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Optimization of Path Loss Models Based on Signal Level Measurements in 4G LTE Network in Sofia

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Abstract. In this paper we present results of code-selective measurements of the signal level in LTE network in Sofia. The investigated area is characterized by large buildings and park with trees. The power level of received reference signal in the selected area is measured by Narda SRM 3006. The path loss dependence on the distance between eNodeB and measurement equipment is obtained in this area. The measurement results are used to optimize of empirical models for correct prediction of the path loss in LTE network in Sofia. Comparison of the results obtained by empirical models before and after tuning is made. The optimized models are characterized by reduced RMS error, thereby increasing the accuracy of estimation of path loss in the investigated area in Sofia.

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1 Introduction

The path loss of the signal is a highly significant parameter in the link budget of 4G LTE networks. For prediction of the path loss are used various signal propagation models. These models found wide application in the process of planning and designing of the mobile networks. In general, the propagation models can be categorized in three primary types – empirical, statistical and deterministic [1]. The empirical models are based on signal measurements and these models give a possibility for quick estimation of the path loss. Most empirical models take in to account dependence of path loss on carrier frequency, height of the transmitter and receiving antenna and parameters of the propagation environment. During feasibility studies for efficiently and effectively initial deployment of LTE network is paramount to be chosen the most appropriate and accurate empirical model for specific environment. This is not an easily solved problem, because the type and profile of the terrain vary significantly in different regions.

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Therefore, there is no universal empirical model for prediction of the path loss, which is applicable in all propagation environments and scenarios. The empirical models can give inaccurate path loss value if the models are applied for prediction in different areas from those for which they are developed. Hence to improve the accuracy of the models it is necessary to adjust their parameters taking into account the influence of the specific environment. These parameters are determined by measuring the signal strength in a selected area.

In the literature there are various analytical approaches for tuning of empirical path loss models based on measurements of signal strength in different mobile networks. The tuning process of Hata model using the mean square error method is applied for Brno, Czech Republic [2]. Hata model is also optimized for suburban area in Malaysia based on least square method [3]. The adjustment of log-distance model for path loss is present in [4].

In this paper are presented results for measurements of reference signal (RS) in Bulsatcom 4G LTE network in Bulgaria, Sofia. The log-distance, COST 231 Hata and Ericsson models are tuned on the basis of experimental data. In our paper we present optimized empirical models for prediction of the path loss in specific area in Sofia.

2 Path Loss Models

In this paper we use specific empirical models, which are applied to predict the path loss of the signal in LTE network [5-7].

2.1 Log-distance model

Log-distance path loss model is a generic model, which is an extension to Friis formula for calculation of the signal attenuation. This model is used to predict the path loss for a wide range of conditions, including both line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios. The formula for path loss is as follows [8]:

$$PL = PL(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + \chi_\sigma \ \ \text{[dB]}. \tag{1}$$

$PL(d_0)$ is the path loss at reference distance d_0 and it is defined as

$$PL(d_0) = 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \ \text{[dB]}\,, \tag{2}$$

where $d_0 = 100$ m and λ is wavelength in [m].

The other parameters are: d is the distance between transmitter and receiver station, n is the path loss exponent and χ_σ is a zero-mean Gaussian distributed random variable in dB, with standard deviation σ also in dB [8].

2.2 COST 231 – Hata model

COST 231 – Hata model has extended Hata‘s model [9] to the frequency band 1500 MHz $\leq f \leq$ 2000 MHz by analyzing Okumura‘s propagation curves [10] in the upper frequency band [11]. The path loss is given below:

$$PL = 46.3 + 33.9 \log_{10}(f) - 13.82 \log_{10}(h_t) - \alpha(h_r) \\ + (44.9 - 6.55 \log_{10}(h_t)) \log_{10} d + c_m \text{ [dB]}, \quad (3)$$

where f is the frequency in [MHz], d is the distance between transmitter and receiver in [km], h_t is the transmitter antenna height in [m]. The parameter $\alpha(h_r)$ is set according to the environment. For an urban environment is defined as [11]

$$\alpha(h_r) = 3.20(\log_{10}(11.75 h_r))^2 - 4.97 \text{ [dB]}, \quad (4)$$

where h_r is the receiver antenna height in [m].

The parameter c_m has different values for different environments: 0 dB for suburban and rural environments; and 3 dB for urban area.

2.3 Ericsson model

This path loss model was created by Ericsson for use in network planning and deployment process of mobile communication network [12]. Ericsson model also stands on the modified Okumura-Hata model to allow room for changing in parameters according to the propagation environment. Path loss according to this model is given by [13]:

$$PL = a_0 + a_1 \log_{10}(d) + a_2 \log_{10}(h_{bs}) + a_3 \log_{10}(h_{bs}) \log_{10}(d) \\ - 3.2(\log_{10}(11.75 h_m))^2 + g(f) \text{ [dB]}, \quad (5)$$

where $g(f)$ is

$$g(f) = 44.49 \log_{10}(f) - 4.78(\log_{10}(f))^2, \quad (6)$$

where f is the frequency in [MHz], d is the distance between the base station and the mobile station in [km], h_{bs} is the base station antenna height and h_{ms} is mobile station antenna height in [m].

The values of parameters a_0, a_1, a_2 and a_3 for different types of terrain are shown in Table 1.

Table 1. Values of a_0, a_1, a_2 and a_3

Type of terrain	a_0	a_1	a_2	a_3
Urban	36.2	30.2	-12	0.1
Suburban	43.2	68.93	-12	0.1
Rural	45.95	100.6	-12	0.1

3 Experimental Measurements

Signal strength measurements are carried out in the Bulsatcom 4G LTE network in Sofia, neighborhood "Studentski grad" and the covered area is shown in Figure 1. In this area coverage of the LTE network is provided by three eNodeBs (black signs in Figure 1), located on the roofs of residential buildings with height of 35 m. The each eNodeB is characterized by following parameters: $P_{tx} = 40$ W, $G_{tx} = 18$ dBi and carrier frequency $f = 1800$ MHz.

In the LTE system, the resource block (RB) is the smallest unit of the radio resource that can be allocated to an individual user for the purpose of data transmission [14]. The RB has a total size of 180 kHz with 12 consecutive subcarriers in the frequency domain and 0.5 ms with 7 OFDM symbols (with the normal cyclic prefix) in the time domain. The smallest unit of resource block is the Resource Element (RE), which consists of one subcarrier at duration of one OFDM symbol [14]. The RE is the smallest unit physical resource can be identified. Power measurement of the reference signal (RS) included in RB, can provide accurate estimation for the received power of one RE. Reference signal

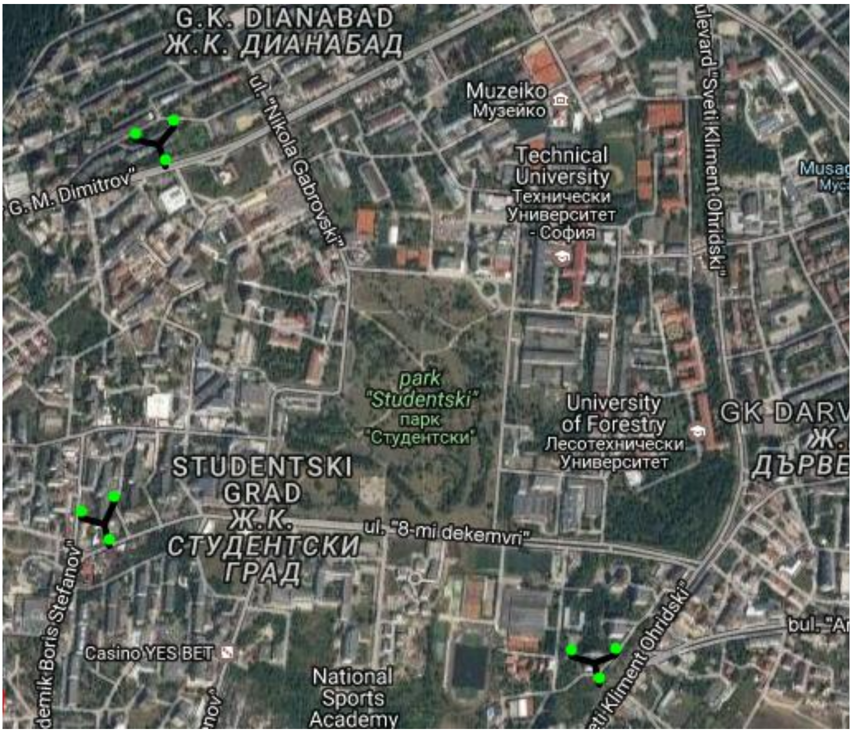

Figure 1. Investigated area.

received power (RSRP) is the linear average over the power contributions of the REs that carry cell-specific reference signals within the considered frequency bandwidth. The RS transmitted power is a static value that strongly depends on the maximum of the transmitted power by eNodeB. The RS transmitted power per RE is constant in the downlink system bandwidth and for all subframes, until cell-specific RS power information is received by the user equipment (UE) [14].

In the investigation Narda Selective Radiation Meter (SRM) 3006 is used for carrying out the signal measurements. The Narda SRM 3006 is a compact, frequency-selective measuring system for high-frequency electromagnetic fields [15]. This device has an integrated GPS module, which allows automatically recording the coordinates at the points of measurement. The signal strength is measured by tree-axis antenna, which ensures isotropic receiving of the signals in frequency range 420 MHz – 6 GHz [15].

The Narda SRM 3006 has a LTE operating mode, which provides code selective measurement method for measuring LTE base station signals. The code selective method extracts the signals from the coded eNodeB signal and allows their accurate measurements. This measurement method is based on the fact that the primary synchronization signals (P-SS), secondary synchronization signals (S-SS) and reference signals (RS) of LTE base stations are coded cell-specifically [16]. Different code is used for each eNodeB and for each sector of the antenna of the base station. By decoding the signal from the receiving antenna of SRM 3006, it is possible to split the immissions up and match them to the corresponding cells. The code-selective method is based on the determination of the radiated electric field produced by the cell-specific Reference Signal in the transmitted downlink signal [17].

Measurements of RS were performed in the area of “Studentski grad” in a large number of locations, as at each location are made 20 measurements and results are averaged.

4 Results and Discussion

In our investigation the measurements of RS are used to determine the path loss of the signal. For this purpose first, the transmitted power of one RE is calculated [17]

$$P_{tx\_\mathrm{RE}} = P_{tx} - 10\log_{10}(12N_{RB}) \ \text{[dBm]}, \tag{7}$$

where P_{tx_RE} is transmitted power per RE in [dBm], $P_{tx} = 46$ dBm is eNodeB transmitted power in [dBm] and N_{RB} is the number of resource blocks.

Secondly, the path loss is determined by the following equation:

$$PL = P_{tx\_\mathrm{RE}} + G_{tx} + G_{rx} - P_{\mathrm{RS\_measure}} \ \text{[dB]}. \tag{8}$$

In the above formula P_{tx_RE} is transmitted power per RE calculated by (Eq. 7) in

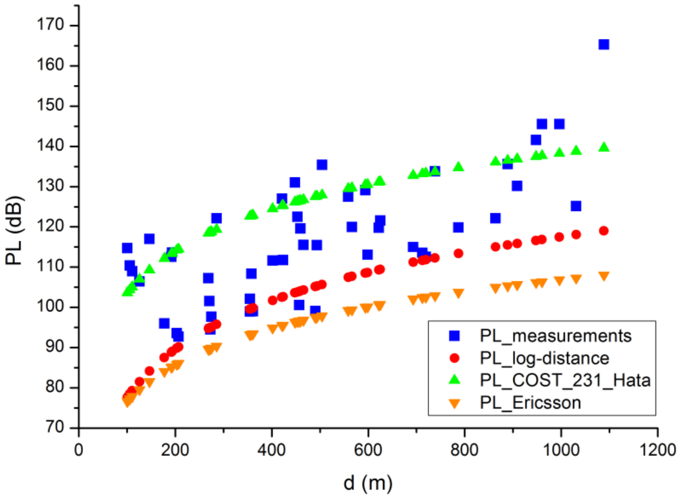

Figure 2. Experimental data and results obtained by three path loss models.

[dBm], $G_{tx} = 18$ dBi is eNodeB antenna gain in [dBi], G_{rx} is receiver antenna gain in [dBi] and $P_{\text{RS\_measure}}$ is the received power of the reference signal measured by Narda SRM 3006. In our case G_{rx} is zero, because Narda SRM 3006 is calibrated with received antenna and cables. Therefore, the results obtained for $P_{\text{RS\_measure}}$, measured by Narda SRM 3006, include receiver antenna gain and cable loss.

Using the above procedure, here are obtained experimental results for the PL dependence on the distance between transmitter and receiver (Figure 2). Presents of LOS at distances shorter than 100 m is the reason for calculation of PL for longer distances. The described in the part 2, three models are applied for calculation of the path loss in the investigated area taking into account the base station parameter $h_{bs} = 35$ m and mobile station height $h_{ms} = 1.5$ m. Obtained results for the prediction of the signal path loss are also presented in Figure 2. The comparison between our measurement results and the predictions obtained by applied empirical models shows that these three models are inadequate in investigated area in Sofia since they could lead to inaccurate value of the path loss. This is a reason for optimizing of theoretical models based on measured data. The Ericsson and log-distance models underestimate the attenuation of the signal while the results for the path loss obtained by COST 231-Hata model are closer to the experimental data values.

The root mean squire error (RMSE) of the differences between the data and the model curves are calculated for all models (Table 2).

Results show that it is necessary tuning of the models for correct prediction of the attenuation of the signal in this area. The main factors in the process of optimiz-

Table 2. RMSE before and after the tuning of the path loss models

Model	RMSE before tuning [dB]	RMSE after tuning [dB]
Ericsson	24.6	11.8
log-distance	18.8	11.8
COST-231 Hata	14.3	11.8

ing of these models are path loss exponent (dependence on d) and attenuation at a fixed distance d_0. The selected models include a different constant coefficients multiplied by the logarithm of the distance between eNodeB and UE. These coefficients are chosen for prediction of path loss in the area for which selected models are developed.

Experimental data for PL is presented in coordinate system (Figure 3) with abscise $\log(d)$, in order to determine accurate dependence of PL ($PL = a + b\log(d)$) on the distance, which to be taken in the selected models. This coordinate system allows determination of the slope ($b \approx 33.884$) of linear dependence of PL on the $\log((d(m))$ by applying the least squire method. The slope of this linear dependence is a physical quantity that gives a measure for the path loss exponent (Eq. 1) in the investigated area. In our case the calculated value of this path loss exponent is about 3.38, which is between 2 (free space) and 4 (multipath propagation). The intercept value with ordinate of this line is taken as an initial value for path loss in all models.

Results for the path loss of the signal obtained by optimized models are presented in Figure 4 and all three models correctly describe the path loss depen-

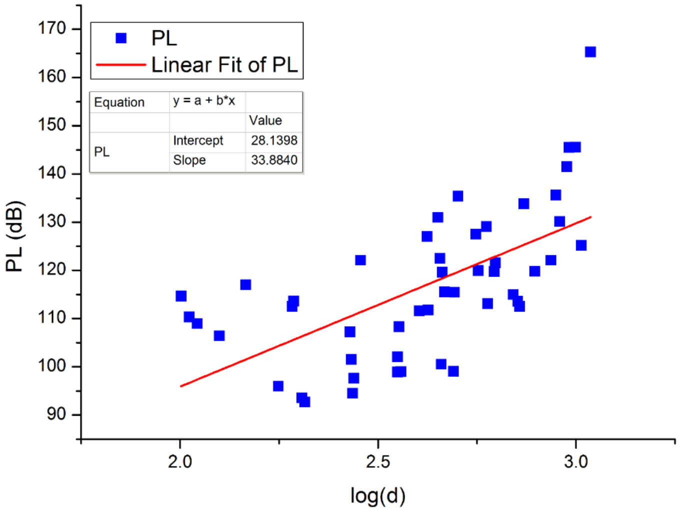

Figure 3. PL dependence on the logarithm of the distance between eNodeB and UE.

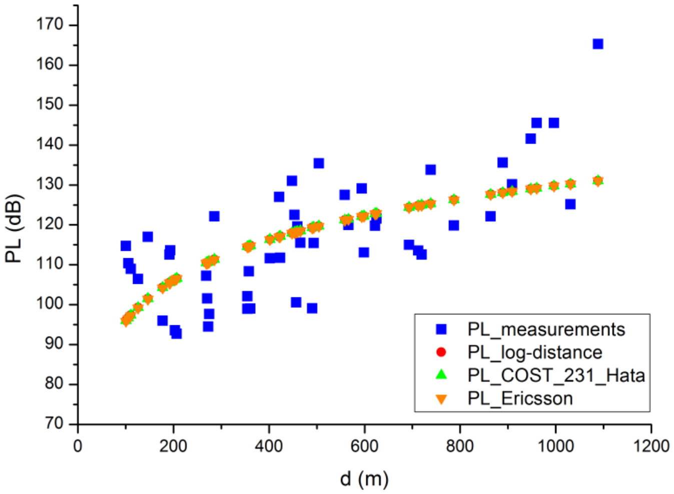

Figure 4. Comparison of optimized path loss models.

dence on the distance. This process reduces significantly the RMSE. COST-231-Hata is characterized by smaller reduction of RMSE (2.5 dB), while Ericsson model is characterized by a great reduction of RMSE (12.8 dB) (see Table 2).

The comparison of the COST-231 Hata model before and after optimization shows that formula (Eq. 3) has to be changed as follows:

$$\begin{aligned} PL = 37.78 + 33.9\log_{10}(f) - 13.82\log_{10}(h_t) - \alpha(h_r) \\ + (44 - 6.55\log_{10}(h_t))\log_{10} d + c_m \ \text{[dB]}\,. \end{aligned} \tag{9}$$

The changes are most significant is in the Ericsson model, where coefficients for urban area are optimized, as $a_0 = 59.11$ and $a_1 = 33.884$.

While in the log-distance model formula is changed as

$$PL = 95.908 + 33.884\log_{10}\left(\frac{d}{100}\right) \ \text{[dB]}\,. \tag{10}$$

The application of this optimized models allow correct prediction of path loss in the specific area in Sofia.

5 Conclusion

The LTE signal levels are precisely measured in the investigated area of Sofia and these results are compared with the three prediction models. The signal measurement results are used for optimization of empirical models. The analysis of the results obtained by optimized models show that their RMSE are significantly reduced. The COST-231-Hata has minimum deviation of RMSE before and after tuning, hence it is appropriate for describing of our experimental data. For accuracy prediction of path loss in the investigated area in Sofia is essential to use optimized models with minimum RMSE.

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References

[1] G. De la Roche, A.A. Glazunov, B. Allen (2013) "*LTE-Advanced and Next Generation Wireless Networks-Channel Modelling and Propagation*", John Wiley & Sons Ltd.

[2] L. Klozar, J. Prokopec (2011) Propagation path loss models for mobile communication. In: *Proceedings of 21st International Conference Radioelektronika*, Brno (Czech Republic), April 2011, vol. 48, pp. 1-4.

[3] R. Mardeni, K.F. Kwan (2010) *Progress in Electromagnetic Research* **13** 91-106.

[4] A. Mousa, Y. Dama, M. Najjar, B. Alsayeh (2012) *Int. J. Comput. Appl.* **60** 5-10.

[5] Ph. Atanasov, Zh. Kiss'ovski (2013) *Bulg. J. Phys.* **40** 265-268.

[6] P.K. Sharma, *et al.*(2016) Comparative analysis of propagation models in LTE networks with spline interpolation. In *2nd International Conference on Communication Control and Intelligent Systems (CCIS)*, IEEE, pp. 3-7.

[7] Ph. Atanasov, Zh. Kiss'ovski (2016) *Comptes rendus de l'Acade'mie bulgare des Sciences* **69** 1631-1640.

[8] T.S. Rappaport (2002) "*Wireless Communications: Principles and Practice*", 2nd ed., Prentice Hall.

[9] M. Hata (1980) *IEEE Trans. Veh. Technol.* **29** 317-325.

[10] Y. Okumura, E. Ohmori, T. Kawano, K. Fukuda (1968) Field strength and its variability in VHF and UHF land-mobile service. *Review of the Electrical Communication Laboratory* **16** 825-873.

[11] COST Action 231 (1999) Digital Mobile Radio Towards Future Generation Systems. COST 231 group Final Report, European Communities, EUR 18957.

[12] Ericsson Radio Systems AB (2001) TEMSTM CellPlanner 3.4 User Guide.

[13] N. Shabbir, M.T. Sadiq, H. Kashif, R. Ullah (2011) Comparison of radio propagation models for Long Term Evolution (LTE) Network, *International Journal of Next-Generation Networks (IJNGN)* **3** No.3, September 2011; arXiv:1110.1519

[14] Ph. Atanasov, Zh. Kiss'ovski (2016) Measurement of the reference signal in 4G LTE network in Sofia. In *Nat. Conf. with Int. Participation Telecom 2016*. Sofia (Bulgaria), October 2016.

[15] NARDA, Datasheet SRM-3006, [Online] Available at: `https://www.narda-sts.com/en/selective-emf/srm-3006/`

[16] NARDA, LTE Principles, [Online] Available at: `https://www.narda-sts.com/en/selective-emf/srm-3006/`

[17] NARDA, LTE Measurement and Methods, [Online] Available at: `https://www.narda-sts.com/en/selective-emf/srm-3006/`