Mobile Signal Path Losses in Microcells behind Buildings

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Abstract. *The paper presents measurement results of the GSM (900 MHz band), UMTS (2100 MHz band), and LTE (1800 MHz band) propagation path loss (PL) in the urban area behind the buildings of ten different heights. The results were compared with the 7 most popular models. It was found that the existing models approximate the experimental results with relatively large errors. The new model, which evaluates the path loss variation nature behind the buildings, is proposed. This new model shows good agreement with measurements for all three mobile technologies. The average relative error is less than 6.5 %.*

Keywords

Cellular networks, radio wave propagation, mobile communications

1. Introduction

The number of mobile phone users is growing at high speed. This is related more to data services demand growth than to the needs of a voice service. Some of mobile phone manufacturers predict that the number of smart phone users will be more than 9.1 billion by 2020 [1]. The data transfer rate, compared with 2015, will increase 8 times and monthly global mobile data traffic will exceed 24.3 exabytes by 2019 [2]. Therefore, it will be necessary for such technologies, which can provide the high data transmission speed and quality. It will be done in the development of new technologies (5G and other) as well as improving the existing ones.

Most countries plan that 5G technology will be realized at frequencies exceeding 10 GHz [3]. However, as it is well known, the increase in frequency causes the decrease of the distance between the base station (hereinafter BS) and User Equipment (hereinafter UE). Therefore, it can be assumed that high speed data will be ensured at the relatively short distances: less than 500 m between the BS and the UE. The mobile coverage planning becomes very important in this case. The accuracy of this planning will be determined by the propagation model accuracy. In this way, the models assessing different effects in the microcells will require the 5G networks planning. Those effects are: reflection, diffraction, refraction, scattering, shadowing, and penetration. However, in order to investigate the 5G it is necessary to have deeper knowledge of the mobile signal propagation characteristics in the microcells for already existing technologies.

The main objectives of this work is to experimentally investigate the path losses in microcells for GSM, UMTS, LTE technologies, to compare these experimental data with the existing propagation prediction models and, if necessary, to propose a new path loss model. This work is continuation of [4] where the 2G technology signal propagation behind the buildings is analyzed.

2. Related Works

Currently, there are quite a lot of models (it is possible to charge more than 60), which allow to assess the propagation losses both in macrocells and microcells. All these models have certain limitations: according to frequency, to the distances between base station BS and user equipment UE, to BS and UE antenna heights, etc. Okumura-Hata and COST 231 Hata are the most popular propagation loss prediction models in macrocells. The path losses in the microcells are usually predictable using Walfish-Ikegami, LEE, ECC 33, Two slope, SUI, and other models. All these models are the functions of the distance between the BS and UE d_{BS}, frequency f, BS and UE antenna highs h_{BS}, and h_{UE} respectively, certain correction coefficients groups C_{n}:

$$PL = \phi\left(d_{\mathrm{BS}}, h_{\mathrm{BS}}, h_{\mathrm{UE}}, f, C_{\mathrm{n}}\right). \tag{1}$$

Some microcells models try to assess the diffraction and reflection effects using additional parameters, such as: the certain angles α, building heights h_{b}, certain spaces (street width) dimensions d_{r} (e.g., Walfish-Ikegami model) or terrain roughness h_{t} (Lee models). The path losses are described as the function in (2):

$$PL = \phi\left(d_{\mathrm{BS}}, h_{\mathrm{BS}}, h_{\mathrm{UE}}, f, C_n, \begin{cases} \alpha, h_{\mathrm{b}}, d_{\mathrm{r}} \\ h_{\mathrm{t}} \end{cases}\right). \tag{2}$$

Some of the works in order to approximate the path losses data in the microcells use models that formally have to be applied only in the macrocells (Okumura-Hata, COST 231 Hata, etc.) [4–9]. However, these macrocell models results do not differ from microcells models (Walfish-Ikegami, ECC 33, Two slope, etc.) results according to the

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accuracy. The above-mentioned works very clearly show this. The works' analysis shows that only certain models at the certain distance from the BS areas may coincide with the experimental results. But at the other distances, the same model results differ from experimental results rather significantly. In particular, the experimental and theoretical results show the clear mismatches in short distances from BS. The experimental results in [7] are well approximated using the SUI model but only over the distances of 300 m. The error between the experimental and model results can reach up to 30 % when the distances are shorter. The experimental results in [8] are compared with the Walfish-Ikegami model results; it is seen that at the distances from the BS shorter than 500 m the results mismatch is significantly higher than 10%. In addition, these experimental results show the clear results scattering similar to the slow fading influence. And it does not depend on the frequency and area (urban or suburban) where measurements are carried out [10]. However, none of models does not evaluate such results scattering. Sometimes there is an attempt to modify the known model using the obtained experimental results. But often such modified models provide not sufficiently good approximations even for the experimental results which were received at the same work. For example, in [11] the optimized Hata model is proposed, it gives good result coincidences in BS1 and BS3 stations. Meanwhile the error can reach about 10% for the BS4 case in the distances between 500 m and 1000 m. Furthermore, there is clearly seen that the errors between the experiment and modeling results are significant at less than 200 m distances.

The received results are spread out in the wide range of path losses values and seem as the certain „swarm“ when the sufficient number of experimental measurements are carried out in the microcells [12–15]. Such "swarm" is also observed at short distances between BS and UE (less than 200 m) when the frequency is high enough (> 20 GHz) [16–18].

Thus, the works' analysis shows that there is still important to investigate the path loss changes in the microcells, especially for short distances between BS and UE.

3. Experimental Setup

The two base stations (hereinafter BS1 and BS2) near Kaunas University of Technology have been chosen for the experiments. The areas around BS1 and BS2 are densely populated. These base stations support GSM (EDGE), UMTS and LTE mobile technologies. Buildings of different heights, at the distances less than 50 m from each other, are in BS1 and BS2 coverage areas. The path losses variation of GSM, UMTS and LTE in BS1 coverage area and only GSM path losses variation in the BS2 coverage area were researched. BS1 frequency for the GSM is 956 MHz, for the UMTS is 2127 MHz, for the LTE is 1819 MHz. BS1 antennas height h_{BS1} is 43 m, ERP (equivalent radiated power) is 62.82 dBm for UMTS, and LTE for GSM ERP is 38.81 dBm. BS2 frequency (GSM) is 945 MHz, antennas height h_{BS2} is 32 m and ERP is 40.01 dBm. Receiver (UE) antennas height h_{UE} was constant at 1.3 m.

Table 1 summarizes the main experimental parameters. h_{b} means the height of the building, d_{BS} means the distance between the base station and the measurement point.

The signal strength measurements were carried out with a spectrum analyzer Anritsu Cell Master MT8212A; its frequency measurement range is from 10 MHz to 3.0 GHz. The results were processed using specialized software Handheld Software Tools (HHST 6.61). The measurements were carried out up to 500 m distance from the base station. UMTS and LTE signals were simultaneously measured and recorded in the spectrum analyzer's memory. GSM signal strength measurements were carried out at other times in similar weather conditions. The signal strength characteristics of behind the 17 buildings whose height varied from 6 to 41 m were measured. In some cases, buildings of the same height are at different distances from the BS. The measurements were carried out behind the building. The first measurement point was chosen at the distance of 1 m from the rear (with respect to the BS) wall of the building. The signal strength was measured every 5 m (UMTS and LTE) and 2 m (GSM), gradually moving away from the house. Ten measurements

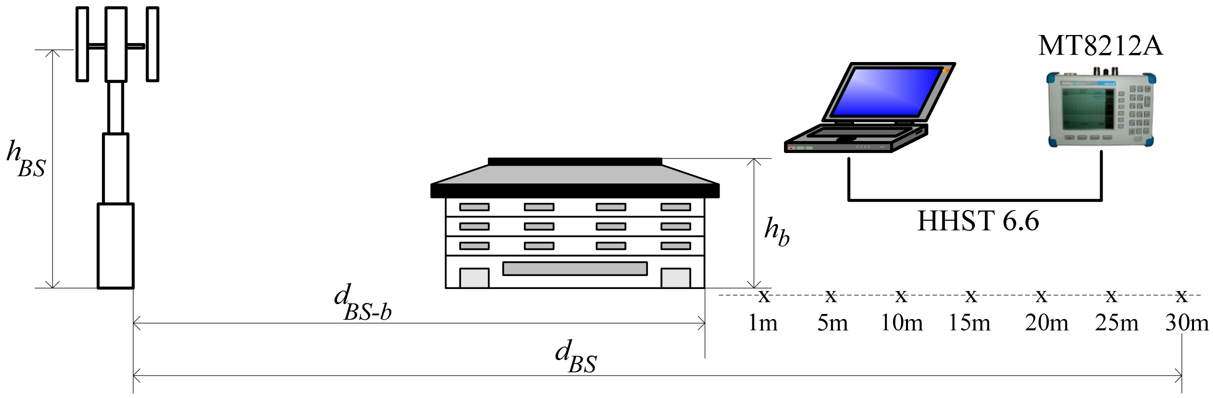

Fig. 1. Experiment scheme (sign x means the measuring point).

	BS1			BS2
	2G	UMTS	LTE	
Frequency [MHz]	956	2127	1819	945
Base station antenna height [m]	43			32
ERP [dBm]	38.81	62.82		40.01
h_{UE} [m]	1.3			
h_{b} [m]	6 – 41			12 – 22
d_{BS} [m]	< 450			
$d_{\mathrm{BS\text{-}b}}$ [m]	< 321	< 302		<382

Tab. 1. Experimental parameters.

were carried out in each point and the results were averaged. The experiment scheme is shown in Fig. 1. The $h_{\mathrm{BS\text{-}b}}$ means the distance from the BS to the building far edge.

The various errors were calculated in order to evaluate the results accuracy according to (3): the relative error δ, the root-mean-square of the measurement result, the root-mean-square of the measurements' mathematical expectation, dispersion σ and skewness γ:

$$\begin{cases} \delta = \dfrac{\frac{1}{n}\left|RSL_i - \langle RSL\rangle\right|}{\langle RSL\rangle}\cdot 100\%, \\ \sigma = \dfrac{1}{n}\sum\limits_{i=1}^{n}\left(RSL_i - \langle RSL\rangle\right)^2, \\ S_{\mathrm{RSL}} = \sqrt{\dfrac{\sum\limits_{i=1}^{n}\left(RSL - \langle RSL\rangle\right)^2}{n-1}}, \\ S_{\langle \mathrm{RSL}\rangle} = \dfrac{S_{\mathrm{RSL}}}{n}, \\ \gamma = \dfrac{\frac{1}{n}\sum\limits_{i=1}^{n}\left(RSL_i - \langle RSL\rangle\right)^3}{\left(S_{\mathrm{RSL}}\right)^3}. \end{cases} \qquad (3)$$

where RSL_i is the signal strength of the separate measuring, dBm; $\langle RSL\rangle$ is the mathematical expectation, dBm; n is the number of measurements.

By summarizing all received errors it was found that the average relative error δ is about 4% for all measurements, the root-mean-square S_{RSL} is about 1.63 dBm, the root-mean-square of the measurement mathematical expectation is $S_{\langle \mathrm{RSL}\rangle}$ is about 0.47 dBm, the dispersion σ is about 9.55.

4. Results

The path loss dependence on technology and the distance d_{BS} is shown in Fig. 2. Very clear dependence on technology can be seen there. The biggest path loss is observed on LTE technology and the lowest to GSM (EDGE). It is seen that the path losses react stronger to the increase of d_{BS} for GSM technology than for UMTS or LTE.

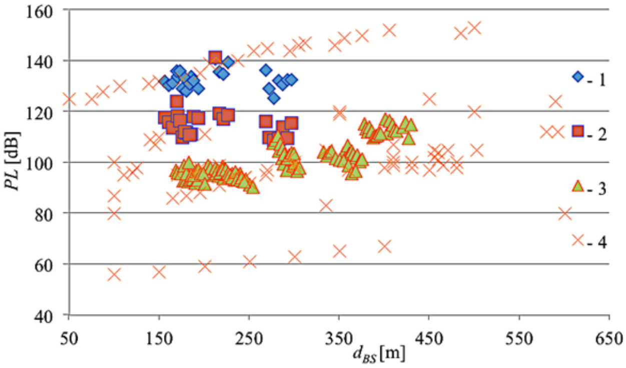

Fig. 2. Comparison of experimental results with the results of [5–7, 19–21]: LTE path loss – 1; UMTS path loss – 2; GSM path loss – 3; results of [5–7, 19–21] – 4.

It can be seen that the results in Fig. 2 are similar to "swarm", as in the results of the other authors. Such "swarm" of the results is due to the fact that results are shown without taking into account the measurement environment of a particular case: the influence of buildings, the measuring point location behind the buildings, the building height, whether the measured path loss is on the line of sight or non-line of sight with the base station, influence of trees, etc. All these environmental factors influence the path losses and, in order to make very accurate assessment of path losses, it is necessary to take into account these factors.

The cumulative distribution function CDF dependence on the path losses for different mobile technologies is shown in Fig. 3; it shows that using more sophisticated signal-forming technology shifts curve to the right. This fact statistically demonstrates that the higher-generation mobile technologies lead to higher path loss. The slope of the curves shows that the smallest errors are received for LTE technology, when the largest errors are for GSM technology. It seems that the highest technology gives the better accuracy.

The experimental path losses results are compared with the most popular 7 models results (Fig. 4); these models approximated the experimental results with relatively high errors. Table 2 summarizes the main propagation model expressions.

However, there is at least one model for the different technologies that allows to evaluate the experimental re-

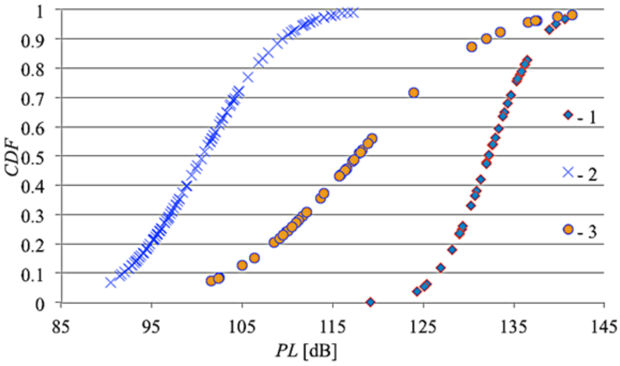

Fig. 3. Experimental path loss CDF for different mobile technologies: LTE – 1, UMTS – 2, GSM – 3.

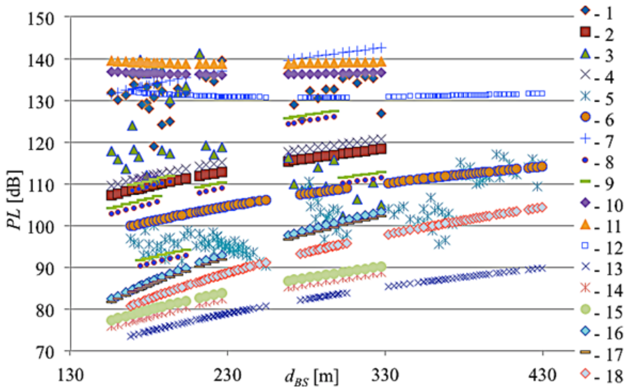

Fig. 4. Comparison of experimental results with some models prediction results: LTE experiment – 1, COST231-Hata (LTE) – 2, UMTS experiment – 3, COST231-Hata (UMTS) – 4, GSM experiment – 5, Okumura Hata (GSM) – 6, Multislope (LTE) – 7, Walfish-Ikegami (LTE) – 8, Walfish-Ikegami (UMTS) – 9, ECC 33 (LTE) – 10, ECC 33 (UMTS) – 11, ECC 33 (GSM) – 12, Clutter Factor (GSM) – 13, Clutter Factor (LTE) – 14, Clutter Factor (UMTS) – 15, Two slope (UMTS) – 16, Two slope (LTE) – 17, Two slope (GSM) – 18.

sults with reasonable errors. For the GSM, the best results (δ is about 18%) are achieved with the SUI and Okumura-Hata models; Hata model gives the best results (δ is about 30%) for UMTS; and Multi-slope model gives the best results (δ more than 10%) for LTE.

The other fact is also seen in Fig. 4. Although in general, the path losses increase with the d_{BS} increasing. The path losses behind the buildings relatively decrease with the distance from BS.

A few things can be seen after analyzing the path losses variation for the different building height and for the different mobile technologies. In particular, this path loss variation can be approximated by linear equation $PL = a\cdot d_{BS} + b$. In addition, when the height of the buildings h_b is the same, but d_{BS} is different, the PL variation can be approximated with the parallel straight lines i.e., the slope of the straight line which is defined by coefficient a does not depend on d_{BS}, but it depends on h_b. Moreover, this coefficient does not strongly depend on mobile technology. The typical examples of these experiments are shown in Fig. 5.

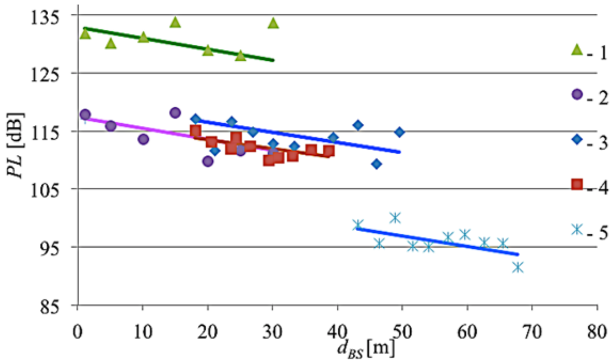

Fig. 5. Path losses variation vs distance behind the building for 18 m high buildings: LTE – 1, UMTS – 2, GSM – 3-5, approximation of results – solid lines.

Model	Description
Okumura Hata	$PL = 69.55 + 26.16\cdot\lg(f) - 13.82\cdot\lg(h_b) - a(h_m) + [44.9 - 6.55\cdot\lg(h_b)]\cdot\lg(d)^b,$ $a(h_m) = 3.2\cdot[\lg(11.75\cdot h_m)]^2 - 4.97),$ $b = 1,\ d \le 20\,\text{km}$
COST231-Hata	$PL = 46.3 + 33.9\cdot\lg(f) - 13.82\cdot\lg(h_b) - a(h_m) + [44.9 - 6.55\cdot\lg(h_b)]\cdot\lg(d) + C_m;$ $a(h_m) = 3.2\cdot[\lg(11.75\cdot h_m)]^2 - 4.97).$
Two slope	$L_{\text{NEAR}} = L_{\text{OH}}(d_{\text{BP}}) + slope_{\text{L}}[\lg(d) - \lg(d_{\text{BP}})],$ $slope_{\text{L}} = \frac{L_{\text{BP}}(d_{\text{BP}})\cdot\lg(d_{\text{BP}}) - L_{\text{FS}}(d_{20})\cdot\lg(d_{20})}{\lg(d_{\text{BP}}) - \lg(d_{20})}$
Multi-slope	$L_{3S} =$ $32.44 + 20\cdot\lg(f) + 10\cdot\lg\left[\frac{d^2 + (h_b - h_m)^2}{10^6}\right],$ $d < 0.04\,\text{km};$ $L_{3S} =$ $L(d_{40}) + \frac{\lg(d) - \lg(d_{40})}{\lg(d_{100}) - \lg(d_{40})}\cdot[L(d_{100}) - L(d_{40})],$ $0.04\,\text{km} < d < 0.1\,\text{km}$
ECC 33	$PL = A_{fs} + A_{bm} - G_t - G_r;$ $A_{fs} = 92.4 + \lg(d) + \lg(f);$ $A_{bm} = 20.41 + 9.83\cdot\lg(d) + 7.89\cdot\lg(f) + 9.56\cdot[\lg(f)]^2;$ $G_t = \lg\left(\frac{h_b}{200}\right)\cdot\left[13.958 + 5.8\cdot(\lg(d))^2\right];$ $G_r = [42.5742 + 13.7\cdot\lg(f)]\cdot[\lg(h_m) - 0.585].$
Walfish-Ikegami	$L_b = \begin{cases} L_o + L_{rts} + L_{msd}, & L_{rts} + L_{msd} > 0; \\ L_o, & L_{rts} + L_{msd} \le 0. \end{cases}$
Clutter Factor	$L = 40\cdot\lg(d) + 20\cdot\lg(f_c) - 20\cdot\lg(h_b) + L_m;$ $h_b,\ h_m \ll d,\ L_m = 76.3 - 10\cdot\lg(h_m).$

Tab. 2. Propagation model expressions.

The path losses variation for 18 m high buildings at different distances from the behind the buildings d_{BS} are shown there. Qualitatively similar results are observed in all other experiments.

The coefficient b determines the initial path loss level at the first measurement point behind the building and it should depend on the distance from the building and frequency. The variation of the straight coefficients a and b, depending on height of building and distance from the building, respectively is shown in Fig. 6 and Fig. 7.

Figure 6 shows that the coefficient a decreases with the increasing of the building height and the decrease is approximated according to line equation (4) with the mean relative error δ of about 7.96%.

$$a = -(0.0037\cdot h_b + 0.1249). \tag{4}$$

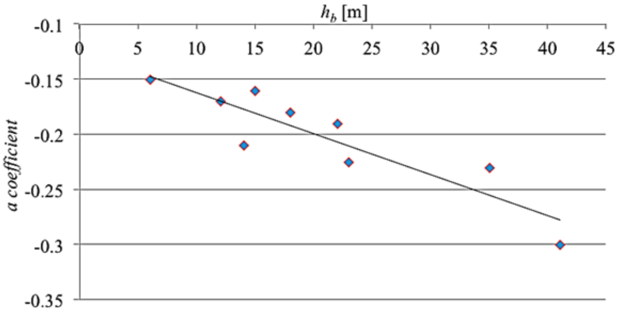

Fig. 6. *a* coefficient variation vs the building high h_b: experimental data – 1, approximation of results – solid line.

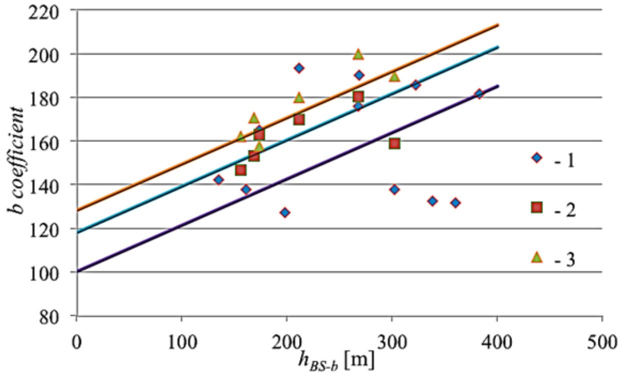

Fig. 7. *b* coefficient variation vs distance from BS $d_{\text{BS-b}}$: GSM – 1, UMTS – 2, LTE – 3, approximation of results – solid lines.

The variation of the coefficient *b*, as can be seen from Fig. 7, depends on the distance from the BS to the building $d_{\text{BS-b}}$, mobile technology and frequency *f*. The variation of the coefficient *b* could be approximated with the parallel line equations (5) for all experimental cases independently from the mobile technology:

$$b = \left(0.2125 \cdot d_{\text{BS-b}} + 20\lg f_{[\text{MHz}]} + \begin{cases} 40.4 \ldots \text{for GSM} \\ 51.5 \ldots \text{for UMTS} \\ 62.8 \ldots \text{for LTE} \end{cases} \right). \tag{5}$$

Comparing the results of the model with the experimental results it was noticed that in some cases the error exceeds 10%. It was observed that when tg*α* (Fig. 8) is less than 0.05, then there is the need to add the correction factor *CF*. In this case equation (5) is:

$$b = \left(0.2125 \cdot d_{\text{BS-b}} + 20\lg f_{[\text{MHz}]} + \begin{cases} 40.4 \ldots \text{for GSM} \\ 51.5 \ldots \text{for UMTS} \\ 62.8 \ldots \text{for LTE} \end{cases} \right) \cdot \\ (-8.98 \cdot \mathrm{tg}\,\alpha + 1.436). \tag{6}$$

Equation (5) and (6) approximate experimentally determined values of coefficient *b* with the following mean relative error: for GSM δ is about 6.47%, for UMTS δ is about 4.75% and for LTE δ is about 3.85%. Thus, by evaluating (4), (5) and (6), the path losses behind the buildings in microcells can be approximated by the equation:

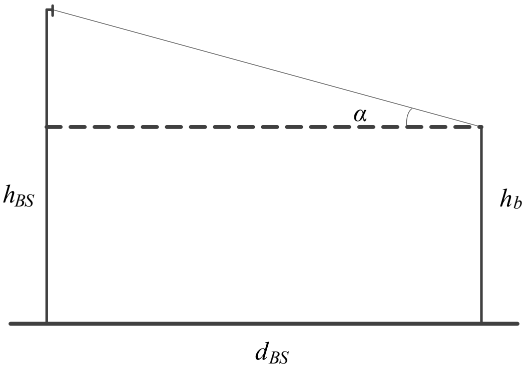

Fig. 8. Diagram explaining the angle α.

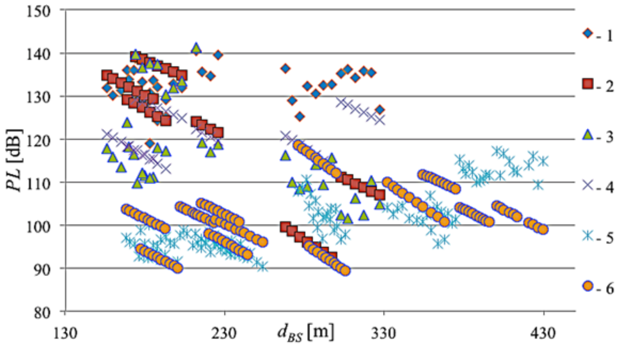

Fig. 9. Comparison of experimental results with the proposed model (7) results: LTE experimental results – 1, LTE model – 2, UMTS experimental – 3, UMTS model – 4, GSM experimental – 5, GSM model – 6.

$$PL = -\left(0.0037 \cdot h_{\text{b}} + 0.1249\right) \cdot d_{\text{BS}} + \\ \left(0.2125 \cdot d_{\text{BS-b}} + 20\lg f_{[\text{MHz}]} + \begin{cases} 40.4 \ldots \text{for GSM} \\ 51.5 \ldots \text{for UMTS} \\ 62.8 \ldots \text{for LTE} \end{cases} \right) \cdot CF \tag{7}$$

where *CF* is 1 if tg$\alpha > 0.05$ and *CF* is (–8.98·tgα + 1.436) if tg$\alpha \leq 0.05$.

The comparisons of the experimental results with the proposed model results are shown in Fig. 9.

The results coincide well enough and the average relative error does not exceed 6.5%. The calculated skewness γ shows that the deviation of the experimental results from the mean (mathematical expectation) is low, because $\gamma_{\text{LTE}} < 3.2 \times 10^{-7}$; $\gamma_{\text{UMTS}} < 7.2 \times 10^{-7}$; $\gamma_{\text{GSM}} < 1.1 \times 10^{-5}$, i.e. in all cases $\gamma \to 0$.

5. Conclusions

Path losses variation with the distance from BS behind the building with different heights for GSM, UMTS and LTE mobile technologies were compared with the results of seven models. It was found that no one of the models describes the experimental results with acceptable accuracy. In addition, these models do not explain certain experimental results scattering, which has the pattern character.

It was found that the path losses decrease behind the building, when the distance from base station increases. This decreasing may be affected of such electromagnetic wave propagation mechanisms as shadowing and diffraction. Such decreasing, in our view, would take place up to position behind the house, where the line-of-sight conditions would start.

It was found that in addition to the generally accepted parameters, such as: ERP, f, d_{BS}, h_{BS}, h_{UE}, h_{b}, path losses are affected by the mobile technology.

The new path losses evaluation model in microcells behind the buildings is proposed. The comparison of the experimental and modeling results gives the error of approximately 6%. This model describes the path losses for GSM, UMTS and LTE mobile technologies. The limits of the results validity are: $h_{\mathrm{BS}} > h_{\mathrm{b}}$, frequency range is $900\ \mathrm{MHz} < f < 2200\ \mathrm{MHz}$, and $100\ \mathrm{m} < d_{\mathrm{BS}} < 500\ \mathrm{m}$.

These results may be useful for improving the existing propagation loss models and developing the new more accurate models, including the models for the new technologies (such as 5G).

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