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COMPARISON OF RADIO WAVES PROPAGATION MODELS IN URBAN AREAS

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ПОРІВНЯННЯ МОДЕЛЕЙ ПОШИРЕННЯ РАДІОХВИЛЬ В УМОВАХ МІСЬКОЇ ЗАБУДОВИ

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Abstract. *The article makes comparative evaluation of radio waves propagation models in urban areas with measurement data for Band 3 (1710–1880 MHz) and Band 7 (2500–2690 MHz) in the LTE network. The mathematical expressions for the Wolfish-Ikegami (WIM) model and the modified Hata model are given. These models are based on averaging a large amount of empirical experimental data and are the most common to solve practical problems of predicting signal levels in radio channels for various purposes. When predicting signal levels using propagation models, the relationship between the losses in the radio line and the parameters of the receiving and transmitting equipment, namely antenna suspension height, transmitter power, frequency, distance from base station, and antenna pattern is taken into account. The signal level measurement (RSRP) in the LTE network was performed for two base stations: MCC = 255, MNC = 03, CID = 41, PCI = 403, f = 2647.5 MHz and MCC = 255, MNC = 03, CID = 32, PCI = 31, f = 1837.5 MHz. The measurements were performed in two Cellular-Z and Net Monitor Lite applications that have similar and rich functionality for analyzing LTE networks. Quantitative estimates of the standard deviation of the measurement data with the signal level prediction data for two models under urban areas were obtained. The root mean square deviation in Band 3 is from 2.98 dB to 3.7 dB, and for lane 7 from 5.98 dB to 7.15 dB. In Band 3, the modified Hata model and the Wolfish-Ikegami model have approximately the same standard deviation to the measurement results. In Band 7, the modified Hatch model is more in line with the experimental data.*

Key words: *LTE, RSRP, Level Prediction, Propagation Model.*

Анотація. *В статі проведено порівняльне оцінювання моделей поширення радіохвиль в умовах міської забудови з даним вимірювань для смуги 3 (1710 – 1880 МГц) та смуги 7 (2500 – 2690 МГц) в мережі LTE. Наведено математичні вирази для моделі Вольфіша-Ікегамі (WIM) і модифікованої моделі Хата. Ці моделі засновані на усередненні великої кількості емпіричних даних експериментальних досліджень та є найбільш поширеними для вирішення практичних завдань прогнозування рівнів сигналів в каналах радіозв'язку різного призначення Вони можуть застосовуватися для різних умов поширення радіохвиль як для LOS (пряма видимість) і NLOS (непряма видимість). При прогнозуванні рівнів сигналу за допомогою моделей поширення враховано зв'язок між втратами в радіолінії та параметрами приймально-передавального обладнання, а саме висоти підвісу антен, потужність передавача, частота передавання, відстань до базової станції та діаграму спрямованості антен. Проведено вимірювання рівня сигналу (RSRP) в мережі LTE для двох базових станцій: MCC=255, MNC=03, CID=41, PCI=403, f=2647,5 МГц та MCC=255, MNC=03, CID=32, PCI=31, f=1837,5 МГц. Вимірювання проведено у двох програмах Cellular-Z та Net Monitor Lite, що мають схожий та багатий функціонал для аналізу мереж LTE. Отримані кількісні оцінки середньоквадратичного відхилення даних вимірювань з даними прогнозування рівня сигналу для двох моделей в умовах міської забудови. Середньоквадратичне відхилення в смузі 3 становить від 2,98 дБ до 3,7 дБ, а для смуги 7 від 5,98 дБ до 7,15 дБ. У смузі 3 модифікована модель Хата та модель Вольфіша-Ікегамі мають приблизно однакові середньоквадратичного відхилення до результатів вимірювань. У смузі 7 модифікована модель Хата більше відповідає експериментальним даним.*

Ключові слова:*LTE,RSRP, прогнозування рівня, модель поширення.*

1 INTRODUCTION

The energy characteristics of radio channels form the basis for the calculation of radio coverage zones and determination of conditions for envisaging electromagnetic compatibility of radio electronic means. The widespread introduction of mobile radio systems in Bands above 1GHz has caused increased interest in the study of radio waves propagation conditions and the development of channel calculation approach. Radio waves propagation models are mathematical tools used to build and optimize wireless networks. These models focus on the prediction of the average signal power, the preset distance from the transmitter, as well as the variability of the signal power in the immediate spatial proximity to a specific location. These models can be divided into two groups: empirical (statistical) and deterministic.

Statistical models based on averaging a large amount of empirical data from experimental studies of field strength obtained under different conditions of radio communication organization have gained wider practical application.

At the same time, it remains relevant to study the propagation of radio waves in order to select a propagation model for specific conditions of radio network organization [1, 2]. In this work makes a comparative analysis of the results of calculations of energy characteristics, performed on different models of propagation of radio waves and comparison of the results with the measured characteristics of radio channel.

2 OVERVIEW OF RADIOWAVES PROPAGATION MODELS

Currently, the statistical model of the Wolfish-Ikegami (WIM) [3, 6] and the modified Hata model [4, 5] are most widely used to solve practical problems of predicting signal levels in radio channels of various purpose. These models along with ITU-R P.1546-6 and ITU-R P.1812-5 [7] are recommended for use by the International Telecommunication Union for predicting signal strengths of mobile radio systems.

The modified Hata model is a further development of the Okumura-Hata model obtained from experimental studies in Tokyo. For urban areas, the propagation loss of a modified Hata model is determined by frequency.

For frequencies 150 MHz $< f \leq$ 1500 MHz

$$L = 69.6 + 26.2\lg(f) - 13.82\lg(\max\{30, H_b\}) + \\ + \alpha\left[44.9 - 6.55\lg(\max\{30, H_b\})\right]\lg(d) - a(H_m). \quad (1)$$

For frequencies 1500 MHz <f $\leq$ 2000 MHz

$$L = 46.3 + 33.9\lg(f) - 13.82\lg(\max\{30, H_b\}) + \\ + \alpha\left[44.9 - 6.55\lg(\max\{30, H_b\})\right]\lg(d) - a(H_m). \quad (2)$$

For frequencies 2500 MHz <f $\leq$ 3000 MHz

$$L = 46.3 + 33.9\lg(2000) + 10\lg(f/2000) - 13.82\lg(\max\{30, H_b\}) + \\ + \alpha\left[44.9 - 6.55\lg(\max\{30, H_b\})\right]\lg(d) - a(H_m). \quad (3)$$

f – frequency, MHz; $H_m = \min\{h_1, h_2\}$ – minimum of the heights of the two antennas considered, m; $H_b = \max\{h_1, h_2\}$ – maximum of the heights of the two antennas considered, m; d – distance, km, should be less than 100 km; $a(H_m)$ –smallest antenna height correction factor:

$$a(H_m) = (1.1\lg(f) - 0.7)\min\{10, H_m\} - (1.56\lg(f) - 0.8) + \max\{0.20\lg(H_m/10)\}. \quad (4)$$

Another model under consideration is the Wolfish-Ikegami (WIM) model. WIM model is used in calculation of attenuation in an urban environment. This model can be used in cases where the base station antenna is located both above and below the line of the roof level. The empirical factors taken into account in the calculation formula include the antenna heights of the base and moving station, the width of streets, the distance between buildings, the height of the buildings and the orientation of the streets in the direction of signal propagation.

In the WIM model, there are two cases: line-of-sight (LOS) and non-line-of-sight (NLOS) propagations. In the case of LOS, if there are no obstacles on the direct signal propagation from the transmitter and receiver, then the WIM model is described by the equation [6]:

$$L_{\text{los}} = 42.6 + 26\lg d_{\text{km}} + 20\lg f_{\text{MHz}}, \quad d \ge 0.02\ldots0.2\text{ km}. \tag{5}$$

Before considering NLOS model let us introduce the following parameters used in this model:

d_{km} – distance in km; b – distance between building (20–50 m); ω – width of streets (usually b/2); h_{BS} – base station antenna height (30–50 m from the ground); h_{m} – height of the antenna of user (1–3 m from the ground); h_{r} – height of buildings;

In the case of NLOS WIM model is described by the equation [6]:

$$L_{\text{nlos}} = L_{\text{fs}} + L_{\text{rts}} + L_{\text{msd}}; \tag{6}$$

L_{fs} – free-space loss:

$$L_{\text{fs}} = 32.4 + 20\lg d_{\text{km}} + 20\lg f_{\text{MHz}}; \tag{7}$$

L_{rts} –diffraction loss and scattering by the roof of buildings:

$$L_{\text{rts}} = -16.9 - 10\lg(w) + 10\lg(f) + 20\lg(h_{\text{r}} - h_{\text{m}}) + L_{\text{ori}}(\varphi); \tag{8}$$

$L_{ori}(\varphi)$ –loss from the angle between the street and the electromagnetic wave:

$\varphi = 0$, if the street and the incident wave are parallel;

if $0 \le \varphi \le 35$ than $L_{\text{ori}}(\varphi) = -10 + 0.354\varphi$;

if $35 \le \varphi \le 55$, than $L_{\text{ori}}(\varphi) = 2.5 + 0.075\varphi$;

in other cases $L_{ori}(\varphi) = 4 + 0.114\varphi$

L_{msd} –losses from multiple diffraction:

$$L_{\text{msd}} = L_{\text{bsh}} + k_{\text{a}} + k_{\text{d}}\lg(d) + k_{\text{f}}(f)\lg(f) - 9\lg(b); \tag{9}$$

$L_{\text{bsh}} = -18\cdot\lg(1 + h_{\text{BS}} - h_{\text{r}})$ if $h_{\text{BS}} > h_{\text{r}}$, in other cases $L_{\text{bsh}} = 0$;

$k_{\text{a}} = k_{\text{a1}}$ if $h_{\text{BS}} \le h_{\text{r}}$, in other cases $k_a = 54$;

$k_{\text{a1}} = 54 - 0.8\cdot(h_{\text{BS}} - h_{\text{m}})$ if $d \ge 0.5$, in other cases $k_{\text{a1}} = 54 - 0.8(h_{\text{BS}} - h_{\text{m}})\cdot\dfrac{d}{0.5}$;

$k_{\text{d}} = 18$ if $h_{\text{BS}} > h_{\text{r}}$, in other cases $k_{\text{d}} = 18 - 15\dfrac{h_{\text{BS}} - h_{\text{r}}}{h_{\text{r}}}$;

$k_{\text{f}}(f) = -4 + 0.7\cdot\left(\dfrac{f}{925} - 1\right)$.

3 CONDUCTING AN EXPERIMENT TO MEASURE RADIO SIGNAL PARAMETERS IN URBAN AREAS

The purpose of the experiment is to measure the dependence of the signal level in the conditions of urban areas in the LTE network from the distance to the antenna of the base station and compare the obtained results with the calculations by the models of Hata and Wolfish-Ikegami.

During measurements, such parameters of radio signal reception are determined:

RSSI (Received Signal Strength Indicator) is received signal level indicator, shows the average total receiving power in OFDM characters. The received wide Band power, including thermal noise and noise generated in the receiver, within the Bandwidth defined by the receiver pulse shaping filter. The reference point for the measurement shall be the antenna connector of the UE. If receiver diversity is in use by the UE, the reported value shall not be lower than the corresponding UTRA carrier RSSI of any of the individual receive antenna branches. [8]

RSRP (Reference Signal Received Power is defined as the linear average over the power contributions (in [W]) of the resource elements that carry cell-specific reference signals within the considered measurement frequency Bandwidth. [8] The RSRP parameter measures the signal strength in a particular sector, excluding noise and interference from other sectors. RSRP levels for the signal range from -75 dBm near the LTE cell to -120 dBm at the cell coverage boundary.

RSRQ (Reference Signal Received Quality) characterizes the quality of the received pilot signals. The RSRQ measurement provides additional information when the value of the RSRP parameter is insufficient to make a decision about the handover or when the cell is re-selected.

SNR – signal-to-noise ratio.

Measurements were made in two applications: Cellular-Z and Net Monitor Lite. These applications have similar and rich functionality for analyzing LTE networks, namely:

– displaying RSSI, RSRP, RSRQ, SNR values online, including for neighboring cells;

– possibility of graphical representation of corresponding parameters;

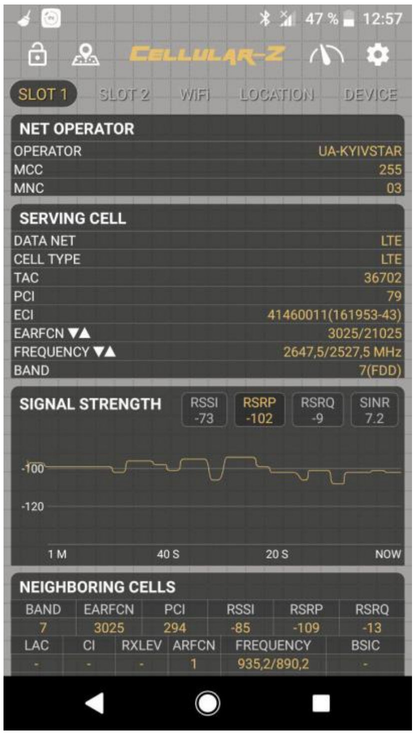
– display of the movement of the subscriber equipment on the map with the display of the level of the parameter to be measured;

– display information about the base station serving the subscriber, such as MCC (mobile country code) is country code in which the BS is located, MNC (mobile network code) is cellular network code, LAC (local area code) is local area code, CID is cell ID, an option provided by the operator to each sector for each BS.

The disadvantages of these two programs are that they do not show the location of the BS from which the signal is received. There is a Network Cell Info Lite program that displays the location of the BS serving the subscriber, but this program does not allow the creation of tables for further processing and analysis of measurement results.

The interfaces of both programs are shown in Figure 1.

a)Interface Net Monitor Lite



б) Interface Cellular-Z

Figure 1– Interfaces for measurement of signal level dependence in urban areas conditions in the LTE network

Measurements were made for the following cases:

– measuring of RSRP of base station of the «Kyivstar» operator MCC = 255, MNC = 03, CID = 41, PCI = 403, f = 2647.5 MHz;

– measuring of RSRP of base station of the «Kyivstar» operator MCC = 255, MNC = 03, CID = 32, PCI = 31, f = 1837.5 MHz.

4 COMPARISON OF EXPERIMENTAL DATA WITH THEORETICAL MODELS DATA

When predicting signal levels by means of propagation models, the relation between the losses in the radio line and the parameters of the transceiver equipment is determined by the following expression:

$$L = \mathrm{EIRP} - P_{\min}; \quad (10)$$

EIRP – equivalent isotropic radiated power, dBm; $P_{\min}$ – signal level at the input of the receiver, dBm;

EIRP is equal to:

$$\mathrm{EIRP} = P_{\mathrm{BS}} + \left(G_{\mathrm{BS}} - F(\Delta,\varphi)\right) - \eta, \quad (11)$$

where P_{BS} –output power of transmitter, дБм; G_{BS} –gain of transmitting antenna relative to isotropic antenna, dB; η – loss of the antenna feeder path, dB. $F(\Delta,\varphi)$ – a factor that takes into account the decrease in radiated power due to the radiation pattern.

In the main direction, this coefficient equals 0. In the general case, calculated by the formula:

$$F(\Delta,\varphi) = 20\lg\left[\frac{E(\Delta)}{E_{max}}\right] + 20\lg\left[\frac{E(\varphi)}{E_{cep}}\right], \quad (12)$$

where $E(\Delta)/E_{max}$ and $E(\varphi)/E_{mid}$ – normalized antenna patterns in the vertical and horizontal planes, respectively; E_{max} – the maximum value of the field strength in the vertical plane; E_{mid} – the average value of the field strength in the horizontal plane (for a circular pattern); Δ, φ – position angle and azimuth of radiation respectively.

The simulation parameters are shown in Table 1.

Table 1 – Simulation parameters

Parameter	Value
Frequency	1710–1880 MHz (Band 3 LTE) 2500–2690 MHz (Band 7 LTE)
Antenna type	80010691v01
Maximum distance	0,5 km
Transmitting antenna height	30 m
Receiving antenna height	1,5 m
Bandwidth	15 MHz
Transmiter power	5 W
Antenna gain	15,2–15,8 dBi
Feeder Loss	1 dB

Figures 2,3 show a comparison of signal level measurement (RSRP) data in the LTE network in Band 3 and Band 7 with signal level prediction data.

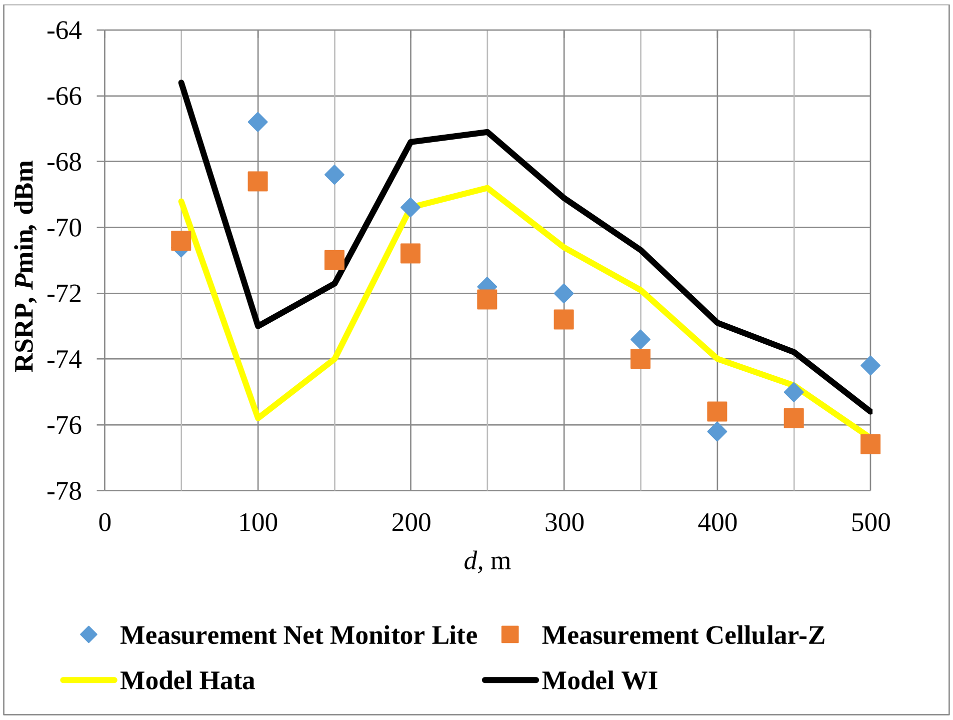


Figure 2 –Comparison of signal level measurement (RSRP) data in LTE Band 3 with signal level prediction data

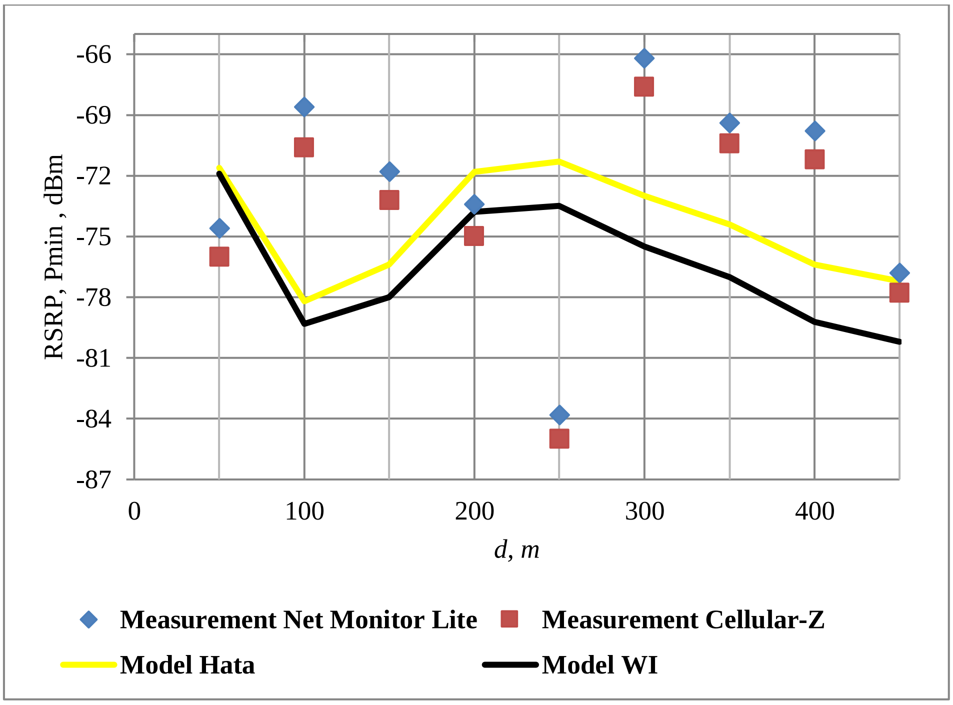


Figure 3 –Comparison of signal level measurement (RSRP) data in LTE Band 7 with signal level prediction data

Table 2 shows the standard deviation of the predicted values for the propagation models from the measurement values.

Table 2 –Estimation of standard deviation propagation models from measured data.

	Standard deviation			
	Band 3		Band 7	
	Hata	WIM	Hata	WIM
Net Monitor Lite	3.7 дБ	3.61 дБ	6.29 дБ	7.15 дБ
Cellular-Z	2.98 дБ	3.43 дБ	5.98 дБ	6.52 дБ

From Table 2 it can be concluded that according to the criterion of standard deviation in Band 3 modified Hata model and Wolfish-Ikegami model have approximately the same standard deviation in the measurement results. In Band 7 modified Hata model more corresponds to experimental data than Wolfish-Ikegami model because standard deviation is less.

Therefore for Band 3 both models are almost equivalent and for Band 7 it is more appropriate to use a modified Hata model which provides greater accuracy in signal level prediction.

5 CONCLUSION

The article considers the propagation models in urban areas, namely modified Hata model and Wolfish-Ikegami model. Using these models, was simulated a loss of propagation of radio waves, with the estimation of the signal level taking into account of the parameters of the LTE network planning for Band 3 and Band 7.

The simulation results obtained are compared with the signal level measurements (RSRP) in the LTE network in urban areas. Standard deviation in Band 3 is from 2.98 dB to 3.7 dB, for Band 7 standard deviation is from 5.98 dB to 7.15 dB.

In the general case in Band 3 modified Hata model and Wolfish-Ikegami model have approximately the same standard deviation in measurements results. In Band 7 modified Hata model more consistent with experimental data.

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