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Study of the dependence of the field strength on the radius of the coverage area of digital terrestrial television broadcasting of the DVB-T2 standard using the Okamura- Khata and Vvedensky models

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ABSTRACT*:* The workinvestigates the dependence of the field strength on the radius of the coverage area of digital terrestrial television broadcasting of the DVB-T2 standard using the Okamura - Khata and Vvedensky models. The calculated data and results of the study are given as, changes in the coverage area from the height of the antenna system of a digital television transmitter, the dependence of the reception radius on the suspension height of the antenna system at a receiving antenna height h_2 = 10 m, the dependence of the change in the coverage radius on the radiation power and the dependence of attenuation in the communication channel on distance between receiver and transmitter.

KEYWORDS: service area, radio visibility, Okamura – Khata model, transmitter power, transmitting antenna gain, transmitting antenna height, receiving antenna height, curvature factor of the earth's surface, field strength, wavelength.

I.INTRODUCTION

In the process of introducing digital terrestrial television broadcasting of the DVB-T2 standard in the cities and regions of the Republic of Uzbekistan, the task was set to ensure full coverage of the service area with specified quality indicators of 98%, provided that the level of interference to television receivers is acceptable for stationary reception. For the calculation of coverage areas, many models have been developed that differ in their methods, methods of parameterization of environmental characteristics, accuracy, speed and applicability for various conditions. At the moment, the coverage area of a television transmitter is calculated in the overwhelming majority of cases on the basis of statistical methods, which have been basic for a long time and are still relevant. In the frequency range of television channels (I – IV bands), the models of Okamura – Khata, B.A. Vvedensky and others.

In free space, a homogeneous non-absorbing medium with a dielectric constant equal to unity, the radio wave front propagates rectilinearly, weakening only with increasing distance from the emitter, regardless of the wavelength. Under these conditions, the effective value of the electromagnetic field strength in millivolts per meter (hereinafter “field strength”) is determined by the following fundamental equation [1].

$$E_{acting} = \frac{2{,}18\sqrt{PG}}{\lambda r^2} \qquad (1)$$

where r is the distance between the transmitting and receiving points, km; P - transmitter power, kW; G is the antenna gain in the direction of the receiving point relative to an elementary (omnidirectional or isotropic) dipole, which radiates energy evenly in all directions. If G is expressed with respect to a half-wave dipole, then a factor of 1.5 is introduced at the root, which is equal to the gain of a half-wave dipole in the direction of maximum radiation relative to an isotropic emitter, i.e., the factor 173 is replaced by 212. To obtain the amplitude value of the field strength, an additional factor of 2 is introduced and the coefficient 173 is replaced by 245 (or 212 by 300) [2].

For convenience of calculations, in some cases, the field strength is expressed in decibels with respect to the field strength equal to 1 mkV / m, and is denoted by dB mkV / m. In this case

ISSN: 2350-0328
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Vol. 8, Issue 4 , April 2021

$$E = 106.59 - 20\lg r + 10\lg P + 10\lg G \qquad (2)$$

where r is in kilometers, P is in kilowatts.

In this case, the field strength created by radiation by a half-wave dipole of 1 kW power is often taken as the initial one. Then the field strength in decibels is $E = 106.59 - 20lg\ r$.

In real conditions, radio waves propagate with a loss of energy, which is taken into account by introducing a special factor in (1), also called the attenuation function F. In (2), the term 201gF is added accordingly. Under certain conditions, the attenuation factor can exceed unity, others an increase (increase) in the field strength occurs.

The line-of-sight distance in kilometers, taking into account the curvature of the Earth and the elevation of the transmitting and receiving antennas h_1 and h_2 in meters, is determined by the formula obtained by solving the corresponding geometric problem.

$$r = 3{,}57 \times \left(\sqrt{h_1} + \sqrt{h_2}\right) \qquad (3)$$

In practice, radio visibility is slightly higher than optical. This is due to partial diffraction of radio waves (bending around the spherical surface of the Earth near the horizon), as well as weak refraction of radio waves (deviation of the direction of propagation of radio waves from a straight line) in the lower layers of the atmosphere.

The radio visibility range increases by about 15% in comparison with the optical one, which is taken into account by the corresponding change in the coefficient in the formula for the line-of-sight distance. Expression (3) for the radio visibility distance takes the form

$$r = 4{,}12 \times \left(\sqrt{h_1} + \sqrt{h_2}\right) \qquad (4)$$

Usually, when calculating the height of the receiving antenna is chosen equal to 10 m. Calculations were made according to formulas (3) and (4). The line-of-sight and radio-visibility distances for these conditions can be found from the graphs (Figure 1). The results obtained by regions and the city of Tashkent of the Republic of Uzbekistan are summarized in Table 1.

Table 1.

Analysis of the change in the coverage area from the suspension height of the antenna system of a digital TV transmitter

№	**Region and city names**	**Antenna system suspension height, h (m)**	**Calculated receiving radius, r_1(km)**	**Radius of confident reception, r_2(km)**
1.	Samarkand region	33	31,77	22,3
2.	Surkhandarya region	35	32,38	22,9
3.	Jizzakh region	44	34,95	25,8
4.	Karakalpakstan Republic	45	35,2	26,2
5.	Navoi region	56	37,98	29,7
6.	Tashkent region	68	40,73	32,7
7.	Namangan region	80	43,02	36,2
8.	Kashkadarya region	100	46,98	39,7
9.	Khorezm region	150	55,01	48,6
10.	Andijan region	186	59,83	53,3
11.	Bukhara region	200	61,76	56,1
12.	Fergana region	246	67,26	61,4
13.	Syrdarya region	250	67,69	62,8
14.	Tashkent city	375	80,39	76,9

ISSN: 2350-0328
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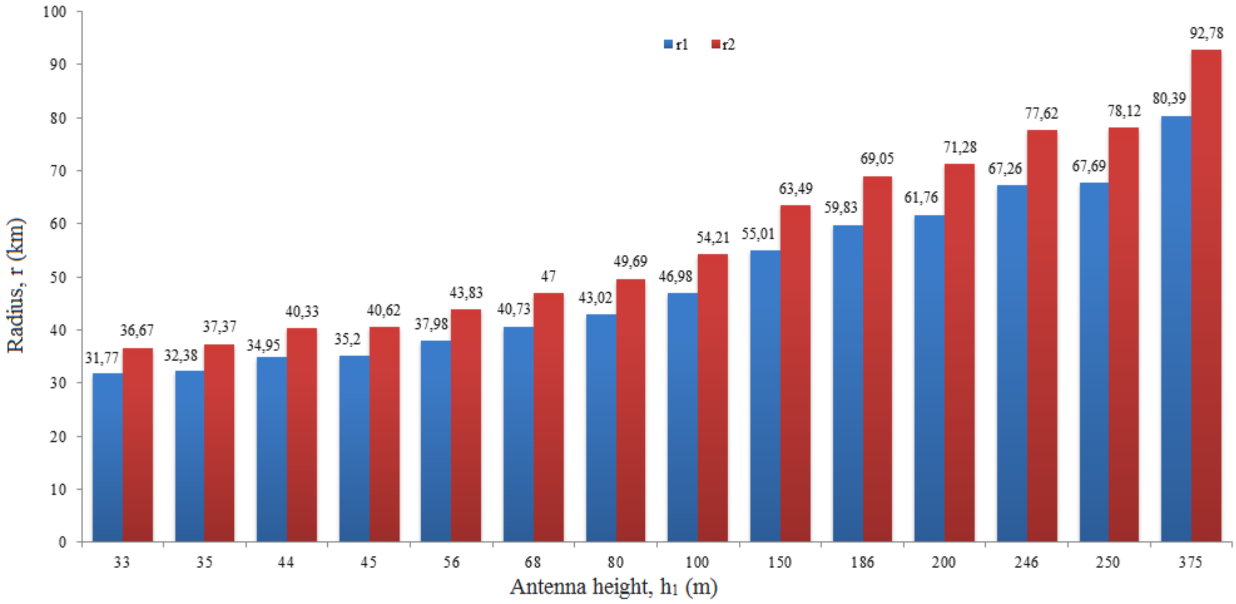

Fig.1. Dependence of line-of-sight range (blue) andradio visibility (red) from the lifting height of the transmitting antenna at the height of the receiving antenna h_2 = 10 m

Introducing the coefficient k_r into (1), we obtain the B.A. Vvedensky:

$$E_{acting} = \frac{2{,}18\sqrt{PG}}{\lambda r^2} h_1 h_2 K_r \qquad (5)$$

Where, P is the transmitter power, kW;
G is the transmitting antenna gain, dB;
h_1 is the height of the transmitting antenna suspension, m;
h_2 is the suspension height of the receiving antenna, m;
k_r is the coefficient of curvature of the earth's surface;
E is the field strength at the receiving point mV / m;
λ - wavelength, m.

Vvedensky's interference formula is valid for a flat Earth and does not take into account its sphericity, which begins to affect at large distances. This formula also does not take into account the presence of refraction (curvature of the trajectory) of radio waves, which, although weakly expressed, still takes place, especially in the long-wave part of the decimeter range. In practice, the Vvedensky formula gives somewhat underestimated values of the field strength in the diffraction zone, as a result of which, in the given form, it can be used at distances equal to 0.7–0.8 line-of-sight distance (3). The influence of the curvature of the Earth and refraction in formula (5) is taken into account by introducing appropriate corrections to the attenuation factor kr. The field in this zone can be calculated, but using more complex diffraction formulas.

In [3], it was proposed to apply the Vvedensky quadratic formula, in which expression (6) is used to calculate the effective value of the electric field strength at the receiving point:

$$E_D = \frac{\sqrt{30P_n G_n}}{r} W_T = \frac{\sqrt{30P_n G_n}}{r} \cdot \frac{4\pi h_1' h_2'}{\lambda r} \qquad (6)$$

where: W_T is the factor of attenuation of the wave field strength on the real path; P_n - transmitter power supplied to the antenna, W; G_n is the gain of the transmitting antenna in the direction of the correspondent in times; h_1 and h_2 are the reduced heights of the transmitting and receiving antennas, m; λ-is the wavelength used in digital communication, expressed in terms of frequency f, c is the speed of light ($300 \cdot 10^6$ m / s), f is the signal frequency in Hz.
Note that the scope of the Vvedensky formula is limited by the following condition:

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International Journal of Advanced Research in Science, Engineering and Technology

Vol. 8, Issue 4 , April 2021

$$r \geq \frac{18h_1^{'}h_2^{'}}{\lambda} \qquad (7)$$

which somewhat reduces its practical value.

In general, the initial limit of applicability of formula (6) is determined by expression (7) [3], and the far limit of its practical application is determined by the maximum line-of-sight range, expressed in kilometers, taking into account possible diffraction outside the specified zone [3-6]:

$$r_{max} = 4{,}12 \times \left(\sqrt{h_1} + \sqrt{h_2}\right) \qquad (8)$$

$h_1 \gg \lambda h_2 \gg \lambda$, what is defined

where h_1 and h_2 are the elevation of the phase centers (in this aspect, since the concepts of phase center and antenna height are not identical concepts) of the transmitting and receiving antennas.

Note that in formula (8) r_{max} in km, and the values of $h_1 \gg \lambda$ and $h_2 \gg \lambda$, in m.

In further research, we will assume that the condition of high-raised antennas is fulfilled for digital communication, others. $h_1\lambda$ and $h_2\lambda$, which is determined by the requirements for the applicability of the Vvedensky formula [6].

At the same time, the parameters and structure of the field are influenced by the electrical inhomogeneity of the troposphere, which manifests itself in the phenomenon of radio wave refraction.

To describe the electrical inhomogeneity in [3], such a quantity is introduced as the vertical gradient of the tropospheric permittivity g, which takes values $-13 \cdot 10^{-8} \ldots 6 \cdot 10^{-8}$ [1 / m].

The g value depends on different climatic zones. As a first approximation that gives an idea of the seasonal distribution (dielectric permittivity of the troposphere), one can use the concept of “standard radioatmosphere” for which $g = -7.85 \cdot 10^{-8}$ 1 / m [3].

According to the concept of calculations from the standpoint of the equivalent radius of the Earth, the vertical gradient of the permittivity of the troposphere can be related to the equivalent radius of the Earth by the following relationship (assuming that g = const) [4]:

$$a_{EE} = \frac{a_E}{\left(1+\frac{a_E g_T}{2}\right)} \qquad (9)$$

Moreover, a_E = 6356863 m is the average radius of the Earth [3].

In calculating the electric field strength at the receiving point using the Vvedensky quadratic formula, the concept of reduced antenna heights is used, which are related to the Earth's equivalent radius by the following expressions [3]:

$$h_1^{'} = h_1 - \frac{r^2}{2a_{EE}}\left(\frac{h_1}{h_1+h_2}\right)^2 \qquad (10)$$

$$h_2^{'} = h_2 - \frac{r^2}{2a_{EE}}\left(\frac{h_2}{h_1+h_2}\right)^2 \qquad (11)$$

Since the validity of the action of the Vvedensky quadratic formula for a spherical surface is determined by the fulfillment of condition (7), it follows that this model is applicable at ranges determined by the boundaries.

$$\frac{18h_1^{'}h_2^{'}}{\lambda} \leq r \leq 4{,}12\left(\sqrt{h_1} + \sqrt{h_2}\right) \qquad (12)$$

Taking into account expressions (10) and (11), formula (12) takes the following form:

$$\frac{18\left(h_1 - \frac{r^2}{2a_{EE}}\left[\frac{h_1}{h_1+h_2}\right]\right)\left(h_2 - \frac{r^2}{2a_{EE}}\left[\frac{h_2}{h_1+h_2}\right]\right)}{\lambda} \leq r \leq 4{,}12\left(\sqrt{h_1} + \sqrt{h_2}\right) \qquad (13)$$

Within the framework of the research conducted, the following conclusion can be drawn. The main parameters that determine the near and far boundaries of the Vvedensky model's coverage area are the elevations of the phase centers of the transmitting and receiving antennas, as well as the working wavelength

An interactive computer simulation program has been developed for calculating the dependences of the field strength according to the Okamura - Khata and Vvedensky formula on the radius of the coverage area [7]:

Using the developed tools, the program allows calculating and investigating the dependences of the following quantities: the strength of the electromagnetic field of a television signal on the radius of the coverage area and the calculation of the strength of the electromagnetic field on the distance between the transmitter and the receiver.

The calculation was performed according to the formula (4) and simulated by the modeling program [7] of the dependence of the receiving radius on the height of the suspension by the antenna system at the receiving antenna height h_2 = 10 m.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 4 , April 2021

Comparison of the calculated data and the simulation results was carried out on the basis of statistical calculations of the average discrepancy and standard deviation between the simulated and calculated values is 0.85% at the location of the receiving antenna (Figure 2).

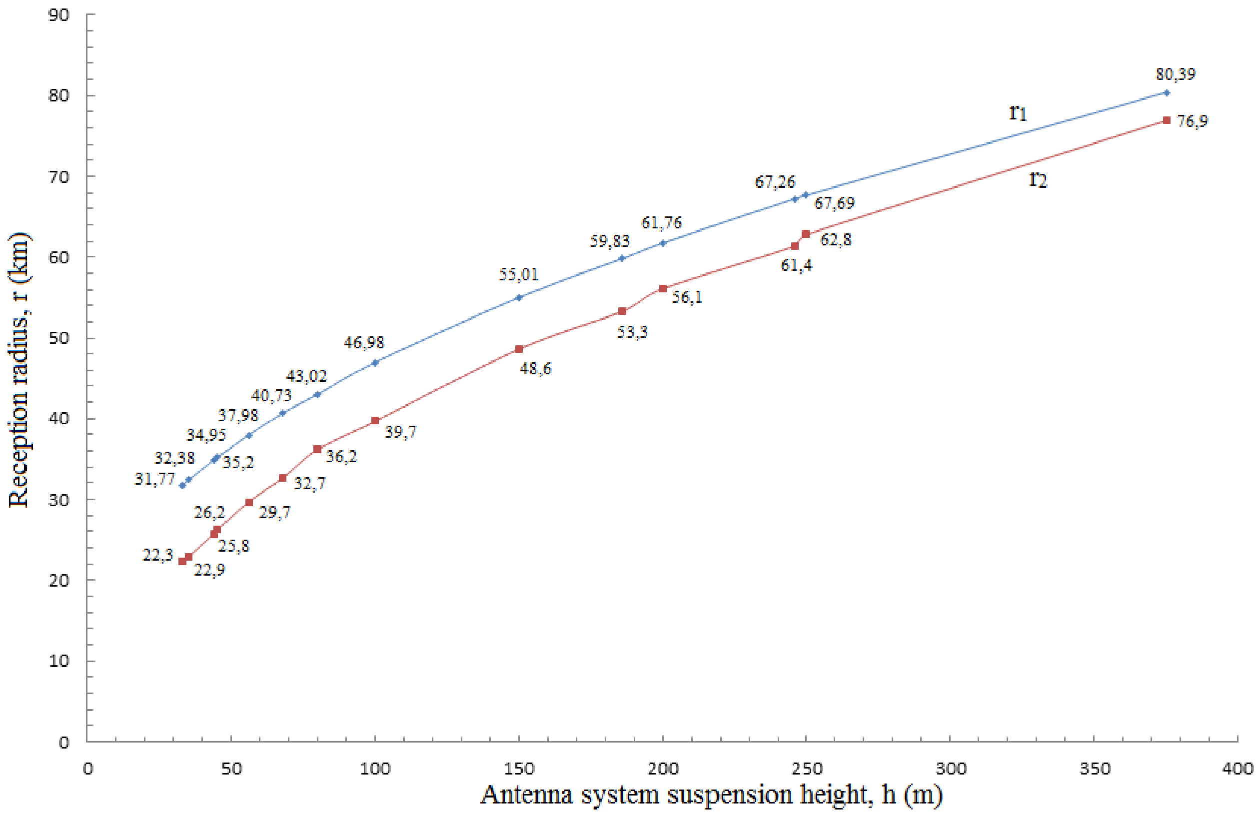

Fig. 2. Calculation of the dependence of the receiving radius (r_1-calculated, r_2-modeled) on the suspension height of the antenna system at the receiving antenna height h_2 = 10 m.

Using formula (5), the radius of the coverage area was calculated, taking into account the required power of digital TV transmitters. In the course of the calculation, the following initial conditions were used: antenna system suspension height - 50 meters, receiving antenna height - 4 meters, transmitting antenna system gain - 9 dB, modulation mode - 64QAM, relative coding rate - 2/3 and guard interval - 1 / 32, transport stream speed - 24 Mbit / s, minimum field strength - 35 dB. The results are summarized in Table 2.

Table 2.

Analysis of the change in the coverage area from the required radiation power of a digital TV transmitter

№	Coverage radius, r (km)	NecessaryDigital TV transmitter power, P (W)
1.	23	902,3
2.	20	516,3
3.	18	334,1
4.	16	210,7
5.	14	122,9
6.	12	66,1
7.	10	31,1
8.	5	1,9

Figure 3 shows a graph of the dependence of the change in the coverage radius on the radiation power.

ISSN: 2350-0328
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Vol. 8, Issue 4 , April 2021

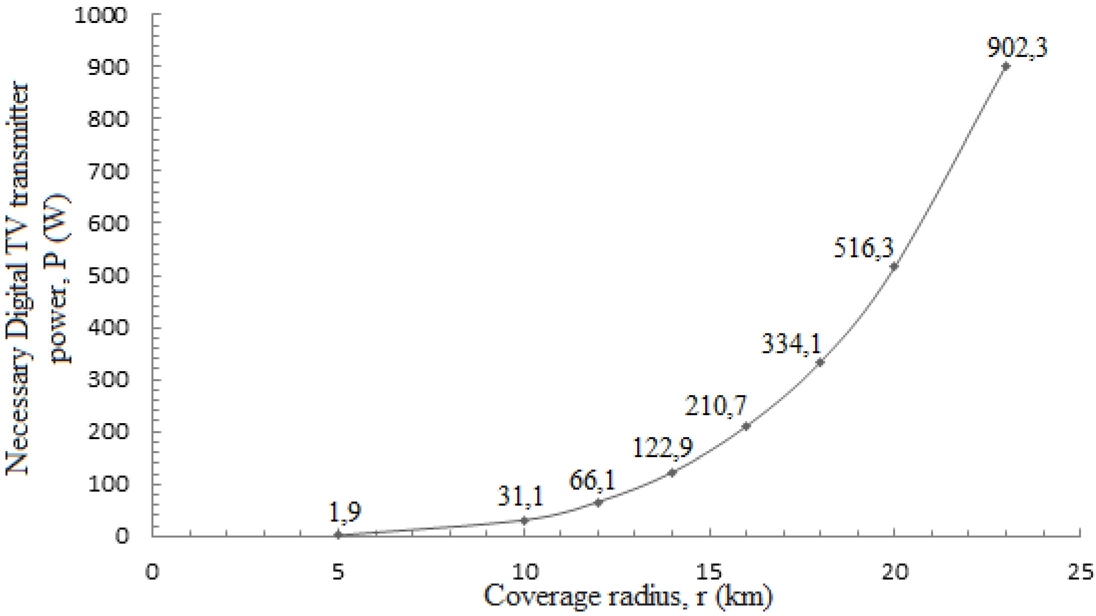

Fig. 3. Graph of the dependence of the change in the coverage radius on the radiation power.

Analysis of the obtained values shows that the given initial conditions for obtaining an extension of the coverage area by 3 km, i.e. from 20 km to 23 km, it is necessary to increase the radiation power of the digital TV transmitter from 517.6 W to 902.3 W, which is an increase in the radiation power by 57.3%.

Thus, it can be concluded that, starting from a certain value of the radius of the coverage area at a given suspension height of the transmitting antenna system, a significant increase in power is required, i.e. inefficient use of power.

The Okamura – Khata model refers to statistical calculation methods and is recommended for calculations in the DVB – T2 standard. It is based on generalized statistical formulas for the attenuation of a radio signal in various types of buildings (urban, suburban, rural). The accuracy of the calculation depends on the careful selection of empirical coefficients based on the analysis of terrain maps [8].

Based on the constructed graphs of the dependence of the median losses L on the distance between the transmitting and receiving antennas, an approximating relation of the following form was proposed:

$$L_{dB} = L_0 + A(f,r) + C(h_c) \qquad (14)$$

Where

$$L_0 = \left(\frac{\lambda}{4\pi r^2}\right)$$

Loss during propagation in free space, A (f, r) is the ratio of the median loss in a city with a quasi-smooth Earth surface to losses in free space for the effective antenna heights of the transmitting station, respectively, h_{Atr} = 200 m and the receiver antenna h_{Atr} = 10 m, C (h_{Atr}) for the transmitter and receiver, respectively, if the effective antenna heights differ from the indicated ones, r is the path length.

Here, a quasi-smooth surface was understood as a route with a length of several kilometers, on which the average height of irregularities did not exceed 20 m.

In (14), the value of L_0 is calculated, and all the others are determined from the plots constructed on the basis of experimental data.

Formula (14) is suitable for frequencies f = (from 150 to 1500) MHz, the range of distances r = (1 ÷ 100) km and the effective height of the base station antenna h_{tr} = (from 30 to 1000) m. The advantage of the Okamura model is its simplicity and versatility, whence its main drawback follows - the lack of accounting for sharp changes in terrain heights. However, the Okamura model serves as the most commonly used calculation model. Its modification was developed in the Khata model [9], also called the Okamura - Khata model. The essence of this model lies in the approximation of Okamura plots by specially selected formulas for various territorial zones, which are conventionally classified into a large city, medium and small city, suburb, rural area, open area. The disadvantages of this model are the same as those of the original Okamura model, and also lead to underestimation of losses for frequencies above 1.5 GHz; models for open "quasi-smooth" terrain are used in the work.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 4 , April 2021

The calculation of the output power of the transmitters will be carried out according to the recommendation ITU – R 1546–3 using the Okamura – Khata method.

The Okamura-Khata method describes the features of radio wave propagation over a "quasi-flat" open area and does not take into account the features of the relief.

The propagation of the main beams from the transmitting station occurs above the roofs of buildings.

The Okamura – Khata equation for the field strength has the following form

$$E_{MED} = 3{,}92 + P_{RTP1} - 6{,}161\log f + 13{,}82\log h_1 + a(h_2) - (44{,}9 - 6{,}55\log h_1)\cdot(\log R)^b (15)$$

where P_{RTP} is the effective radiated power of the transmitter (RTP), dBW, f -transmitter radiation frequency, h_1 is the height of the transmitter antenna suspension above surface of the earth, h_2 is the height of the receiver antenna above the Earth's surface, a $(h)_2$ is the correction factor for the height of the receiving antenna, R is the radius of the coverage area, b is the factor extending the model's effect for the path length.

Additional factor b to correct the calculation in the formulaOkamura - Khata field strength in rural areas is as follows

$$b = 1 + \left(0{,}14 + 1{,}87\cdot 10^{-4}\cdot\frac{f}{10^6} + 1{,}07\cdot 10^{-3}\cdot h_1\right)\cdot\left(\log\left(\frac{R}{20}\right)\right)^{0,8} \quad (16)$$

The calculation according to the model (15) of the dependence of the attenuation in the communication channel on the distance between the transmitting and receiving antennas for several types of terrain. In (Figure 4) graphs are presented.

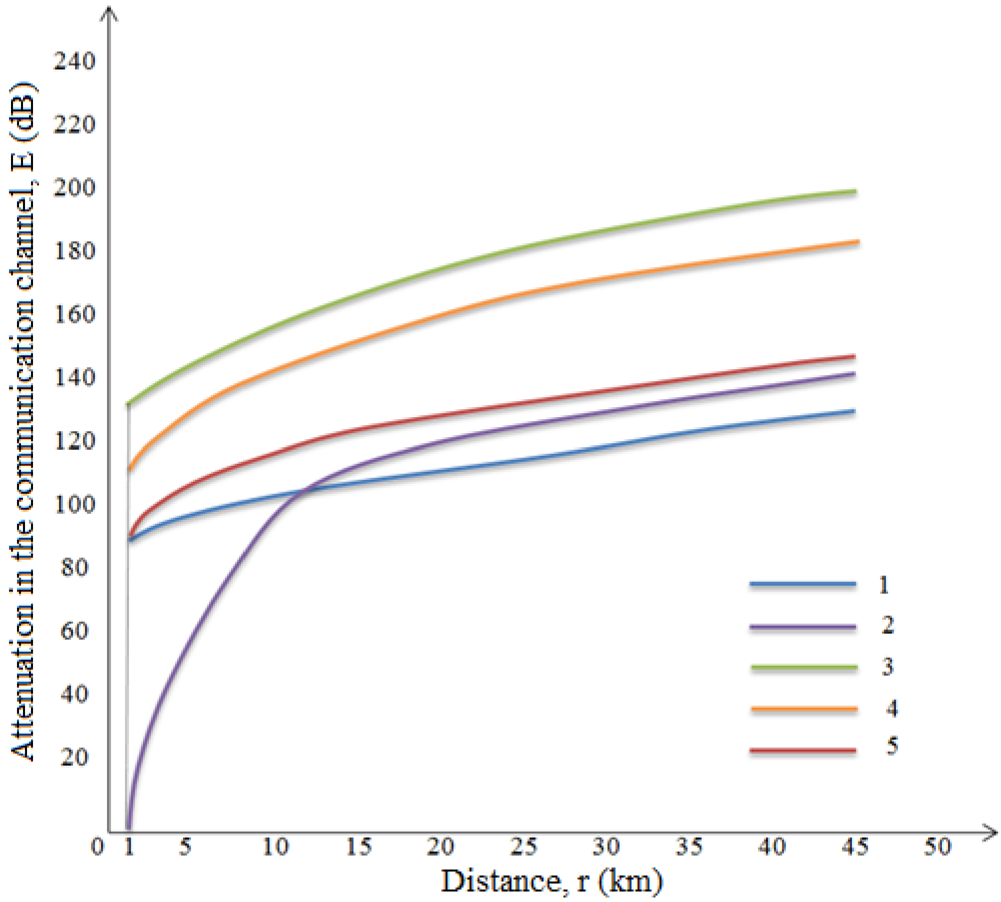

Fig. 4. Dependence of attenuation in the communication channel on the distance between receiver and transmitter

1 - free space, 2 - two-beam model; Okumura – Khata model, 3 - urban area, 4 - suburban area, 5 - rural area.

The lowest attenuation is observed in free space, since there are no objects in the transmission zone that absorb or reflect energy. On the other hand, radio propagation losses in an urban area are high due to the presence of a large number of tall, nearby buildings and other obstacles. In the suburban area, the attenuation value is significantly higher than the level corresponding to rural areas. For example, at a distance of 10 km, the difference in attenuation values is about 20.3 dB [10].

II. CONCLUSION

Within the framework of the research carried out, the following conclusions can be drawn. The main parameters that determine the near and far boundaries of the Vvedensky model's coverage area are the rise heights of the phase centers of the transmitting and receiving antennas, as well as the working wavelength. In practice, Vvedensky's formula gives somewhat underestimated values of the field strength in the diffraction zone, as a result of which, in the given form, it can be used at distances equal to 0.7–0.8 line-of-sight distances.

Comparison of the calculated data and simulation results was carried out on the basis of statistical calculations of the average discrepancy and standard deviation between the simulated and calculated values is 0.85% at the location of the receiving antenna

Starting from a certain value of the radius of the coverage area at a given suspension height of the transmitting antenna system, a significant increase in power is required, others. inefficient use of power.

The Okamura – Khata model belongs to statistical calculation methods and is recommended for calculations in the DVB – T2 standard.

In the suburban area, the attenuation value is significantly higher than the level corresponding to rural areas.

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