Electromagnetic Field Strength Level Prediction by Neural Model – Application to Broadcasting

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Abstract - **This paper presents the neural model for efficient prediction of the electromagnetic field strength level for a UHF/VHF transmitter based on a multilayered perceptron (MLP) network. The proposed neural model has four input parameters, the distance from the transmitter, the effective antenna height, the terrain irregularity factor, and the clearance angle of the receiving antenna, and one output parameter, the field strength level for certain azimuth. According to the training set values, this neural model enables fast and accurate computing of the field strength level for any given effective antenna height between 37.5 m and 1200 m, terrain irregularity factor from 10 m to 500 m, clearance angle of the receiving antenna from – 20° to 1°, and for all distances from the transmitter in 10 km to 250 km range.**

Keywords - **Neural model, electromagnetic field level, ITU-R P370-7 recommendation.**

I INTRODUCTION

The efficient prediction of EM field strength is essential for modern telecommunication systems design. 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 EM field strength do not take all of these parameters into account. Generally these methods are statistic, deterministic or pseudo-deterministic.

Statistic method recommended by ITU-R, recommendation 370-7 [1, 2], is used most often in prediction of the electric field strength level. This method is based on a visual reading of the electric field strength directly from the curve which gives the dependency of the field strength in dB(μV/m) from the distance and effective antenna height, Fig 1. Afterwards the correction factor, directly read from the curve which gives its dependency from the terrain irregularity, and the correction factor, directly read from the curve which gives its dependency from the clearance angle, must be added to this value. The biggest problem with this method is that the values of the effective antenna height are discrete, and for the other values the appropriate interpolation [2] must be applied, so if the large number of readings is in question this job can be very long and tedious.

The good alternative to this method is modeling the propagation curves with neural networks. The first neural models, based on the multilayer perceptron (MLP) network

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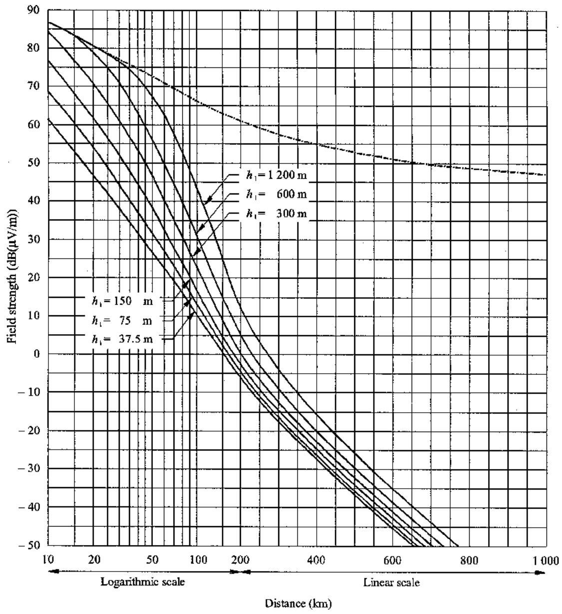

Fig. 1. Electric field strength level in dependence from the distance and the effective antenna height (the curves are given for half wave dipole antenna with 1kW power, and the 450-1000 MHz band, for 50% time and 50% locations.

[3-7], developed in [6, 7, 8] have shown a great speed and good accuracy in predicting the electric field strength level of the transmitter. These MLP models had two inputs, the distance from the transmitter and the effective antenna height. In [9] the terrain irregularity is the third input of the MLP model. Here, the more complex MLP model, with the clearance angle as the fourth input, is elaborated. The first results of this model were given in [10].

II NEURAL MODEL FOR THE ELECTRIC FIELD STRENGTH LEVEL PREDICTION

Problem that is being modeled is finding the electric field strength level as the function of the distance from the transmitter, the effective antenna height, the irregularity factor, and the clearance angle:

$$E = f(r, h_e, \Delta h, \theta) \qquad (1)$$

The complex neural model is composed of three multilayer perceptron networks. The first MLP network models the ITU-R P.370-7 propagation curves shown in Fig.1. The second MLP network models the electric field strength level correction due to the effect of the terrain irregularity, and the third MLP network models the electric field strength level

TABLE I - TESTING RESULTS FOR PROPAGATION CURVES

MLP network	Two-phase training	
	WCE[%]	ATE[%]
M4-5-5	1.65	0.45
M4-6-6	1.97	0.48
M4-7-7	1.6	0.45
M4-8-8	2.74	0.61
M4-8-5	3.21	0.84
M4-8-8	12.94	0.77
M4-9-5	4.13	1.14
M4-9-8	3.34	1.03

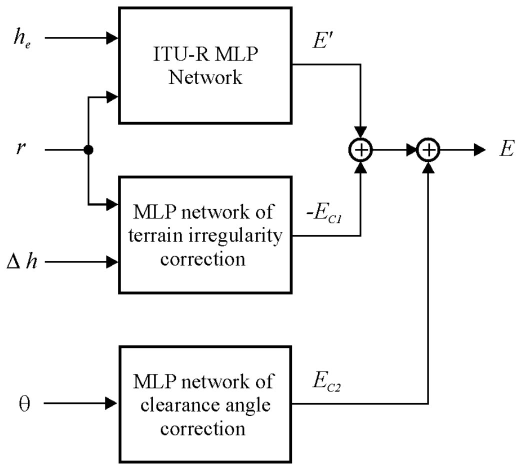

Fig. 2. The complex integrated neural model for the electric field strength level prediction for UHF/VHF transmitter.

correction caused by the effect of the clearance angle. As shown in Fig.2. the final neural model forms the resulting electric field strength level E [dB(μV/m)], according to

$$E = (E' - E_{c1}) + E_{c2} \quad (2)$$

The output of the first MLP network is the electric field strength level E'[dB(μV/m)]. The terrain irregularity correction factor E_{C1}[dB], is output of the second MLP network, whereas the clearance angle correction factor, E_{C2}[dB], is the output of the third MLP network.

The first two neural networks both have two neurons in the input layer, and one neuron in the output layer. The third neural network has one neuron in the input as well as in the output layer. All three networks have two hidden layers of neurons, which is optimal according to [6, 7]. The activation functions of the hidden layers are sigmoid, while the neurons of the output layers have linear activation functions. In notation of the neural networks we used M_n-l_1-l_2-…-l_{n-2}, where n is the number of layers, and l_1, l_2, …, l_{n-2} are the numbers of neurons in corresponding hidden levels.

In order to model the required function more accurately, the training procedure of the first (ITU-R) neural network had two phases [6, 8]. In the first phase, called "the coarse training" the neural networks are trained on a large training set of 10000 samples generated by the approximate method [2] in range 30 m ≤ h_e ≤ 1400 m and 1 km ≤ r ≤ 650 km, using the

TABLE II - TESTING RESULTS FOR TERRAIN IRREGULARITY CORRECTION

MLP network	Classic training	
	WCE[%]	ATE[%]
M4-4-2	10.64	3.30
M4-4-4	11.35	3.32
M4-9-7	9.4	3.64
M4-10-7	11.48	3.58
M4-10-10	8.93	3.68
M4-14-11	13.44	3.58
M4-16-10	13.51	3.33
M4-22-20	9.76	2.82

TABLE III - TESTING RESULTS FOR CLEARANCE ANGLE CORRECTION

MLP network	Classic training	
	WCE[%]	ATE[%]
M4-3-2	2.94	0.87
M4-4-4	2.46	0.49
M4-5-5	2.82	0.58
M4-6-5	2.63	0.57
M4-7-4	2.07	0.57
M4-9-9	2.53	0.63
M4-10-10	2.46	0.61
M4-12-12	2.08	0.54

Quasi-Newton training method with the accuracy of 10^{-3}.This method is less efficient than the Levenberg-Marquart method, but more applicable on a large training set.

In the second phase ("the fine training"), ITU-R networks from "the coarse training" indicating the best performance were retrained on a smaller training set of 155 samples, obtained directly from the ITU-R P.370-7 curves, Fig. 1. The Levenberg–Marquart method (with the maximum absolute error of 10^{-4}) was applied in this training phase, because it is very efficient for a small training set. Testing of the networks after the final phase of training was fulfilled on a set of 73 samples, also obtained from the propagation curves. The pre-knowledge from the first training phase has improved the accuracy and the neural network learning rate. Training of the second and the third MLP networks (modeling the terrain irregularity correction and the clearance angle correction, respectively) was carried out on a classic manner, applying the Levenberg-Marquardt method with the given accuracy of 10^{-4}. The second neural network is trained on a set of 187 samples in range 10 km ≤ r ≤ 250 km and 10 m ≤ Δh ≤ 500 m and tested on 47 samples, both directly obtained from the ITU-R correction diagram [1]. A training set for the third neural network comprised 50 samples in range $-20^o \le \theta \le 1^o$ obtained from the appropriate ITU-R diagram [1], while the test set of 20 samples was used for network testing. Testing results of successfully trained neural networks are presented in Tables I, II and III, together with the average test error (*ATE*) and the worst case error (*WCE).* The minimum of the average test error was the basic criterion for selection of the best MLP network.

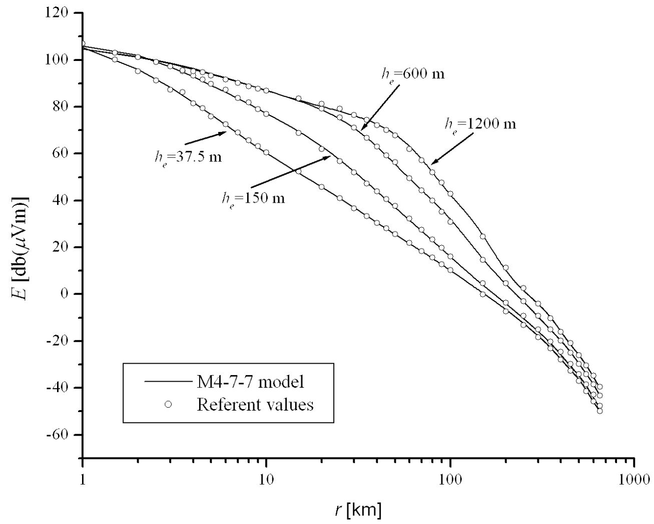

Fig. 3. Comparison of the propagation curves generated by M4-7-7 network and referent values.

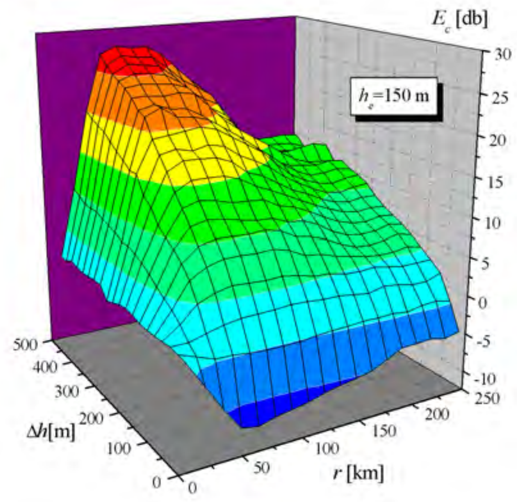

Fig. 4. Three-dimensional presentationof the correction depending on the terrain irregularity Δh and the distance r, generated by the M4-22-20 network.

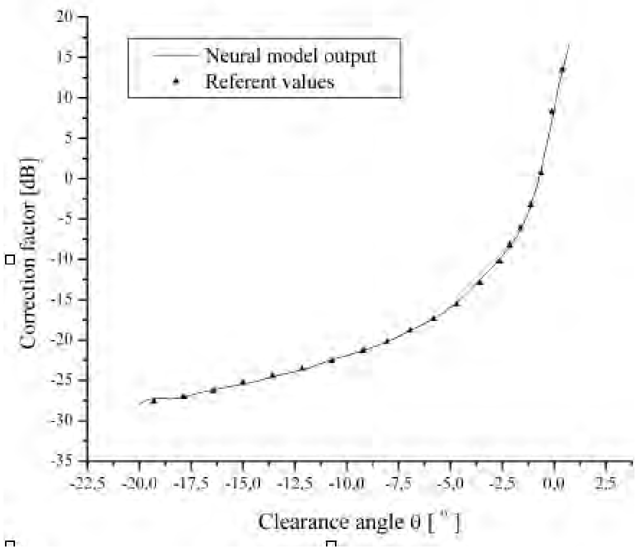

Fig 5. Comparison of the correction depending on clearance angle of the receiving antenna obtained by M4-4-4 model with referent values.

III Simulation Results

After the error analysis, we chose a neural network with the best performances from each of the Tables I, II and III. These three networks are used in the integrated neural model, as shown in Fig. 2. Selected networks are:

- M4-7-7 for the prediction of the electric field strength level depending on the effective antenna height h_e and the distance from the transmitter r,
- M4-22-20 that gives the electric field strength level correction as the function of the terrain irregularity factor Δh and the distance from the transmitter r,
- M4-4-4 for the receiving antenna clearance angle (θ) correction.

The neural network M4-7-7 is employed for the simulation of the electric field strength level depending on the effective antenna height h_e and the distance from the transmitter r. Propagation curves for several values of the effective antenna height, generated by this network, are presented in Fig. 3, together with referent values obtained from the ITU-R diagrams. It is obvious that modeled curves are very close to the referent values, which emphasizes high accuracy of the neural network.

Fig. 4 is a three-dimensional presentation of the correction depending on the terrain irregularity factor Δh and the distance from the transmitter r, for the constant effective antenna height h_e=150 m, generated by the M4-22-20 neural network.

The receiving antenna clearance angle correction, generated by the M4-4-4 network is shown in Fig.5. Referent values, obtained directly from the ITU-R correction diagram, are consistent with the neural network output values.

Fig. 6 shows the resulting electric field strength level on the output of the complex neural model depending on the distance from the transmitter when there is no receiving antenna clearance angle correction (θ = -0.73˚) and when this correction is present (θ = -10˚, θ = -5˚ and θ = 0.5˚), with the constant effective antenna height h_e = 150 m and the terrain irregularity factor Δh = 20 m. It is obvious that the output values of the neural model are very close to referent values from the ITU-R diagrams.

Complete 3D functions $E = f(r, h_e = 150\text{ m}, \Delta h, \theta = -5˚)$ and $E = f(r, h_e, \Delta h = 300\text{ m}, \theta = -0.73˚)$ are shown in Figs. 7 and 8, respectively.

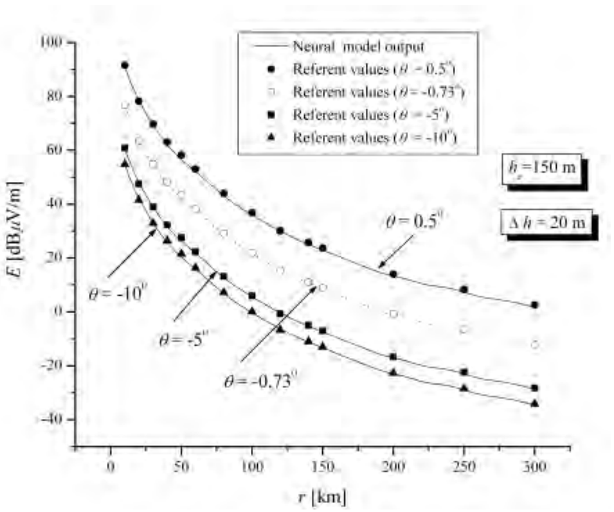

Fig 6. Comparison of the resulting electric field strength level generated by the complex neural model with referent values for different receiving antenna clearance angle values.

IV Conclusion

The widespread statistical method for the electric field strength level calculation in broadcasting systems is based on visual determining of the electric field strength level from the ITU-R P.370-7 curves. The electric field strength level, in this way, is estimated with sufficient accuracy, but the method itself is too complicated and time-consuming. Modeling the ITU-R propagation curves by neural models based on MLP networks could be a convenient alternative to the classic method. This conclusion results from the fact that the output values of the developed neural model are in excellent agreement with the electric field strength levels assessed from the ITU-R diagrams, while generating of the output values is extremely fast (values in 15 000 points are calculated in less than 5 seconds on PIII 450MHz hardware platform with 128 MB RAM).

Due to the high calculation rate, proposed neural model can be applied in systems for automatized determination of the service area for a VHF/UHF transmitter.

V References

[1] Recommendation ITU-R P.370-7, VHF and UHF Propagation Curves for the Frequency Range from 30 MHz to 1 000 MHz, Broadcasting services.

[2] B. Milovanović, N. Vasić, V. Stanković, A. Atanasković, J. Joković, "Approximation of the Propagation Curves from the Recommendation ITU-R P. 370-7", TELSIKS 2001 Conference Proceedings, Niš 2001, pp.699-702.

[3] S. Haykin, *Neural Networks*, New York, IEEE, 1994.

[4] J. Hertz, A. Krogh and R. Palmer, Introduction to the Theory of Neural Computation, Addison-Wesley, 1991.

[5] B. Milovanović, Z. Stanković, S. Ivković, "Modelling of the Cylindrical Metallic Cavity Loaded by Lossy Dielectric Slab Using Neural Networks", NEUREL 2000 Conference Proceedings, Beograd 2000, pp. 141-145.

[6] Z. Stanković, B. Milovanović, J. Jovković, J. Antonijević, "Modeling of the ITU-R P.370-7 Propagation Curves by Neural Network", ICEST 2002 Conference Proceedings, Niš 2002, pp. 103-106.

[7] Z. Stanković, B. Milovanović, J. Antonijević, J. Jovković, "Neural Model of the Propagation Curves from ITU-R P.370-7", NEUREL 2002 Conference Proceedings, Beograd, September 2002, pp. 191-196.

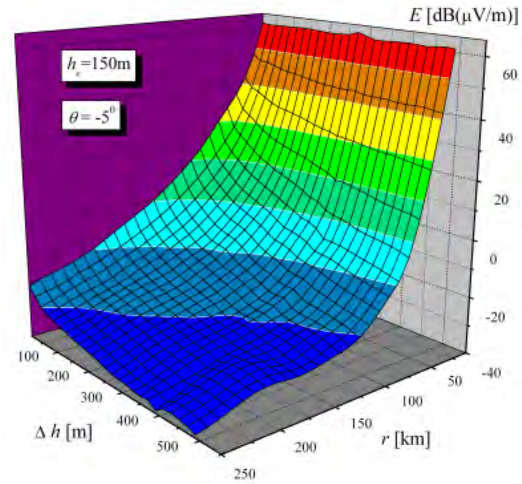

Fig. 7. Three-dimensional representation of the electric field strength level, depending on the distance from the transmitter *r* and the terrain irregularity factor *Δh*, generated by the complex neural model.

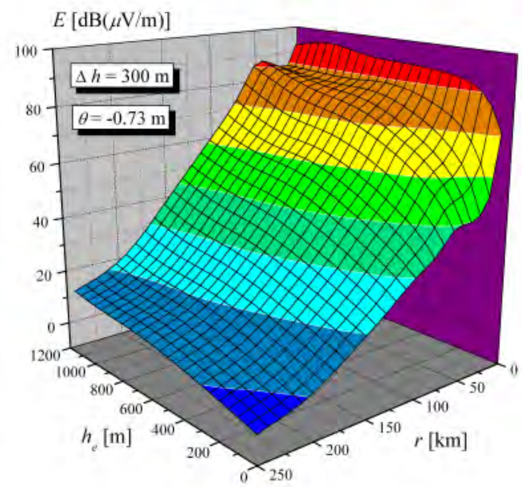

Fig. 8. Three-dimensional representation of the electric field strength level, depending on the distance from the transmitter *r* and the effective antenna height h_e, generated by the complex neural model

[8] Z. Stanković, N. Vasić "Neural Approach in Modelling of the Propagation Curves from Recommendation ITU-R P.370-7", ETRAN 2003 Conference Proceedings, H. Novi 2003.

[9] B. Milovanović, Z. Stanković, A. Stošić "Prediction of the Electromagnetic Field Strength Level using Neural Model", TELSIKS 2003 Conference Proceedings, Niš 2003, pp.457.

[10] B. Milovanović, Z. Stanković, A. Đorđević, M. Veljković "Neuronski model za predikciju nivoa elektromagnetnog polja u radio-difuziji", YUINFO 2004, Conference Proceedings, Kopaonik 2004.