Hybrid Empirical-Neural Model of the Influence of Foliage Areas on EM Propagation in Urban Environment

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Abstract –**The paper presents a hybrid empirical neural (HEN) model for prediction electric field strength of RF transmitter in frequency range 150-1500 MHz in urban environment. The model is based on connection between Okamura-Hata model and artificial neural network. Besides antenna frequency, transmitter antenna height, distance between antenna and receiver, the proposed HEN model considers both characteristics of foliage areas and characteristics of buildings in urban environment that EM wave goes throughout to predict electric field strength.**

Keywords – **EM propagation, artificial neural network, Okamura-Hata model.**

I. INTRODUCTION

Considerable interest has been shown recently in the development of efficient model for electric (*E*) field level prediction. For many purposes, such as modeling of up-to-date wireless communication system, it is very important to predict accurately the coverage area provided by a given transmitting station. A propagation of EM wave is influenced by a large number of global and local parameters, such as relief, objects in the line of sight, clime area, atmosphere refraction index, multiple paths propagation, etc. The methods that are being used for the prediction of *E* field strength, whatever they are empirical, semi-empirical or static, do not take all of these parameters into account and have limitation in usage areas or accuracy due to done approximations.

The use of artificial neural networks [1,2] for the electromagnetic waves propagation modeling is a convenient alternative to previous models, which often do not provide adequate results from the aspect of calculation time and accuracy. Neural network can be more accurate and faster then empirical and approximated models [3-8] because of two its important advantages. The first is neural network architecture which is consisted of connected small processing units (neurons). In this way, neural network can be used for modeling high-distributed and high-parallel problems. The second is neural network ability to learn function dependence on the basis of solved examples rather then to learn to execute some well known function dependence. After successful learning process of neural network, it can be used not only for known examples but also for unknown examples. This ability is called generalization and it enables *E* field level prediction in points when measured data do not exist. But, the main disadvantage of MLP models is a need for providing a large set of training data, which could be difficult and time-consuming process [4-6]. Hybrid Empirical-Neural (HEN) model for *E* field level prediction, which incorporates Okamura-Hata model as empirical knowledge, needs smaller set of training data then MLP model for achieving satisfying model accuracy.

Measured results from ITU-R P.1546 Recommendation [9] have been used for developing HEN model for transmitter *E* field level prediction. These values have been modified using statistic formulas due to influence of buildings and foliage areas in urban environment. EM wave is attenuated during its propagation thought urban environment by foliage areas objects (threes, plants, etc.) and by buildings that can be located at propagation path. If propagation area parameters are considered, the neural model for *E* field level prediction will be more accurate. Calculating attenuation of partial foliage area and partial building clutter, the prediction EM wave loss is more efficient due to real propagation area parameters have been taken into account.

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II. HYBRID MODEL FOR E FIELD LEVEL PREDICTION IN URBAN AREAS

Hybrid models for model for *E* field level prediction in urban areas is a combination of an empirical model and a multilayered perceptron network (MLP) [3,7,8], which upgrades the empirical model. Such model is formed in two phases. In the first phase, the empirical model of the propagation area is realized using Okamura-Hata model. Following extensive measurements of urban and suburban radio propagation losses, Okumura published many empirical curves useful for cellular systems planning. These empirical curves were subsequently reduced to a convenient set of formulas known as the Hata model that are widely used in the industry. According to this model, the median propagation loss A_e for longer distances in urban environment (expressed in dB) has a linear and a logarithmic component, as shown in equation (1) [10]

$$\begin{aligned} A_e[dB] &= 69.55 + 26.16 \cdot \log_{10}(f[\mathbf{MHz}]) - \\ &- 13.82 \cdot \log 10(h_{tef}[\mathbf{m}]) - g(h_{ref}[\mathbf{m}]) + \\ &(44.9 - 6.55 \cdot \log_{10}(h_{tef}[\mathbf{m}])) \cdot (\log_{10}(d[\mathbf{km}]))^b \end{aligned} \quad (1)$$

where h_{tef} (30 -200 m) and h_{ref} (1 – 10 m) are base station and mobile antenna heights in meters, respectively, d (1 – 200 km) is the link distance in kilometers, and f (150-1500 MHz) is the centre frequency in megahertz. The term $g(h_{ref})$ is an antenna height-gain correction factor that depends upon the

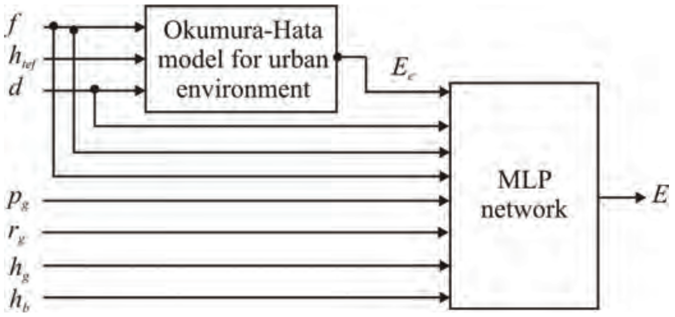

Fig. 1 Hybrid-empirical model for E filed level prediction in urban area

TABLE I TESTING RESULTS

HEN model	WCE[%]	ACE[%]	r^{ppm}
HEN4-15-11	8.6338	1.2305	0.9975
HEN4-12-11	13.5397	2.2277	0.9935
HEN4-10-10	14.5830	2.8001	0.9879
HEN4-12-12	13.5390	2.8376	0.9903
HEN4-14-11	9.6935	2.8757	0.9882
HEN4-9-9	10.8844	3.2997	0.9900
HEN4-17-11	16.6155	3.4473	0.9813
HEN4-5-3	16.5172	3.4490	0.9838

environment. It is given for small and medium cities (cities whose buildings height is not bigger then 15 m) by equation (2):

$$g(h_{ref}\,[m]) = (1.1\cdot\log_{10}(f[\text{MHz}]) - 0.7)h_{ref} - \\ -(1.56\cdot\log_{10}(f[\text{MHz}]) - 0.8) \tag{2}$$

and for big cities (cities whose buildings height is bigger then 15 m) when f>300 MHz by equation (3):

$$g(h_{ref}\,[m]) = 3.2\cdot\log_{10}(11.75\cdot h_{ref})^2 - 4.97 \tag{3}$$

and when f≤300 MHz by equation (4):

$$g(h_{ref}\,[m]) = 8.29\cdot\log_{10}(1.54\cdot h_{ref})^2 - 1.1 \tag{4}$$

The factor b represents extension of Okumura-Hata model to longer distances. It equals 1 for smaller distances, but it is calculated by equation (5) for longer distances:

$$b = \begin{Bmatrix} 1, & d < 20km \\ 1 + (0.14 + 0.000187\cdot f[\text{MHz}] + 0.00107\cdot h_{tef}{}')\cdot & \\ \cdot(\log 10((d[\text{km}]/20)^{0.8}, & d \geq 20\,\text{km} \end{Bmatrix} \tag{5}$$

where

$$h_{tef}{}' = \frac{h_{tef}\,[m]}{1 + 7\cdot 10^{-6}\cdot h^2{}_{tef}\,[m]} \tag{6}$$

In the second phase, a MLP network and the empirical model are integrated (as shown in Fig. 1). Due to h_{ref} mobile station height is 1.5 m, the MLP network in the hybrid model models the function:

$$E = f_{MLP}(f, h_{tef}, d, E_e, p_g, r_g, h_g, h_b) \tag{7}$$

The inputs of the MLP network are centre frequency in megahertz f, distance between transmitter and receiver in kilometers d, h_{tef} base station height in meters, the E_e field level which is calculated by Okamura-Hata model, percentage of foliage areas in the propagation path p_g, distance between foliage areas and transmitter in percentages r_g, average height of foliage areas objects in meters h_g and average height of buildings in urban environment in meters h_b. The output of the MLP network is predicted E field level in dB (μV/m).

The neural network has eight neurons in the input layer, one neuron in the output layer and two hidden layers of neurons. The activation functions of the hidden layers are sigmoid, while the neurons of the output layers have linear activation functions. The neural networks were trained using Levenberg-Marquardt method with 10^{-4} performance goal. The notation of HEN models is Hn-l_1-l_2-…-l_{n-2} where n represents layer number in the MLP part, and l_1-l_2-…-l_{n-2} are the numbers of neurons of each hidden layer.

The measurements of electric field strength, necessary for the training and testing of the neural networks, were obtained from ITU-R P.1546 recommendation, corrected using statistic formulas [11,12] and satisfied 50 % location and 50 % time. The training set contained 35113 samples whit following range of input parameters: 150 MHz≤f≤1500 MHz, 37.5 m≤h_{tef}≤ 200 m, 1 km≤d≤15 km, 5%≤p_g≤90%, 5%≤r_g≤(1-p_g), 1 m≤h_g≤20 m and 5m≤h_b≤60m.

III. TESTING RESULTS

The testing set contained 7318 samples that are not used in training process. Testing results of successfully trained neural networks are presented in the Table I together with the average test error (ATE), the worst case error (WCE) and the Pearson Product-Moment correlation coefficient (r^{PPM}). The minimum of the average test error was the basic criterion for selection of the best MLP network of HEN model. Selected neural model is HEN4-15-11.

IV. SIMULATION RESULTS

The hybrid empirical-neural model HEN4-15-11 is employed for the simulation of the electric field strength level depending on centre frequency f, distance between transmitter and receiver d, base station height h_{tef}, percentage of foliage areas in the propagation path p_g, distance between foliage areas and transmitter r_g, average height of foliage areas objects h_g and average height of buildings in urban environment h_b. Propagation curves of dependence of E field strength on percentage of foliage areas in the propagation path p_g for several values of distance d between receiver and

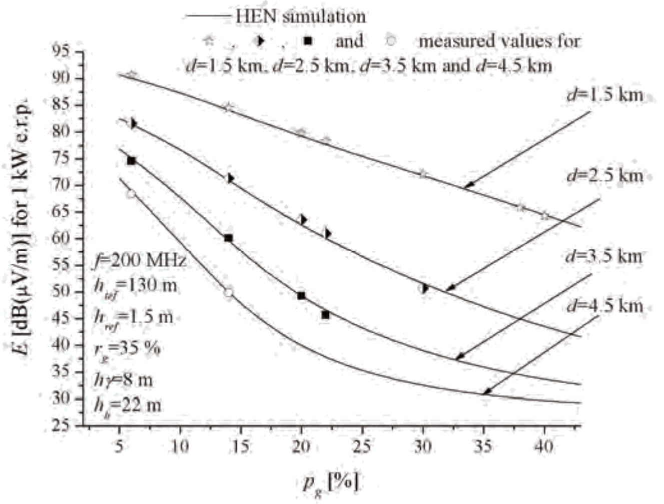

Fig. 2 Electric field strength vs. percentage of foliage areas in the propagation path p_g for different values distance d between receiver and transmitter

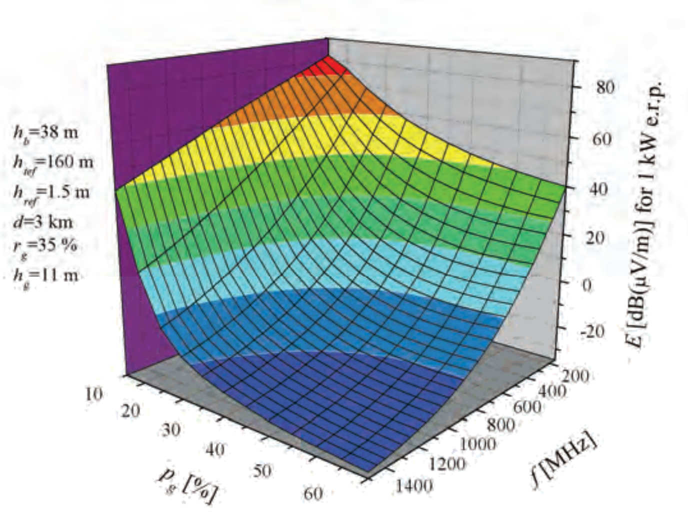

Fig. 4 Electric field strength vs. percentage of foliage areas in the propagation path p_g and frequency f

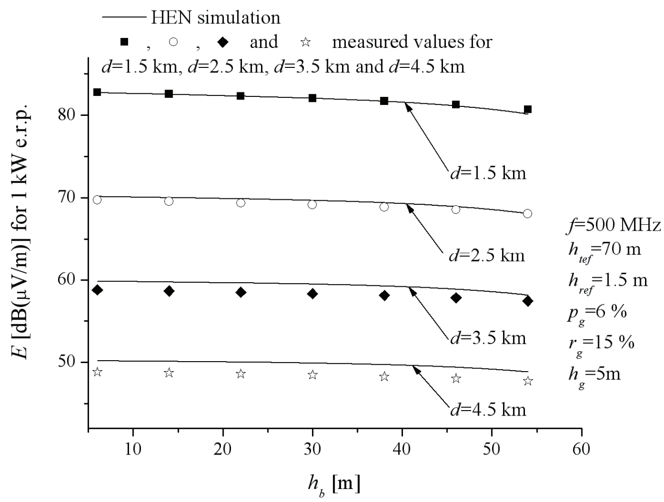

Fig. 3 Electric field strength vs. average height of buildings in urban environment h_b for different values distance d between receiver and transmitter

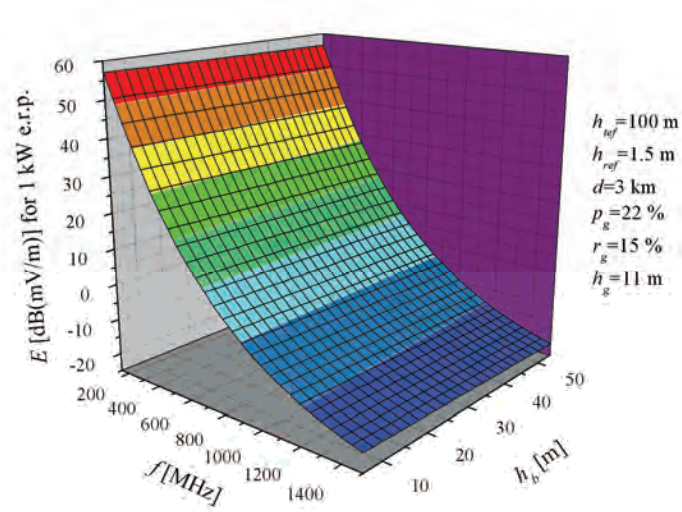

Fig. 5 Electric field strength vs. average height of buildings in urban environment h_b and frequency f

transmitter, generated by selected HEN4-15-11 model, are presented in Fig. 2, together with measured values obtained from the ITU-R P. 1546 Recommendation [10]. It is obvious that modeled curves are very close to the referent values, which emphasizes high accuracy of the neural network.

Similarly, the Fig. 3 represents E field strength versus average height of buildings in urban environment h_b for different values distance d between receiver and transmitter. It could be seen that measured values [10] and values obtained by the hybrid model are in good agreement and for this reason the use of hybrid-empirical model is quite reasonable.

Fig. 4 is three-dimensional presentation E field strength versus percentage of foliage areas in the propagation path p_g and frequency f. If we use HEN simulation to obtain 336 values of E field strength representing in Fig.4 we will finish simulation process for less then 5 seconds. If we want to measure on 336 different locations, we need significantly more time. For these reasons, HEN simulation is good alternative in applications where simulation results have to be finished in certain period of time. The same conclusion is reached from Fig. 5 where 200 values of E field strength versus average height of buildings in urban environment h_b and frequency f are presented.

V. Conclusion

Qualitative analysis of transmitter antenna work in up-to-date broadcasting systems requires accurate E field level prediction. Neural model of EM propagation can be good alternative of previous used empirical and semi-empirical models that are based on many approximations and that do not considere propagation area characteristicas. Also, when the set of training data is smaller or when the model accuracy needs to increase, the best choise is hybrid empirical neural modeling.

Considering attenuation by foliage areas objects (threes, plants, etc.) and by buildings that can be located at propagation path, *E* field level prediction is more accurate and efficient. Proposed HEN model was trained using measured results from Recommendation ITU-R P. 1546 [10], but its main advantage is that it does not depend on training set values. It can be trained using real measured values from urban environment in our country, what will be plan of fallowing research of this group of authors.

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