-117	104,9	-121,30	4,30	-116,66	0,34
26	residlow	4	803	-112	103,2	-119,63	7,63	-114,02	-2,02
27	residlow	4	807	-117	102,9	-119,33	2,33	-113,74	3,26
28	residlow	4	1.424	-115	107	-123,35	8,35	-119,97	-4,97
29	residlow	4	727	-121	97,7	-114,14	-6,86	-108,15	12,85
30	residlow	4	1.044	-106	103	-119,40	13,40	-114,80	-8,80
31	residlow	4	400	-108	97,1	-113,58	5,58	-105,31	2,69
32	residlow	4	1.227	-115	104,8	-121,18	6,18	-117,21	-2,21
33	residlow	4	1.188	-109	110,2	-126,58	17,58	-122,49	-13,49
34	residlow	4	845	-118	100	-116,42	-1,58	-111,01	6,99
35	residlow	4	1.000	-118	104,7	-121,10	3,10	-116,34	1,66
36	residlow	4	1.781	-114	108,1	-124,41	10,41	-121,90	-7,90
37	residlow	4	1.259	-115	104,4	-120,77	5,77	-116,90	-1,90
38	residlow	4	1.333	-109	106,3	-122,66	13,66	-119,02	-10,02
39	residlow	4	512	-101	95,1	-111,56	10,56	-104,23	-3,23
40	residlow	4	466	-103	99,7	-116,17	13,17	-108,48	-5,48
41	residlow	4	831	-112	100,6	-117,02	5,02	-111,55	0,45
42	residlow	4	595	-102	100,1	-116,55	14,55	-109,80	-7,80
43	residlow	4	1.427	-118	107	-123,35	5,35	-119,97	-1,97
44	residlow	4	1.186	-121	105,8	-122,18	1,18	-118,08	2,92
45	residlow	4	870	-113	103,8	-120,22	7,22	-114,92	-1,92
46	residlow	4	849	-112	100,4	-116,82	4,82	-111,43	0,57

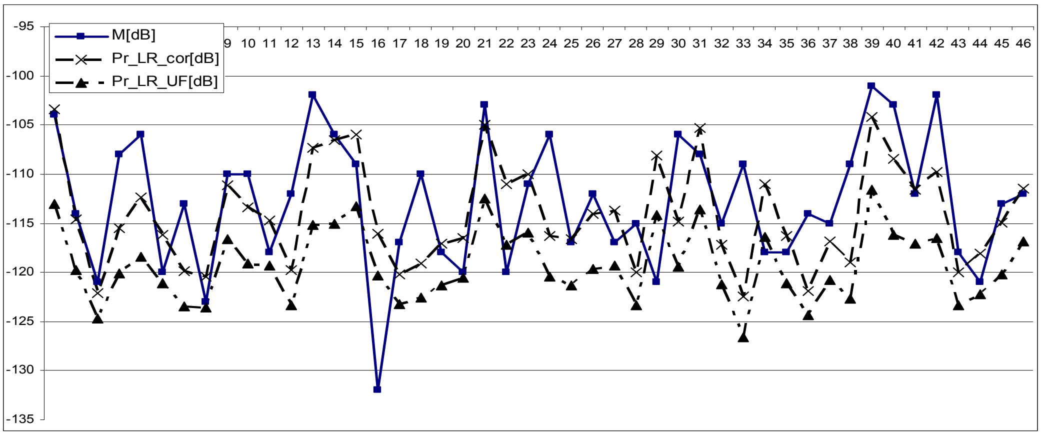

Fig. 5 Characteristics for the measured power and the predicted power with Longley-Rice urban factor respectively with Longley-Rice new correction for the testing points

The results presented in table 2 were used to determine the optimul value of the *k* coeficients of the correction. This stage, in coverage calculation practice, is called „calibration of the model”. For a confirmation of the correction eficency, a new set of measurements was considered (presented in table 3), named the „testing set of measurements”. The resulting diagrams are presented in the fig. 5.

For a statistics analysis of the study, it was calculated, for both sets of data, the mean error and the standard deviation (stdev). This statistics is presented in table 4 and 5.

Table 4 – Statistics for calibration data

Model	Mean error [dB]	Stdev [dB]
Longley-Rice+UF	4,39	5,30
Longley-Rice+C	0,38	5,04

Table 5 – Statisctics for testing data

Model	Mean error [dB]	Stdev [dB]
Longley-Rice+UF	6,49	5,84
Longley-Rice+C	-1,34	5,9

It can be seen that for the new corection, the mean error is smaller than for the UF corection. Also, the standard deviation have good values, being under 6 dB.

V. CONCLUSION

The study clearly show that the Longley-Rice model can be applied with good results for urban prediction. The UF correction have a good statistic but for the new corerection, by introducing a diffraction loss caracterization term, the results are better.

The new correction have some deficiences:

- prediction can be done only at the street level;
- don’t calculate the ray through the building;
- the vegetation it is not quantified;
- the correction was not tested to different frequencies.

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