Validation of Empirical Radiowave Propagation Models for Diagnostics of Intrasystem EMC and Electromagnetic Safety of Microcellular Radio Networks

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***Abstract*—At mass coverage of populous urban areas by wireless communications services the microcellular structure of cellular radio networks and tendency of further reduction of its sites are occur. However, the widely used empirical radio wave propagation models (Okumura-Hata, COST231-Hata, COST231-Walfish-Ikegami, Lee, etc.), as a rule, are defined for propagation on distances between mobile and base stations not less than 1 km. Under these conditions at few hundred meters of microcells' dimensions specific for such urban-area networks, the use of these models for intrasystem EMC diagnostics and electromagnetic safety analysis of microcellular radio networks must be extra validated. In this paper the analysis of applicability of empirical models for diagnostics of intrasystem EMC and electromagnetic safety of microcell's structure of urban area cellular networks at cell radius less than 1 km is performed. This analysis is executed with the use of three-dimensional multibeam radio wave propagation model (X3D model) and 3D model of typical urban area covered by 2-6 floors buildings of 6-20 m height. As a criterion of estimation of compliance of models parameters the "Mean difference", "Mean error", "Standard deviation" and "Root mean square error" are used. As a result the conclusion concerned the applicability of the known empirical models of UHF radio wave propagation in urban area of the considered type at diagnostics of intrasystem EMC and electromagnetic safety of microcellular radio networks is given. For these models the range of values of base stations antenna height over terrestrial surface is defined, at which the smallest differences between estimations of radio wave attenuation in microcells at usage of empirical models and X3D model at specified conditions, is observed, and also possibilities of its usage at distances less than 1 km and at extended frequency ranges are discussed.**

Keywords*—*Intrasystem EMC; cellular communications; base stations; electromagnetic safety; radio wave propagation models

I. INTRODUCTION

Nowadays because of mass coverage of populous urban areas by wireless communications services, which is accompanied by increasing of terrestrial density of mobile stations (MS) on urban area and base stations (BS) for its servicing, the tendency of reducing of cells dimensions of cellular communications up to sizes in some hundred meters is observed. Taking into account this circumstance, the question about electromagnetic safety of cellular communications for the population, intrasystem electromagnetic compatibility (EMC) (levels of intrasystem interference at estimation of quality of service) and electromagnetic ecology of environment in these conditions are of the great interest. Carrying out mentioned researches is related to usage of models of radio wave propagation (RWP) between BS and MS for definition of levels of useful signal and intranetwork interference. However, the widely used empirical models of RWP, as a rule, are defined for distances between BS and MS not less than 1 km and for a limited frequency band. Therefore, for small cells sizes, specific for urban cellular communications with microcellular structure, possibility of application of empirical models for diagnostics of intrasystem EMC and analysis of electromagnetic safety of cellular radio networks must be extra validated.

Earlier in papers [1-6] attempts to optimize and extend the range of definition of a number of the most suitable empirical models of RWP were undertaken, adding in them the correction factor for more objective estimation of levels of attenuation at RWP on distance less than 1 km between BS and MS for different terrain types and for different standards of wireless communications. Therefore, these results can be recognized adequate only for those terrain types, on which measurements were performed.

The goal of this paper is estimation of applicability of the known empirical models of RWP for diagnostics of intrasystem EMC and analysis of electromagnetic safety of cellular networks with microcellular structure on typical urban area, specific for many cities of Eastern Europe.

For this goal the simulation of conditions of RWP on distance less than 1 km with usage of three-dimensional algorithm of RWP of X3D [7] and three-dimensional model of part of typical urban area with buildings of 6-20 m height at MS allocation at urban area out of buildings (outdoor), and also comparison of estimations of levels of signal, obtained by

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usage of the empirical models and the model of X3D, are executed.

II. Initial Models and Data

Models and initial data used at behavior simulation of conditions of RWP are given below.

A. RWP Model for urban (city) area

The three-dimensional model of X3D [7] of multipath RWP on urban area is used. It is based on usage of three-dimensional SBR (Shooting and Bouncing Ray) algorithm, used for determination of paths of RWP rays from BS to MS in three-dimensional space. Model has no restrictions on usage in the accepted conditions. The parameters of the three-dimensional RWP model are the following: an amount of reflections of each ray - up to 6, an amount of points of diffractions - no more than 1, a corner between two adjacent rays which are starting from one BS - 0.25 degrees, an amount of rays which are starting from one BS - up to 10.

B. Model of urban area.

The topographical computer model of a fragment of city housing of a central part of Minsk is used (Fig.1).

The following characteristics of model are accepted at analysis performance:

1) The considered fragment of urban area conforms to the territory type of “urban high-rise” [8].

2) Buildings height is mainly 6-20 m (2-6 floors).

Fig. 1. Model of a fragment of city housing of a central part of Minsk with one BS (Tx1) and MS (Rx1-RxN)

3) The earth surface of the considered fragment of urban area is mainly flat, therefore it is accepted as flat at the simulation.

4) Type of a covering of an earth surface – asphalt.

5) The scenario of simulation of conditions of RWP with usage of X3D model with allocated one BS Tx1 with different heights of its antenna and coordinates of placement, and set of MS Rx”N” (N=1,…,200) with step of 5 m along with linear traces with different angle of azimuth relative to BS with beginning in the point, which coordinates coincide with coordinates of point of BS Tx1 placement (Fig. 1), on considered fragment of urban area, is used.

6) The simulation of conditions of RWP is executed for distances beetween BS and MS of 0,1…1 km. Such distances conform to the cell radius type of “micro-cell” [8].

C. Empirical RWP models

The analysis is executed for the following known empirical models of RWP:

1) Okumura-Hata model [9]. It is defined for the frequency range of 500…1500 MHz and distances between BS and MS of 1…20 km for BS antenna heigth of 30…200 m and MS antenna height of 1…10 m.

2) COST231-Hata model [10]. It is defined for the frequency range of 1500…2000 MHz and distances between BS and MS of 1…20 km for BS antenna heigth of 30…200 m and MS antenna height of 1…10 m.

3) COST231-Walfish-Ikegami model [10]. It is defined for the frequency range of 800…2000 MHz and distances between BS and MS of 0.2…5 km for BS antenna heigth of 4…50 m and and MS antenna height of 1…3 m, and also takes into account the parameters of urban area (building height, street width, etc.). At usage of this model the height of buildings is accepted maximal (equal to 20 m).

4) Lee model [11]. It is defined for frequency 900 MHz and distances between BS and MS from 1 km. The model includes a frequency adjustment factor that can be used to increase the frequency range analitically.

5) Ibrahim and Parsons model [12]. It is defined for the frequency range of 150…1000 MHz and distances between BS and MS less than 10 km for BS antenna heigth of 30…300 m and MS antenna height less than 3 m.

6) Ericsson model [13]. It is defined for the frequency range of 150…1500 MHz and distances between BS and MS from 1 km.

D. RWP models for microcell.

Models of RWP for microcell:

1) Optimized COST231-Hata model [14]. It is based on measurements of levels of signal on distance between BS and MS less than 1 km on urban area and utilizing COST231-Hata model. Model for microcell is developed and optimized using particle swarm optimization algorithm, and validated for distances between BS and MS of 0.1…1 km and frequency of 1800 MHz.

2) Model of RWP for microcell [15]. It is developed using multiple regression analysis for measured levels of signal in an urban area of different cities on distances between BS and MS less than 1 km and for range of frequency of 400…8000 MHz at BS antenna heights of 30…120 m and MS antenna height of 1.5 m.

E. The system parametres of simulation.

1) The analysis is performed for BS with frequency of signal of 1800 MHz.

2) Equivalent isotropic radiated power of BS antenna is 43 dBm.

3) Type of BS and MS antenna is accepted as isotropic.

4) MS antenna height is H_{ms} = 2.0 m at comparison of results of estimation of signal levels, obtained with usage of empirical models and the model of X3D, H_{ms} = 1.5 m at comparison of results of estimation of signal levels, obtained with usage of empirical models and models of RWP for microcell.

5) BS antenna height is H_{bs} = 30…50 m.

III. THE RESULTS OF BEHAVIOUR SIMULATION AND DISCUSSION

A. Comparison of empirical models and the model of X3D

In Fig. 2-4 the examples of distribution of values of signal attenuation, obtained with usage of multibeam model of X3D (these values are designated in gray color) at various BS antenna heights are shown. The corresponding calculated curves of dependences of signal attenuation at propagation between BS and MS with usage of the listed above empirical models are given on the same figures.

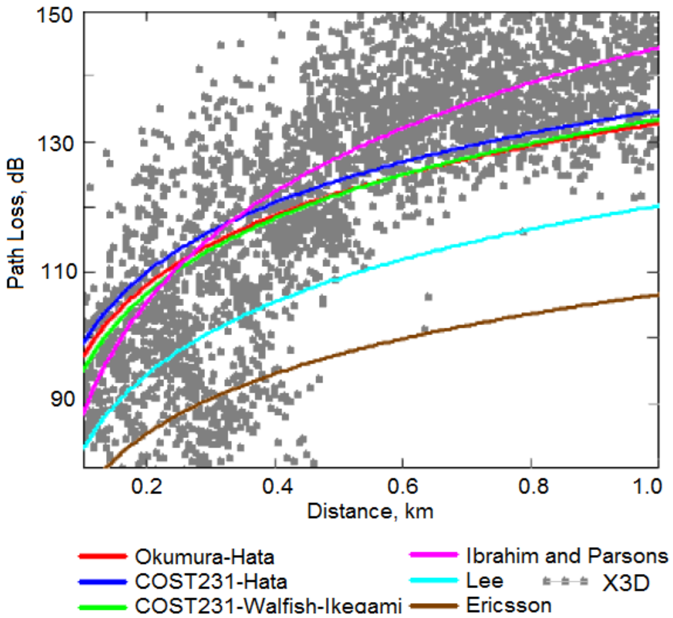

Fig. 2. The example of distribution of values of signal attenuation obtained with usage of 3XD model at BS antenna height H_{bs} = 30 m

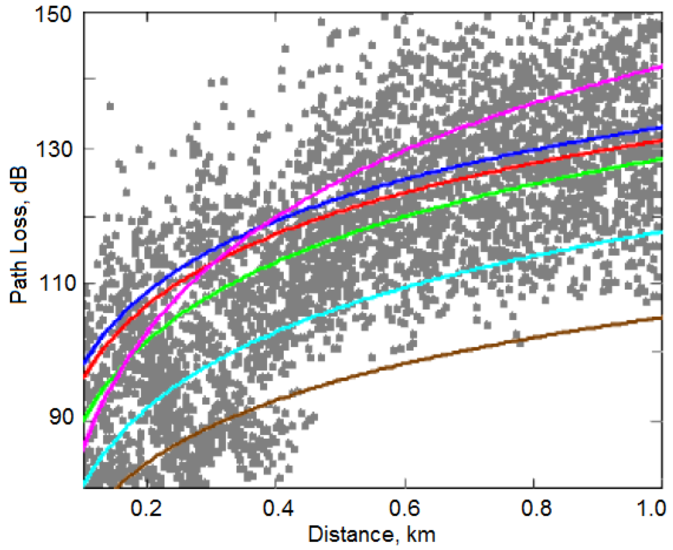

Fig. 3. The example of distribution of values of signal attenuation obtained with usage of 3XD model at BS antenna height H_{bs} = 40 m

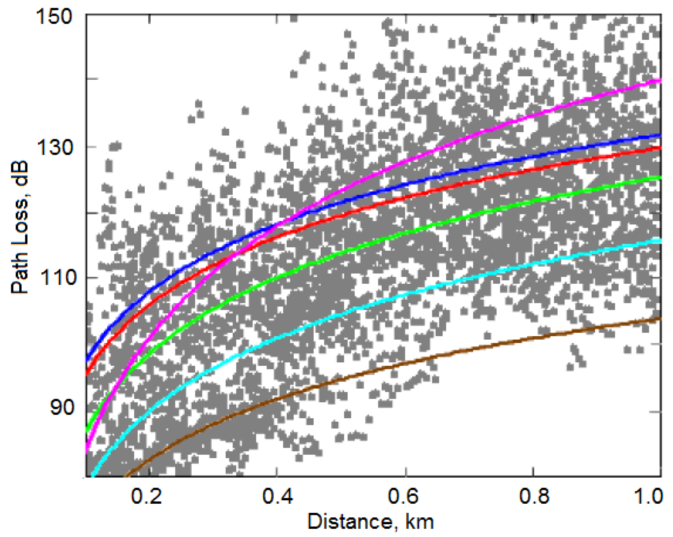

Fig. 4. The example of distribution of values of signal attenuation obtained with usage of 3XD model at BS antenna height H_{bs} = 50 m

Below in Fig. 5-7 dependence of signal attenuation from distance between BS and MS at various BS antenna heights is shown. The Okumura-Hata, COST231-Hata, Lee, Ericsson, Ibrahim and Parsons empirical models are used at the parameters, which do not belong to the range of definition of these models (frequency, distance between BS and MS). Points of black color on graphs in Fig. 5a-7a correspond to an arithmetic mean of values of signal attenuation, obtained using X3D model, and thin lines of black color correspond to the sum of an arithmetic mean and a root mean square deviation of an arithmetic mean. Points of black color on graphs in Fig. 5b-7b correspond to median values of signal attenuation, obtained using X3D model, and thin lines of black color correspond to the first and the third quartiles of distribution of values of signal attenuation. The field of graphs is conditionally divided into sections A, B and C, corresponding to the ranges of distances between BS and MS: D_A = 0.1…0.4 km, D_B = 0.4…0.7 km, D_C = 0.7…1 km.

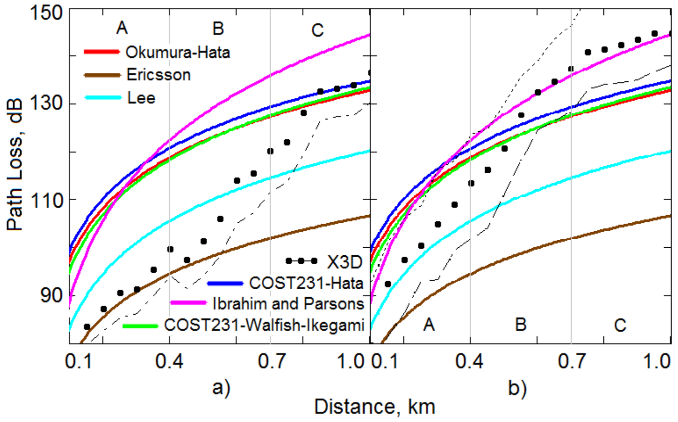

Fig. 5. Dependence of values of signal attenuation from distance between BS and MS at usage of empirical models of RWP and the model of X3D at BS antenna height H_{bs} = 30 m

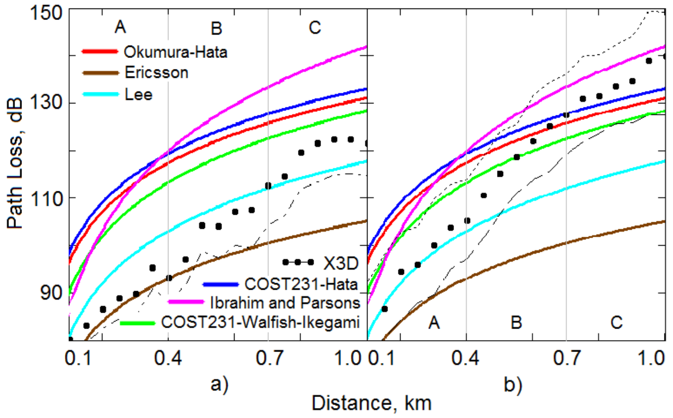

Fig. 6. Dependence of values of signal attenuation from distance between BS and MS at usage of empirical models of RWP and the model of X3D at BS antenna height H_{bs} = 40 m

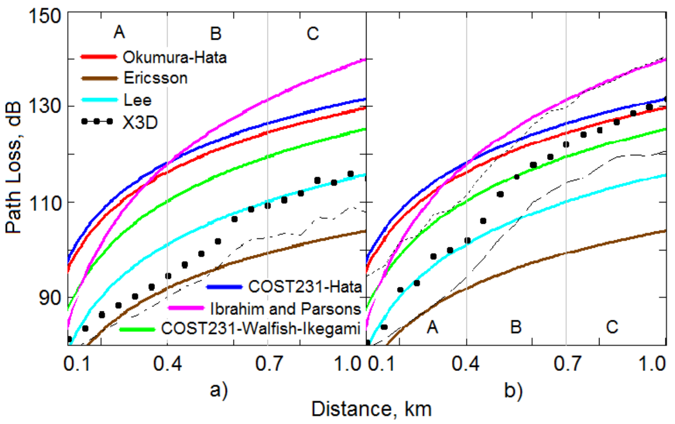

Fig. 7. Dependence of values of signal attenuation from distance between BS and MS at usage of empirical models of RWP and the model of X3D at BS antenna height H_{bs} = 50 m

In Tables 1-3 the results of calculation of the parameters: Mean Error (*ME*), Error's Standard Deviation (*ESD*), Root Mean Square Error (*RMSE*) in watts, which are criteria at comparison of results of estimation of signal levels, obtained with usage of empirical models of RWP and the model of X3D at various BS antenna heights are given below. The calculating formulae of these parameters are the following [1]:

$$ME = \frac{1}{M}\sum_{i=1}^{M}\left|y_i - \hat{y}_i\right| \qquad (1)$$

$$ESD = \sqrt{\frac{1}{M}\sum_{i=1}^{M}\left(\left|y_i - \hat{y}_i\right| - ME\right)^2} \qquad (2)$$

$$RMSE = \sqrt{\frac{1}{M}\sum_{i=1}^{M}\left|y_i - \hat{y}_i\right|^2} \qquad (3)$$

where y_i is level of signal, obtained with usage of empirical models of RWP, W; $\hat{y}_i$ is level of signal, obtained with usage of X3D model, W; M is number of MS placement on certain distance between BS and MS.

TABLE I. RESULTS OF CALCULATION OF *ME*, *ESD* AND *RMSE* AT COMPARISON OF SIGNAL LEVELS, OBTAINED WITH USAGE OF EMPIRICAL MODELS AND X3D MODEL AT BS ANTENNA HEIGHT H_{BS} = 30 M

d, km	*ME*, W	*SDE*, W	*RMSE*, W	*ME*, W	*SDE*, W	*RMSE*, W
	Okumura-Hata model			COST231-Hata model		
0.1	$1.1\cdot10^{-7}$	$1.5\cdot10^{-7}$	$1.9\cdot10^{-7}$	$1.1\cdot10^{-7}$	$1.5\cdot10^{-7}$	$1.9\cdot10^{-7}$
0.4	$1.7\cdot10^{-9}$	$5.1\cdot10^{-9}$	$5.4\cdot10^{-9}$	$1.7\cdot10^{-9}$	$5.1\cdot10^{-9}$	$5.4\cdot10^{-9}$
0.7	$1.2\cdot10^{-11}$	$5.8\cdot10^{-11}$	$5.9\cdot10^{-11}$	$1.1\cdot10^{-11}$	$5.8\cdot10^{-11}$	$5.9\cdot10^{-11}$
1.0	$9.3\cdot10^{-13}$	$2.1\cdot10^{-13}$	$9.6\cdot10^{-13}$	$5.7\cdot10^{-13}$	$1.6\cdot10^{-13}$	$5.9\cdot10^{-13}$
	COST231-Walfish-Ikegami model			Lee model		
0.1	$1.1\cdot10^{-7}$	$1.5\cdot10^{-7}$	$1.9\cdot10^{-7}$	$1.2\cdot10^{-7}$	$1.0\cdot10^{-7}$	$1.6\cdot10^{-7}$
0.4	$1.7\cdot10^{-9}$	$5.1\cdot10^{-9}$	$5.4\cdot10^{-9}$	$1.9\cdot10^{-9}$	$4.9\cdot10^{-9}$	$5.3\cdot10^{-9}$
0.7	$1.2\cdot10^{-11}$	$5.8\cdot10^{-11}$	$5.9\cdot10^{-10}$	$7.2\cdot10^{-11}$	$4.4\cdot10^{-11}$	$8.4\cdot10^{-11}$
1.0	$7.9\cdot10^{-13}$	$3.6\cdot10^{-13}$	$8.2\cdot10^{-13}$	$1.9\cdot10^{-11}$	$2.1\cdot10^{-13}$	$1.9\cdot10^{-11}$
	Ibrahim and Parsons model			Ericsson model		
0.1	$1.0\cdot10^{-7}$	$1.4\cdot10^{-7}$	$1.8\cdot10^{-7}$	$3.7\cdot10^{-7}$	$1.3\cdot10^{-7}$	$3.9\cdot10^{-7}$
0.4	$1.7\cdot10^{-9}$	$5.1\cdot10^{-9}$	$5.4\cdot10^{-7}$	$6.8\cdot10^{-9}$	$2.9\cdot10^{-9}$	$7.4\cdot10^{-9}$
0.7	$1.2\cdot10^{-11}$	$7.3\cdot10^{-11}$	$6.0\cdot10^{-11}$	$1.3\cdot10^{-9}$	$5.9\cdot10^{-11}$	$1.3\cdot10^{-9}$
1.0	$1.2\cdot10^{-13}$	$1.7\cdot10^{-13}$	$2.1\cdot10^{-13}$	$4.3\cdot10^{-10}$	$2.1\cdot10^{-13}$	$4.3\cdot10^{-10}$

TABLE II. RESULTS OF CALCULATION OF *ME*, *ESD* AND *RMSE* AT COMPARISON OF SIGNAL LEVELS, OBTAINED WITH USAGE OF EMPIRICAL MODELS AND X3D MODEL AT BS ANTENNA HEIGHT H_{BS} = 40 M

d, km	*ME*, W	*SDE*, W	*RMSE*, W	*ME*, W	*SDE*, W	*RMSE*, W
	Okumura-Hata model			COST231-Hata model		
0.1	$1.2\cdot10^{-7}$	$1.2\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.2\cdot10^{-7}$	$1.2\cdot10^{-7}$	$1.7\cdot10^{-7}$
0.4	$4.0\cdot10^{-9}$	$1.0\cdot10^{-8}$	$1.1\cdot10^{-8}$	$4.0\cdot10^{-9}$	$1.0\cdot10^{-8}$	$1.1\cdot10^{-8}$
0.7	$9.8\cdot10^{-11}$	$3.8\cdot10^{-10}$	$4.0\cdot10^{-10}$	$9.7\cdot10^{-11}$	$3.9\cdot10^{-10}$	$4.0\cdot10^{-10}$
1.0	$5.2\cdot10^{-12}$	$1.9\cdot10^{-11}$	$2.0\cdot10^{-11}$	$4.7\cdot10^{-12}$	$1.9\cdot10^{-11}$	$2.0\cdot10^{-11}$
	COST231-Walfish-Ikegami model			Lee model		
0.1	$1.2\cdot10^{-7}$	$1.1\cdot10^{-7}$	$1.6\cdot10^{-7}$	$1.1\cdot10^{-7}$	$5.8\cdot10^{-8}$	$1.3\cdot10^{-7}$
0.4	$4.0\cdot10^{-9}$	$1.0\cdot10^{-8}$	$1.1\cdot10^{-8}$	$4.3\cdot10^{-9}$	$1.0\cdot10^{-8}$	$1.1\cdot10^{-8}$
0.7	$1.0\cdot10^{-10}$	$3.9\cdot10^{-10}$	$4.0\cdot10^{-10}$	$1.9\cdot10^{-10}$	$3.4\cdot10^{-10}$	$3.9\cdot10^{-10}$
1.0	$6.2\cdot10^{-12}$	$1.9\cdot10^{-11}$	$2.0\cdot10^{-11}$	$3.4\cdot10^{-11}$	$9.9\cdot10^{-12}$	$3.5\cdot10^{-11}$
	Ibrahim and Parsons model			Ericsson model		
0.1	$1.2\cdot10^{-7}$	$9.0\cdot10^{-8}$	$1.5\cdot10^{-7}$	$5.4\cdot10^{-7}$	$1.2\cdot10^{-7}$	$5.5\cdot10^{-7}$
0.4	$4.0\cdot10^{-9}$	$1.0\cdot10^{-8}$	$1.1\cdot10^{-8}$	$1.1\cdot10^{-8}$	$5.5\cdot10^{-9}$	$1.2\cdot10^{-8}$
0.7	$2.1\cdot10^{-10}$	$3.9\cdot10^{-10}$	$4.0\cdot10^{-10}$	$1.7\cdot10^{-9}$	$2.4\cdot10^{-10}$	$1.7\cdot10^{-9}$
1.0	$4.2\cdot10^{-12}$	$2.0\cdot10^{-11}$	$2.0\cdot10^{-11}$	$6.0\cdot10^{-10}$	$2.0\cdot10^{-11}$	$6.1\cdot10^{-10}$

TABLE III. RESULTS OF CALCULATION OF *ME*, *ESD* AND *RMSE* AT COMPARISON OF SIGNAL LEVELS, OBTAINED WITH USAGE OF EMPIRICAL MODELS AND X3D MODEL AT BS ANTENNA HEIGHT H_{BS} = 50 M

d, km	*ME*, W	*SDE*, W	*RMSE*, W	*ME*, W	*SDE*, W	*RMSE*, W
	Okumura-Hata model			COST231-Hata model		
0.1	$1.1\cdot10^{-7}$	$9.2\cdot10^{-8}$	$1.5\cdot10^{-7}$	$1.1\cdot10^{-7}$	$9.3\cdot10^{-8}$	$1.5\cdot10^{-7}$
0.4	$2.2\cdot10^{-9}$	$5.2\cdot10^{-9}$	$5.6\cdot10^{-9}$	$2.2\cdot10^{-9}$	$5.2\cdot10^{-9}$	$5.7\cdot10^{-9}$
0.7	$3.0\cdot10^{-10}$	$1.7\cdot10^{-9}$	$1.7\cdot10^{-9}$	$3.0\cdot10^{-10}$	$1.7\cdot10^{-9}$	$1.8\cdot10^{-9}$
1.0	$8.1\cdot10^{-12}$	$3.3\cdot10^{-11}$	$3.4\cdot10^{-11}$	$7.8\cdot10^{-12}$	$3.7\cdot10^{-11}$	$3.5\cdot10^{-11}$
	COST231-Walfish-Ikegami model			Lee model		
0.1	$1.0\cdot10^{-7}$	$6.6\cdot10^{-8}$	$1.2\cdot10^{-7}$	$1.4\cdot10^{-7}$	$9.3\cdot10^{-8}$	$1.7\cdot10^{-7}$
0.4	$2.2\cdot10^{-9}$	$5.1\cdot10^{-9}$	$1.1\cdot10^{-8}$	$2.7\cdot10^{-9}$	$4.5\cdot10^{-9}$	$5.2\cdot10^{-9}$
0.7	$3.0\cdot10^{-10}$	$1.7\cdot10^{-9}$	$1.7\cdot10^{-9}$	$4.1\cdot10^{-10}$	$1.7\cdot10^{-9}$	$1.7\cdot10^{-9}$
1.0	$1.1\cdot10^{-11}$	$3.2\cdot10^{-11}$	$3.4\cdot10^{-11}$	$5.1\cdot10^{-11}$	$2.4\cdot10^{-11}$	$5.7\cdot10^{-11}$
	Ibrahim and Parsons model			Ericsson model		
0.1	$9.6\cdot10^{-8}$	$4.3\cdot10^{-8}$	$1.7\cdot10^{-7}$	$7.5\cdot10^{-7}$	$9.4\cdot10^{-8}$	$7.6\cdot10^{-7}$
0.4	$2.2\cdot10^{-9}$	$5.2\cdot10^{-9}$	$5.6\cdot10^{-9}$	$1.2\cdot10^{-8}$	$2.8\cdot10^{-9}$	$1.2\cdot10^{-8}$
0.7	$3.0\cdot10^{-10}$	$1.7\cdot10^{-9}$	$1.8\cdot10^{-9}$	$2.4\cdot10^{-9}$	$1.2\cdot10^{-9}$	$2.7\cdot10^{-9}$
1.0	$7.3\cdot10^{-12}$	$3.4\cdot10^{-11}$	$3.5\cdot10^{-11}$	$7.9\cdot10^{-10}$	$3.4\cdot10^{-11}$	$7.9\cdot10^{-10}$

The analysis of the resulted estimations (in general for distances of 0.1-1.0 km and BS antenna heights of 30-50 m) testifies to the following:

1) At usage of Ericsson model the greatest difference between results of estimation of levels of signal, obtained with this empirical model and X3D model, is observed. This difference is approximately $7.9\cdot10^{-10}\ldots7.5\cdot10^{-7}$ W. Application of this empirical model will lead, as a rule, to overestimated levels of useful signal and pessimistic estimation of levels of intranetwork interference on considered urban area.

2) At usage of Okumura-Hata, COST231-Hata, COST231-Walfish-Ikegami, Ibrahim and Parsons models the smallest difference between results of estimation of levels of signal, obtained with these empirical models and X3D model ($1.2\cdot10^{-13}\ldots1.2\cdot10^{-7}$ W) is observed.

3) At comparison of results of estimates of signal levels, obtained with usage of Lee model and X3D model, the difference makes $1.9\cdot10^{-11}\ldots1.4\cdot10^{-7}$ W. At usage of this model for considered urban environment estimation of levels of useful signal, as a rule, will be optimistic, and estimation of levels of intranetwork interference will be pessimistic.

The detailed analysis of distinctions of estimates of signal levels for ranges of distances of A, B, C testifies to the following:

4) In the range of distances of A at BS antenna height H_{bs} = 30 m essential difference between results of estimates of signal levels at usage of all considered empirical models and X3D model is observed. This difference makes $1.7\cdot10^{-9}\ldots$ $\ldots1.1\cdot10^{-7}$ W. Increasing of BS antenna height up to 40-50 m insignificantly influences on the difference ($2.2\cdot10^{-9}\ldots1.2\cdot10^{-7}$ W).

5) In the range of distances of B at BS antenna height H_{bs} = 30 m the smallest difference between results of estimates of signal levels at usage of Okumura-Hata, COST231-Hata, COST231-Walfish-Ikegami, Ibrahim and Parsons models, is observed. Better agreement between results, obtained using COST231-Hata model and X3D model, is observed. The difference makes $1.1\cdot10^{-11}\ldots1.7\cdot10^{-9}$ W. In this case using these empirical models the levels of useful signals which is close to median value of signal levels obtained using X3D model, will be received. At increasing of BS antenna height up to 40-50 m the difference between results of estimates of signal levels essentially increases up to $9.7\cdot10^{-11}\ldots4\cdot10^{-9}$ W. Estimation of useful signal levels with usage of these empirical models will be pessimistic, and estimation of intranetwork interference levels will be optimistic in this case.

6) In the range of distances of C at BS antenna height H_{bs} = 30 m the smallest difference between results of estimates of signal levels using Okumura-Hata, COST231-Hata, COST231-Walfish-Ikegami, Ibrahim and Parsons models is observed. Better agreement between results, obtained using Ibrahim and Parsons model and X3D model, is observed. Using these empirical models the optimistic estimation of useful signal levels and pessimistic estimation of intranetwork interference levels will be obtained in this case. The difference between result of estimates of signal levels is $1.2\cdot10^{-13}\ldots$ $\ldots1.2\cdot10^{-11}$ W. At increasing of BS antenna height up to 40-50 m, this difference essentially increaces up to $4.2\cdot10^{-12}\ldots$ $\ldots3.0\cdot10^{-10}$ W. In this case using these empirical models the levels of useful signals which is close to median value of signal levels obtained using X3D model, will be received.

B. *Comparison of empirical models and models of RWP for microcell*

In Fig. 6 dependence of signal attenuation from distance between BS and MS at BS antenna height of 30 m at usage of empirical models and models of RWP for microcell (optimized COST231-Hata [14] and RWP model for microcell [15]) is given.

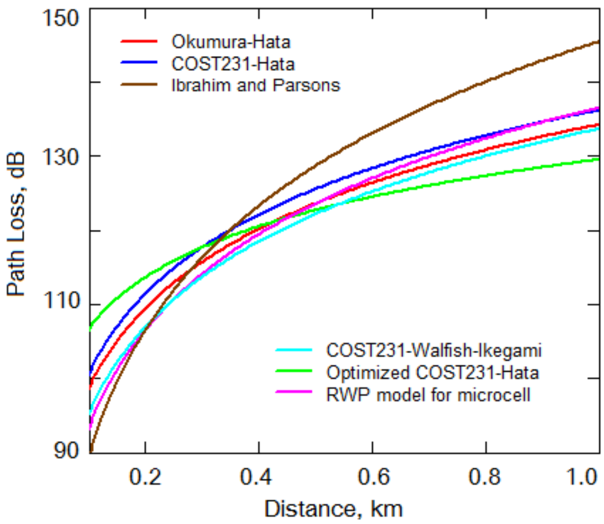

Fig. 8. Dependence of signal attenuation from distance between BS and MS at usage of empirical models and models of RWP for microcell at BS antenna height H_{bs} = 30 m

In Table 4 results of calculation of mean difference (*MD*) [16] and maximal difference between results at comparison of estimates of signal levels, obtained with usage of empirical models and models of RWP for microcell are given. Calculating formula of *MD* is given below:

$$MD = \frac{\sum_{i=1}^{N} \left| CV - MV \right|}{N} \quad (4)$$

where *M* is the number of MS placement, *CV* is level of signal, obtained with usage of empirical models, W; *MV* is level of signal, obtained with usage of models of RWP for microcell, W.

TABLE IV. RESULTS OF CALCULATION OF DIFFERENCE AT COMPARISON OF RESULTS OF ESTIMATES OF SIGNAL LEVELS, OBTAINED USING EMPIRICAL MODELS AND MODELS OF RWP FOR MICROCELL AT VARIOUS BS ANTENNA HEIGHTS

BS antenna height, m	Okumura-Hata model		COST231-Hata model		Ibrahim and Parsons model	
	Mean, dB	*Max,* dB	*Mean,* dB	*Max,* dB	*Mean,* dB	*Max,* dB
	Optimized COST 231-Hata model for microcell [14]					
30	3.2	7.9	4.1	5.9	10.1	16.8
40	3.2	7.7	4.0	5.8	10.5	18.2
50	3.5	7.6	4.0	5.7	10.4	19.3
	Model of RWP for microcell [15]					
30	1.7	5.2	2.5	7.1	5.8	13.0
40	3.3	8.3	5.3	10.3	7.4	10.5
50	5.4	10.8	7.4	12.7	8.6	11.7

The mean difference between results of estimates of signal levels, obtained using empirical models and models of RWP for microcell is approximately 2-10 dB. It in addition shows possibility of application of Okumura-Hata, COST231-Hata, Ibrahim and Parsons models for distances between BS and MS less than 1 km.

IV. CONCLUSION

The results given above testify to the following.

1) The results of estimates of signal levels, most coinciding with results received using X3D model on considered urban area, can be obtained at usage of Okumura-Hata, COST231-Hata, COST231-Walfish-Ikegami, Ibrahim and Parsons empirical models of RWP. The Okumura-Hata, COST231-Hata, Ibrahim and Parsons models can be applied for distances between BS and MS of 0.4 - 1 km.

2) The results of simulation have shown, that it is possible to use Okumura-Hata, Ibrahim and Parsons models at frequency of 1800 MHz for estimation of levels of useful signal and levels of intranetwork interference on considered urban area.

3) The results of estimates of signal levels using Okumura-Hata, COST231-Hata, COST231-Walfish-Ikegami, Ibrahim and Parsons empirical models, which is the closest to results at usage of X3D, can be obtained at BS antenna heights of 30-40 m for considered territory of urban area at microcellular network structure.

4) For estimation of electromagnetic background [17], of electromagnetic safety of cellular communications, and for diagnostics of intrasystem EMC (for estimation of levels of intranetwork interference) at support of high quality of service in cellular communications COST231-Hata model or Ibrahim and Parsons models also can be recommended, because the results of estimates of signal values with its usage most coincide with results obtained using X3D model on considered urban area.

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