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DETERMINE THE DISTANCE STABLE CONNECTION FOR UNMANNED AERIAL VEHICLE UNDER THE INFLUENCE OF CITY CONDITIONS

Attempts are made to analyze in detail the models of stable connection distances' determination for Unmanned Aerial Vehicle in a city (town) conditions. The appropriateness of Okumura-Hata and Walfich-Ikegami models' usage for enumeration of radio-waves loss is described in short. Also data are given about the importance of their usage for taking into account the city (town) architecture's peculiarities.

Keywords: connection, area of reach, design, prognosis, radio waves.

Introduction. Unmanned Aerial Vehicles (UAVs) of small sizes are used for keeping track of certain objects in the city (town). Necessity of given design is provoked with the highest level of responsibility during the flying of UAV in a town boundaries. The most suitable way for this purpose is the UAVs flight on low-altitudes when they can be in the radio-shadow of city (town) buildings and have some problems with radio wave receiving. To forecast the radio waves spreading in the city (town) conditions it is necessary to use the Okumura–Hata and Walfich–Ikegami models, which are able to predict the loss of power of radio waves on the basis of radio frequency, range, position and height of antennas of UAV and control center of Unmanned Aircraft System (UAS), terrain configuration etc. The average heights of terrain configuration (e. g. building heights) are in the focus of attention.

Review of methods. The Hata Model for Urban Areas, also known as the Okumura–Hata model for being a developed version of the Okumura Model, is the most widely used radio frequency propagation model for predicting the behavior of ranges of proof connection in built up areas. This model incorporates the graphical information from Okumura model and develops it further to realize the effects of diffraction, reflection and scattering caused by city structures.

The traditional Okumura–Hata model formula for average power loss of propagations is shown below, dB [1 – 3]:

$$L = 69,55 + 26,16\log_{10} f - 13,82\log_{10} h_1 - a(h_2) + (44,9 - 6,55\log_{10} h_1)\log_{10} d - K,$$

where h_1(30–200) – transmitting station UAS antenna height (m); h_2 (1–10) – UAV antenna height (m); d (1–20) – distance from control center UAS to UAV (km); f (150–1500) – operating frequency of UAV (MHz); $a(h_2)$ – correction factor for UAV unit antenna height (dB).

The COST231-Hata model extends Hata's model for use in the 1500–2000 MHz frequency range, where it is known to underestimate path loss. The model is expressed in terms of the following parameters:

$$L_{XHata} = 43,33 + (44,9 - 6,55\log_{10} h_1)\log_{10} d + 33,9\log_{10} f - a(h_2) - 13,82\log_{10} h_1 + C,$$

where $C = 0$ – for suburban and open areas, $C = 3$ for urban area.

Okumura model was originally built into three modes, one for urban, suburban and open areas. The model for urban areas was built first and used as the base for others The Okumura–Hata model also has two more varieties for propagation in Suburban Areas and Open Areas. The original Okumura model for Urban Areas is a radio propagation model that was built using the data collected in the city of Tokyo, Japan.

However the cities of Ukraine on relief considerably differ from the cities of Japan. For the concrete districts of Kyiv it is possible to distinguish comparatively the simple fragments of relief for the detailed analysis of their sizes and form. The necessity of such approach is conditioned by that at far less than, than in Tokyo, variation of sizes of building, stronger "waveguide effects" show up in cross-section of streets and shading a few building which are located small of back straight propagation of waves. For more exact prognostication of distance of proof connection, it should to apply such methods of calculation, which take into account the interference and diffraction phenomena in terms to the fragment of town building.

Decision of problem. The COST 231 Walfisch–Ikegami model uses more sile-specific building clutter data to capture the propagation effects due to reflections and roof-lop diffractions. The model therefore has deterministic elements rather than being purely statistical. It is more complex than the Okumura–Hala models and is more suited to smaller macro-cells in urban areas or micro-cells where the antenna is placed at roof-top levels. The model presents different formulas for cases when there is a LOS (line-of-site) signal component, and for when there is no LOS (NLOS) component. The formula for the case of LOS is simple and only depends on the frequency and the distance. In the NLOS case, the path loss is made up of a free-space path loss and two other components that are used to capture the effects due to signal diffractions and scattering from the roof-tops and multi-screen diffractions. These latter effects depend on the street width, the street direction relative to a direct line between the transmitter and receiver, roof heights, and building separations. The model therefore assumes that the signal propagates over roof-tops and is diffracted by the roof-top edges in reaching the receiver. If the roof-top diffraction effects are not present, for instance in small micro-cells where the antennas are placed below the average roof-top level of surrounding buildings, the model can overestimate the path losses. Therefore it should be used cautiously in application to small micro-cells, with results verified by measurements.

The model assumes uniform building spacing and identical dimensions with no terrain variations over the area. This is another aspect that should be kept under consideration when applying the model.

The Walfisch–Ikegami formulas are given by [2; 3]:

$$L_{\mathrm{LOS}} = 42{,}64 + 26\log_{10} d \; + 20\log_{10} f,$$

where d > 0,030 km when receiver is in LOS.

When receiver is in NLOS: L_{fs} – loss in free space; L_{msd} – multiscreen diffraction losses; L_{rts} – roof-lop to streeet diffraction and scatter loss effects.

The formulas for L_{fs}, L_{msd}, L_{rts} is:

$$L_{rts} = -16{,}9 - 10\log_{10} n + 10\log_{10} f \; + 20\log_{10} \Delta h_m + L_{ori},$$

$$L_{\mathrm{NLOS}} = \begin{cases} L_{fs} + L_{fs} + L_{fs}; & L_{rts} + L_{msd} \geq 0; \\ L_{fs}, & L_{rts} + L_{msd} < 0, \end{cases} \tag{1}$$

$$L_{ori} = \begin{cases} -10 + 0{,}354\varphi; & 0 \leq \varphi \leq 35°; \\ 2{,}5 + 0{,}075(\varphi - 35°); & 35° \leq \varphi \leq 55°; \\ 4{,}0 - 0{,}114(\varphi - 55°), & 55° \leq \varphi \leq 90°. \end{cases}$$

The heights of buildings and their spatial spacing along the line of sight simulated multiple diffraction losses in the way:

$$L_{msd} = L_{bsh} + k_a + k_d \log_{10} d + k_f \log_{10} f \; - 9\log_{10} b.$$

In this expression – shadow gain (negative damping) at the height of the antenna setup control center larger than the height of the roof:

$$L_{bsh} = \begin{cases} -18\log_{10}(1+\Delta h_b), & \Delta h_b > 0; \\ 0, & \Delta h_b \le 0. \end{cases}$$

Parameters k_a, k_d, k_f determine the dependence of losses from a distance and frequency. Frequency-dependent factor k_f is determined separately for the conditions of the city, suburbs and villages separately developed formulas.

Parameters of the model Walfisch–Ikegami is [2; 3]:

h_b – control center's transmitting station antenna height, m (4–50);

h_m – UAV antenna height (m);

h_R – conventional height rooftops (m);

$\Delta h_b = h_b - h_R$ – transmitting station antenna height over the roof of the house (m);

$\Delta h_m = h_R - h_m$ – UAV antenna height over the roof of the house (m);

b – distance between buildings, (m);

n – width of the street ($b/2$ – recommended if no data);

φ – angle of incidence of the wave.

So, the formula for NLOS is (1).

Analysis of results. Calculation results are in good agreement with measurements for the antenna control centers of UAS that are larger than standard roofs: the average error is ± 3 dB and standard deviation of 4–8 dB. However prophesied error becomes larger for $h_1 \approx h_R$, compared with the situation when $h_1 >> h_R$.

In addition, the effectiveness of the model below for $h_1 << h_R$. The model does not allow to analyze multipath propagation and reliability assessment of losses on the road decreases, as if the terrain is rough or ground cover houses uniformly.

Graphic representation of the differences of two models at 900 MHz, while the control center's antenna height 50 m and distance from 1 to 5 km is shown in fig. 1.

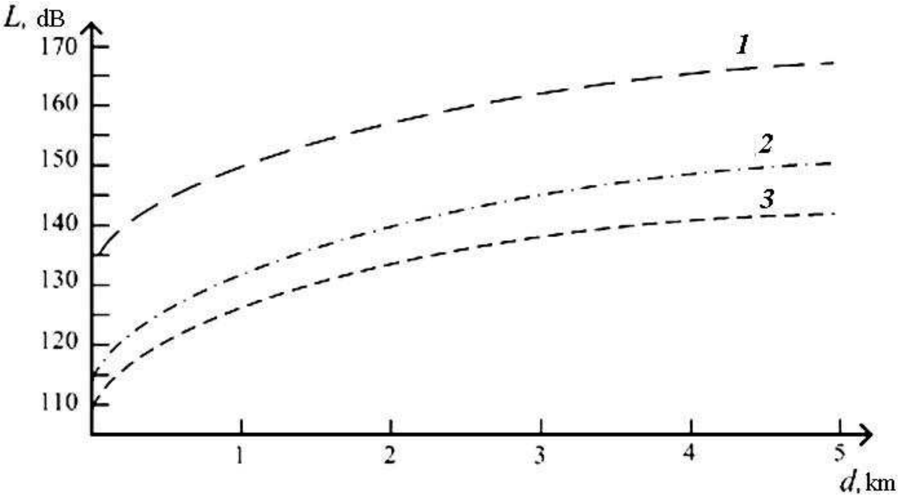

Fig. 1. Dependence of losses from a distance by model Okumura–Hata (curve *1*), *Walfisch–Ikegami* model (curve *3*), and the results of measurements (curve *2*)

From consideration of figures 1 obviously, that for the terms of town building the model of Walfisch–Ikegami gives results which better comport with the results of measuring, than model Okumura–Hata. It is conditioned by that for town building the model of Walfisch–Ikegami gives more detailed and more exact prognosis, than model Okumura–Hata, as takes into account concrete forms and sizes of building.

Conclusion. As a result of analysis of existent normative methods of prognostication of losses of propagation of radio waves will draw conclusion about that, for the distance-finding of proof connection in the conditions of the middle or large east Europe city, relief of which substantially differs from Tokyo (which the worked out models of Okumura–Hata were for), is expedient to use the model of Walfisch–Ikegami together with a certain model Okumura–Hata for clarification of calculations after separate directions, which characteristic heterogeneities of relief, which is marked higher (cross-section of street, a few frontal located building and other), are present on. Suggest to conduct prognostication of distances of proof connection in two stages: on the first stage to define average power losses on all circle on an azimuth after a model Okumura–Hata, and on the second stage more in detail to define losses for the characteristic details of relief of city after the model of Walfisch–Ikegami is an accumulation of building, crossing and axes of streets. Thus, on results the indicated procedures it is possible finally to define distances of proof connection of control center of UAS with the radio electronic systems of UAV, to which belong system of external mission-control, system of collection and passed to information, system of supervision and other.

References

1. Recommendation of the International Telecommunication Union ITU R.525-2 (01/1994).
2. Recommendation of the International Telecommunication Union ITU R.368-9 (02/2007).
3. Recommendation of the International Telecommunication Union ITU R.452-14 (10/2009).

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Визначення відстані стійкого зв’язку для безпілотного літального апарату в умовах міста

Проведено аналіз моделей визначення відстаней стійкого зв’язку для безпілотного літального апарату в умовах міста. Виявлено доцільність сумісного застосування моделей Окумура–Хата й Уолфіша–Ікегамі для розрахунку втрат при поширенні радіохвиль. Це дозволить більш точно враховувати особливості рельєфу міської забудови.

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Определение расстояния устойчивой связи с беспилотным летательным аппаратом в условиях города

Проведен анализ моделей для определения расстояний устойчивой связи с беспилотным летательным аппаратом в условиях города. Показана целесообразность совместного применения моделей Окамура–Хата и Уолфиша–Икегами для расчета потерь при распространении радиоволн. Это позволит более точно учитывать особенности рельефа городской застройки.