ISBN 978-3-200-02328-4

APPLICABILITY EVALUATION OF OKUMURA, ERICSSON 9999 AND WINNER PROPAGATION MODELS FOR COVERAGE PLANNING IN 3.5 GHZ WIMAX SYSTEMS

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ABSTRACT

Within areas lacking appropriate or having no wire infrastructure at all, fixed WiMAX is recognized as a viable business solution for delivering broadband services to the end users. While in developing countries (like Bosnia and Herzegovina), such areas are widespread among suburban and rural topography, it is of great interest to provide preconditions for planning of these networks. In order to create preconditions for WiMAX planning, the most important problem that must be solved is its coverage prediction. The problem becomes more important considering the fact that, up to date, no globally verified tool for WiMAX coverage prediction is developed. With that in mind, within our research, some of existing empirical propagation models for WiMAX coverage planning are tested with respect to real measurement results conducted all over the world. Similar analysis, with proposed novel metric for models evaluation, is presented in authors' previous work [1], considering some of the most popular empirical propagation models, so far developed. However, in order to improve results obtained in [1], within this paper, additional set of empirical propagation model is tested, providing more general conclusion about the most appropriate empirical propagation model for 3.5 GHz WiMAX coverage planning.

Index Terms **-** fixed WiMAX, 3.5 GHz, empirical propagation models, path loss, radius estimation

1. INTRODUCTION

WiMAX (Worldwide Interoperability for Microwave Access) is recently developed telecommunications technology which enables wireless transmission of voice, video and data [2]. Although there are two versions of standard, fixed (defined within specification 802.16-2004) and mobile WiMAX, within this paper, only fixed WiMAX is considered. Fixed WiMAX is a wireless broadband technology which can serve fixed located users with high data rates (up to 75 Mbps) over large distances (up to 5 km in point-to-multipoint topology). It is able to provide broadband access solution for a wide number of users, without the need to lay down cable infrastructure. Accordingly, among different fixed broadband access solutions, fixed WiMAX is recognized as a viable business model where inappropriate or none wired access is available (especially in suburban and rural areas and within developing countries).

However, as with any new technology, there are many issues that affect the implementation and the utilization of WiMAX systems. Having in mind that WiMAX is a wireless technology, one of the most important issues is its coverage planning [3]. It must provide information about optimal number and positions of WiMAX base stations, necessary to cover specific area and provide satisfying quality of service.

The capability of determining optimal number of base stations and their locations, without deploying ray tracing models (which are very expensive and time consuming) can be achieved using empirical propagation models [4]. Several empirical propagation models are developed to date, but neither of them (according to authors' knowledge) is globally verified and recommended for use on 3.5 GHz.

There are many papers ([5] - [9] etc.) in which applicability of some existing propagation models for WiMAX on 3.5 GHz were evaluated. However, results and conclusions within these papers are restricted to specific locations (where related measurements are conducted) and are often contradictory. Therefore it is impossible to conclude which model is the most appropriate for WiMAX coverage planning in general.

Thus, within this paper, measurement results from [5] - [9] are gathered and the applicability of existing empirical propagation models are tested in respect to *all* independent signal strength measurements performed on different locations over the world. Based on shots from the air and photos of measurement areas, considered locations are first classified according to similarities of their topography (urban, suburban and rural). In regard to data sets within each topology type, models evaluations are done using radius prediction mean error - specifically developed metric for models evaluating, presented in authors previous paper [1], which allow as to choose the most accurate empirical propagation model for WiMAX coverage prediction in general.

Using developed metric, COST 231, Erceg, SUI, ECC-33 models accuracy (mainly treated for higher frequencies in [4] - [6]), are evaluated in [1]. Results showed that SUI-C models was the most appropriate for coverage planning in rural topographies, while ECC-33 and COST 231 (for medium cities) were the most appropriate for suburban and urban locations respectively. Even though these models are chosen among others as the most appropriate, their radius prediction mean errors were still very high.

In order to get more accurate prediction results, additional set of models are tested within this paper: Okumura and recently developed Ericsson 9999 and WINNER II models, since their validity for WiMAX coverage planning hasn't been tested upon larger set of data, so far. According to authors' knowledge, seven tested models make the largest models set tested for 3.5 GHz WiMAX up to date. Having in mind that all models are tested upon gathered set of independent and dislocated measurement results, this research gives us possibility to perform the most comprehensive conclusions about existing empirical propagation models applicability for 3.5 GHz WiMAX coverage planning.

Following the same methodology presented in [1], results in this paper show improvements compared to previously obtained results, which justify the idea of this paper. Accordingly, for rural location, radius coverage mean error is significantly reduced (using Okumura model) with respect to results obtained in [1]. For suburban locations, improvements are also made (using WINNER II model), while for urban location, previously chosen model [1] (COST 231) remains the best candidate for coverage area radius estimation.

This paper is organized as follows: after brief presentation of evaluation methodology in Section 2, collected WiMAX experimental results on 3.5 GHz are overviewed in Section 3. In Section 4, Okumura, Ericsson 9999 and WINNER II models are described, followed by the results of these models accuracy evaluation for radius prediction on 3.5 GHz in Section 5. Section 6 summarizes the results, providing guidelines for the most accurate WiMAX coverage planning on 3.5 GHz, using existing empirical propagation models.

2. EVALUATION METHODOLOGY

In order to find the most accurate existing empirical propagation model for WiMAX coverage planning within each topography type, it was necessary to develop a unique metric, which could be applied to real WiMAX signal strength measurement results collected. The metric needed, termed as radius prediction error, is described in details in authors' previously published paper [1]. It allows us to choose the most applicable empirical propagation model in general (for each topography type) - no matter how dislocated areas with similar topography characteristics, are.

Prior to presenting the evaluation metric, it is also important to explain coverage radius term and the significance of its accurate prediction in the process of wireless cellular systems coverage planning (as WiMAX itself).

In order to determine number of base stations in coverage planning process, coverage area for each base station first must be estimated. However, due its irregularity, real coverage area can not be analytically described. Common approach in literature is to approximate real irregular coverage area with circular shape, in which, a specific service is going to be available with given satisfying coverage area reliability. Therefore, the problem of coverage planning can be translated into a problem of determining circular area around each base station, or more precisely, its radius, placing accurate coverage radius prediction in to the focus of coverage planning.

Based on previously written, coverage radius can be defined as maximum circular boundary at which signal strength at least equals to receiver sensitivity (P_{min}), and can easily be determined as:

$$R = 10^{(Pt - A - Pmin - z\sigma)/B} \qquad (1)$$

where P_t is transmitter power, and A, B and σ (standard deviation of shadowing) are propagation parameters. Parameter z is related to given coverage area reliability and can be calculated using D. O. Reudink diagram and expression for well known cell edge reliability [1].

For given measurement scenario (which include defined values of P_{min} and P_t together with transmitter and receiver antenna highs and topography type), propagation parameters can be determined in two ways: extracting them from fields signal strength measurements or using empirical propagation models.

During fields trial measurements, signal strength samples vs. distance are collected. Based on these samples and considering lognormal distribution of shadowing, propagation parameters $A = A_{qe}$, $B = B_{qe}$, $\sigma = \sigma_{qe}$ - now termed as quasi experimental, can be estimated using linear regression and least square methodology [1]. While these parameters are estimated within reviewed papers [5] - [9] for specific WiMAX measurement scenarios, they are used as an input in this analysis. They allow us to calculate quasi experimental coverage radiuses $R = R_{qe}$ using (1), which can be considered as satisfactorily accurate real coverage area radius for each measurement scenario.

On the other hand, for each measurement scenario, propagation parameters can be evaluated using empirical propagation models. In these models, parameters $A = A_{model}$, $B = B_{model}$ are given in form of a function of transmitter and receiver heights, frequency and topography type, while modeled radiuses $R = R_{model}$ for each location can be calculated also using (1).

Accordingly, the applicability of each empirical propagation model for radius prediction can be evaluated using radius prediction error in respect to quasi experimental radius, for each location separately:

$$e_r = |(R_{qe} - R_{model})/R_{qe}| \qquad (2)$$

However, while this paper aims to find the most appropriate model in general, the smallest radius prediction mean error, in respect to all measurement scenarios which belong to the same topography type, is chosen as a relevant metric for models evaluation.

3. OVERVIEW ANALYSIS OF WIMAX EXPERIMENTAL RESULTS ON 3.5 GHZ

Following commonly used topography classification, considered measurement areas within [5] - [9] (for which appropriate quasi experimental propagation parameters are available) are classified as rural, suburban and urban, and treated separately. Classification is performed based on shots from the air and photos of measurement areas (looking at average building heights and average building density) and their topographical similarities.

Accordingly, examples of WiMAX measurement in typically rural environment are recognized within papers [5] (results for rural environment) and [6], having in mind that area with low density of buildings (not exceeding two floors) and rare vegetation can be considered as rural [10].

Measurement environments within residential areas with buildings usually less than four floors are classified as suburban in [4] and are recognized in papers [5] (results for suburban environment), [7] and [8].

Moreover, measurement environments described in [5] (results for urban environment) and [9] are treated as the same kind of urban environment, having in mind that within this analysis, just typical European urban zones of a medium size city are considered (while highly urban zones, like those in USA, are not considered).

Summarized measurement scenarios' descriptions and quasi experimental propagation parameters from these papers can be found in [1] (in form of appropriate mean path loss curves), while values of calculated quasi experimental radiuses for each scenario can be found in [11].

4. PRESENTATION OF TREATED EMPIRICAL PROPAGATION MODELS

In order to evaluate empirical propagation models accuracy for WiMAX coverage area prediction using (2), it is also necessary to calculate modeled radius for each scenario and each model individually. These radiuses can be calculated using (1) and existing functional dependencies of propagation parameters of antenna height and topography types given in these propagation models.

When it comes to empirical propagation model, the most treated empirical propagation models for WiMAX coverage planning are: COST231, Erceg, SUI and ECC-33 models. Their accuracy is tested in [1] in respect to same set of data overviewed in Section 3. However, in order to perform more general conclusions, analysis is within this paper extended with additional models: Okumura, Ericsson 9999 and WINNER II model which are briefly described below.

Okumura's model is an empirical model based on extensive measurements made in Japan at several frequencies within the range of 100 to 1920 MHz [12], although it is typically extrapolated up to 3 GHz [13] or up to 5 GHz [14]. Its propagation parameters can be expressed as:

$$A_{Okumura} = [32.45 + 20\log(f) + A_{mu} - G(h_t) - G(h_r) - G_{area}]$$
$$B_{okumura} = 20 \tag{3}$$

for frequency f in MHz and transmitter (h_t) and receiver heights (h_r) in m. The median attenuation relative to free space (A_{mu}) and additional correction factor (G_{area}) considering different types of terrain (suburban, quasi-open area and open area) can be obtained using appropriate set of curves given in [13] and [14]. Transmitter $G(h_t)$ and receiver $G(h_r)$ gain factors can be computed according to equations given in [13].

Ericsson model 9999 is Ericsson's implementation of Hata model. In that model, propagation parameters are given as [4], [10]:

$$A_{Ericsson} = [a_0 + a_2\log(h_t) - 3.2(\log(11.75h_r)^2 + 4.49\log(f) - 4.78(\log(f))^2]$$
$$B_{Ericsson} = [a_1 + a_3\log(h_t)] \tag{4}$$

Parameters a_0, a_1, a_2 and a_3 are constants and their default values within this model are: a_0 = 36.2, a_1 = 30.2, a_2 = –12 and a_3 = 0.1 [4], [10], for all terrain types.

Additionally, in this model, the modification of model parameters is possible according to propagation environment and they can be modified for better fitting for specific propagation conditions. Accordingly, in [15], as a result of experimental measurements obtained in Osjek, Croatia on 3.5 GHz, following values are obtained: a_0 = 36.2, a_1 = 20.7 for urban areas and a_0 = 26.2, a_1 = 20.7 for suburban and rural areas.

WINNER II model was developed by the group of authors within WINNER project, based on results of measurements carried out within WINNER, as well as results from the open literature. Model can be used for frequency range (2 to 6 GHz), and the number of scenarios (e.g. different indoor scenarios, micro-cell scenarios, macro-cell scenarios etc.) [16]. Among 17 different scenarios, D1, C1 and C2 are chosen for WiMAX coverage planning within this paper. Assuming distance between transmitter and receiver in m and frequency in GHz, propagation parameters are within WINNER II model [16], given in Table I.

Accordingly, for each measurement scenario described in Section 3, modeled propagation parameters of Okumura ($A_{model} = A_{Okumura}$ and $B_{model} = B_{Okumura}$), Ericsson ($A_{model} = A_{Ericsson}$ and $B_{model} = B_{Ericsson}$) and WINNER II ($A_{model} = A_{WINNER}$ and $B_{model} = B_{WINNER}$) models are calculated using (3), (4) and equations from Table I respectively. Modeled radiuses are then estimated using (1). That allows us to calculate radius prediction mean errors for each model, as an average value of radius prediction errors of individual measurement scenarios belonging to the same topography type.

TABLE I. WINNER II model

LOS D1	$A_{WINNER} = 44.2 + 20\log(f/5)$ $B_{WINNER} = 21.5$	$10\text{ m} < d < d_{bp}$
	$A_{WINNER} = 10.5 - 18.5\log(h_t) - 18.5\log(h_r) - 1.5\log(f/5)$ $B_{WINNER} = 40$	$d_{bp} < d < 10\text{ km}$
NLOS D1	$A_{WINNER} = 55.4 + 0.26(h_t - 25) - 0.9(hr - 1.5) + 21.3\log(f/5)$ $B_{WINNER} = 25.1 - 0.13(h_t - 25)$	$50\text{ m} < d < 5\text{ km}$
LOS C1	$A_{WINNER} = 41.2 + 20\log(f/5)$ $B_{WINNER} = 23.8$	$30\text{ m} < d < d_{bp}$
	$A_{WINNER} = 11.65 - 16.2\log(h_t) - 16.23\log(h_r) + 3.8\log(f/5)$ $B_{WINNER} = 40$	$d_{bp} < d < 5\text{ km}$
NLOS C1	$A_{WINNER} = 31.46 + 5.83\log(h_t) + 23\log(f/5)$ $B_{WINNER} = 44.9 - 6.55\log(h_t)$	$50\text{ m} < d < 5\text{ km}$
LOS C2	$A_{WINNER} = 39 + 20\log(f/5)$ $B_{WINNER} = 26$	$10\text{ m} < d < d_{bp1}$
	$A_{WINNER} = 13.47 - 14\log(h_t) - 14\log(h_r) + 6\log(f/5)$ $B_{WINNER} = 40$	$d_{bp1} < d < 5\text{ km}$
NLOS C2	$A_{WINNER} = 34.46 + 5.83\log(h_t) + 23\log(f/5)$ $B_{WINNER} = 44.9 - 6.55\log(h_t)$	$50\text{ m} < d < 5\text{ km}$

5. TESTING RESULTS

Rural locations: According to methodology presented in Section 2, applicability of Okumura open and quasi-open model, Ericsson rural (default and modified) and WINNER II D1 (LOS and NLOS) models are tested in respect to experimental results for locations classified as rural in Section 3. Averaged test results for all treated rural location (in terms of radius prediction mean error), considering receiver sensitivity P_{min} = -87 dBm, transmitter power P_t = 40 dBm and coverage are probability of 90%, are summarized in Figure 1.

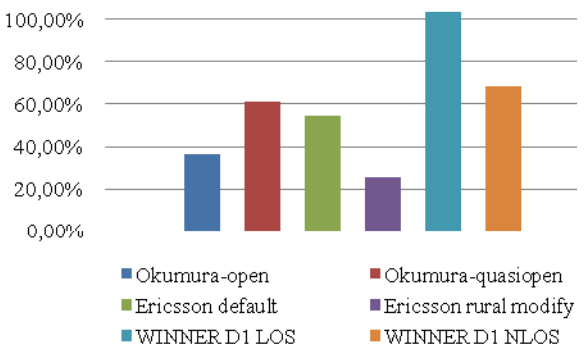

Fig. 1. Radius prediction mean errors for rural locations

According to Figure 1, both Okumura and Ericsson models give improvements with regards to results obtained in [1] (delegating SUI-C model with radius prediction mean error equals to 55% as the most accurate one), while WINNER II model seems to be inappropriate for radius estimation for WiMAX on 3.5 GHz. Among all tested models, the most appropriate is Ericsson modified model, with the smallest radius prediction mean error equals to 26%.

Suburban locations: In respect to quasi experimental results for suburban topography type presented within Section 3, Okumura suburban and urban, Ericsson suburban (default and modify) and WINNER II C1 (LOS and NLOS) models are tested. The results, showing the most appropriate model type within each of them, are given in Figure 2.

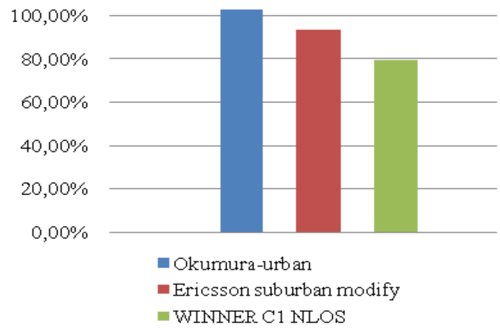

Fig. 2. Radius prediction mean errors for suburban locations

In respect to Figure 2, the most appropriate model for radius estimation within suburban locations is WINNER II C1 NLOS model, giving mean prediction error equals to 80%. While this value is also smaller then the value obtained using ECC-33 model (which equals to 83% and which is delegated as the most appropriate model for suburban coverage planning in [1]), WINNER II C1 NLOS model can be delegated as the most appropriate for WiMAX coverage planning in suburban locations among all tested models.

Urban locations: Within urban locations, Okumura urban model gives the most accurate radius prediction among other Okumura model types, having mean prediction error of 84%.

Default Ericsson models largely underestimate coverage area radiuses within urban location, while its modified urban version gives mean radius prediction error equal to 78%.

Among models tested within this paper, the most accurate results within urban topographies are obtained using WINNER II NLOS model, with the error of 74%.

However, for urban locations, previously tested COST 231 model for medium cities in [1] gives radius prediction mean error less than 60%, which delegate this model as the most accurate for WiMAX coverage planning in urban locations.

6. CONCLUSION

While accurate estimation of coverage area radius is recognized as one of the major task during WiMAX system planning, ability of accurate cell radius prediction is recognized as a valid metric for empirical propagation models evaluation. In order to find the most appropriate existing empirical propagation model for WiMAX radius prediction, in our previous analysis [1] COST 231, Erceg, SUI and ECC-33 models are tested. However, in order to obtain more general results, within this paper, additional empirical propagation models (Okumura, Ericsson 9999 and WINNER II) are tested which makes this research very comprehensive. All these models are tested in respect to real WiMAX measurement results collected from different reviewed papers, which additionally increase the generality of conducted conclusions.

Accordingly, among seven tested models and their different types, following conclusions can be obtained: the most accurate 3.5 GHz WiMAX coverage planning can be obtained using Ericsson rural modify model for rural, WINNER II NLOS model for suburban and COST 231 (for medium sized cities) for urban locations.

In the absence of any other solution, these models can be used for WiMAX coverage planning, while they give the most accurate results among many tested existing empirical propagation models. However, this research showed that, due to high prediction error, existing empirical propagation models are not accurate enough for 3.5 GHz WiMAX coverage planning. That makes useless commonly used practice of models evaluation on specific isolated topography, within further similar researches, and emphasizes the necessity for development of dedicated empirical propagation models for WiMAX on 3.5 GHz.

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