

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

186,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Performance Analysis and Noise Immunity *WiMax* Radio Channel

Oleksii Strelnitskiy, Oleksandr Strelnitskiy, Oleksandra Dudka,
Oleksandr Tsopa and Vladimir Shokalo
*Kharkiv National University of Radio Electronics (KhNURE), Kharkiv,
Ukraine*

1. Introduction

Currently, *WiMAX* systems acquired widespread adoption, to help organize the network at *MAN* (*Metropolitan access network*) level. It is assumed that in the next decade, the performance of such systems can achieve 50 bits/second/Hz. This is due primarily to the fact that in *MAN* network large amounts of multimedia confidential information of high quality are transmitted. So it requires not only high speeds, but also the appropriate level of noise immunity. Therefore, the performance and noise immunity are the two main indicators of the radio system quality. The radio waves propagation (*RWP*) models in radio channel play a decisive role in their calculation. Several mechanisms of radio wave propagation are known, including the so-called street-wave channels (Fabricio, 2005) (Wei, 2007), that was already noted in the development of analog communication (Porrat, 2002). These channels are identified by the authors as wavelength channels formed by architectural buildings (*WCAB*) (Strelnitskiy, 2007). However, the existing mathematical models are extremely complicated, so they become ineffective in the calculation of large branching networks of urban and this fact makes it difficult to assess these characteristics. Performance is evaluated as the ratio of transmission rate to channel bandwidth and noise immunity is defined as the probability of a bit (*BER*) or packet errors (*PER*). The authors propose general approach to the *WCAB* representation in the form of microwave multipole.

Then the multipolar model of branched-line and outdoor radio channels is described. It allows us to calculate the attenuation of radio waves in the city streets. The reliability of the model is established by comparing the results of numerical and field experiments conducted by the authors. Performance and noise immunity of *WiMAX* communication channel estimates are given in the conclusion section.

2. Mathematical model of branched wavelengths, which are formed by architectural buildings

To form a mathematical model of *WCAB* we propose to adopt the following approach. Fig. 1 shows the city district fragment with the base station (*BS*) placed on the square.

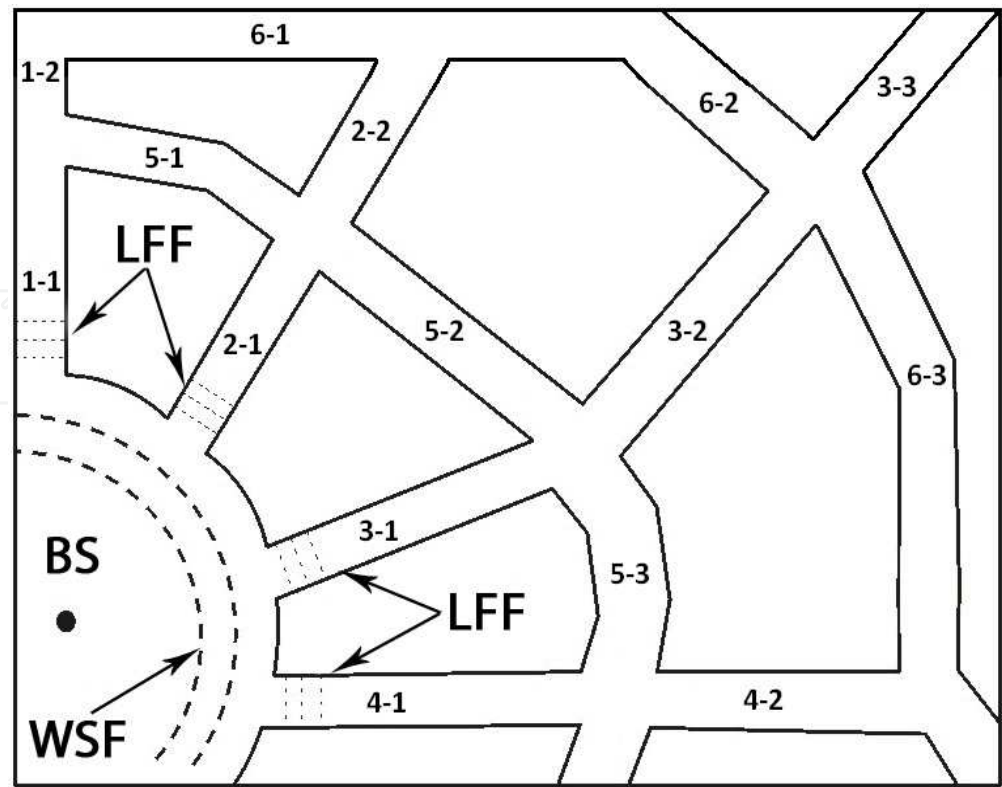


Fig. 1. Fragment of the city region

Numerals indicate segments of streets. For example, the designation 1-2 should be read: the second part of the first street. *BS* radiates waves of spherical front (*WSF*). Further we shall consider (based upon the Huygens principle) that in the radial streets (denoted by numbers 1-4 in Fig. 1) the radiated spherical wave is transformed into a series of waves with the locally flat front (*LFF*). A further approach is to use the following approximations. The street is represented by several continuous, homogeneous and smooth surfaces, which form the guide system with losses. Straight-line segment of length l of this guide system is replaced by an equivalent two-wire line segment. Wave resistance and wave factor β of this line are equal to the characteristic impedance and wave ratio of free space. Equivalence should be determined by equality of power transferred to the real and equivalent systems, i.e. largest attenuation. The attenuation is determined by losses in *RWP*, calculated by *RWP LAN-MAN* model (Strel'nitskiy, 2008), phase – by value βl . As a result, segments of the line are easily represented by matrices of the quadripole scattering [*S*] (Gostev, 1997).

The properties of these segments are as follows: all lines have equivalent impedance equal to Z_0 because they spread a wave of T-type; street intersection (for example, 2, 3 c 5, 6 on Fig. 1) is a set of included equivalent line segments and in terms of circuit theory it is a power distribution system (*PDS*).

CPM with n equal divisions of channels, described by the matrix [*S*] of ideal multipoles, together with segments of lines with losses constitute a particular scheme, the calculation of which can be performed by cyclic algorithm. As a result, the considered scheme is equivalent to a multipole (Gostev, 1997) (Fig. 2), which can be used to determine the amplitude of the field at any point of *WCAB*.

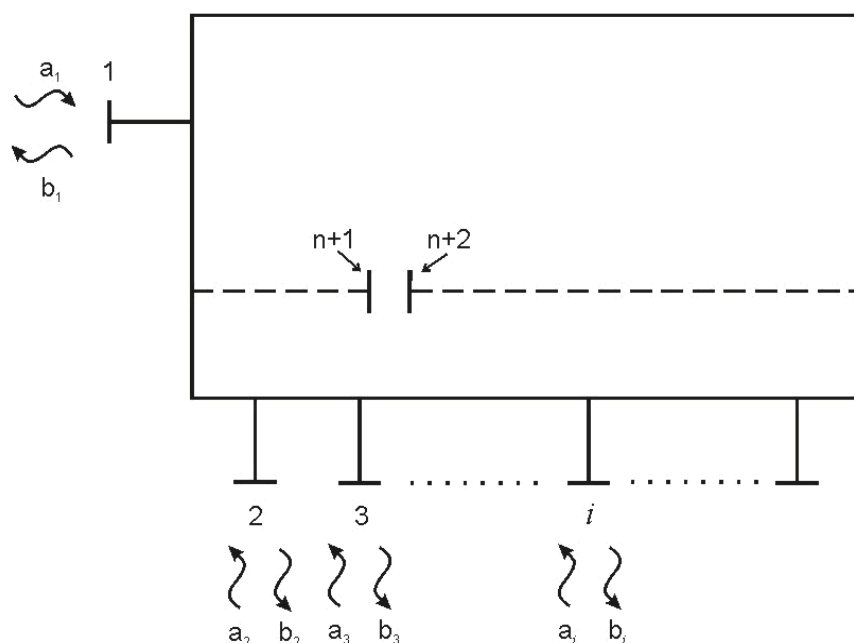


Fig. 2. Equivalent multipole

In this case, the problem is formulated as follows. Let there be a chain, equivalent to WCAB and containing the n external arms. It is required to determine the amplitude and phase of the field in a certain section of the circuit produced in accordance with these WCAB coordinates. In general, the circuit is excited with any number of arms (Fig. 2., where a_i, b_i – normalized amplitudes of the incident and reflected waves). For example in the case of Fig. 1 the number of excitation sources is 4.

The problem is solved by the method (Gostev, 1997). Let us isolate the circuit section in which you want to determine the amplitude and phase of the signal. Conventionally, we break the transmission line at this point (Fig. 2). Let us denote additional arms through $n+1$ and $n+2$, and the matrix of the resulting multipole - via $[S_{ij}](i, j = 1, 2, \dots, n+1, n+2)$.

In (Gostev, 1997) it is shown that if an equivalent multipole is excited with the i -th arm, then the values of the normalized amplitudes of the reflected waves in the $(n+1)$ and $(n+2)$ arms will be written as:

$$b_{n+1} = \frac{S_{n+1,i}(1 - S_{n+1,n+2}) + S_{n+1,n+1}S_{n+2,i}}{(1 - S_{n+1,n+2})(1 - S_{n+2,n+1}) - S_{n+2,n+2}S_{n+1,n+1}} \cdot a_i, \quad (1)$$

$$b_{n+2} = \frac{S_{n+2,i}(1 - S_{n+2,n+1}) + S_{n+2,n+2}S_{n+1,i}}{(1 - S_{n+1,n+2})(1 - S_{n+2,n+1}) - S_{n+2,n+2}S_{n+1,n+1}} \cdot a_i. \quad (2)$$

In this case the resulting wave in the cross section

$$b_{\Sigma} = b_{n+1} + b_{n+2}. \quad (3)$$

If the circuit is excited with the arms, the resultant wave can be written as (Gostev, 1997):

$$b_{\Sigma} = \frac{\sum_{i=1}^k \left[S_{n+1,j} \left(1 - S_{n+1,n+2} + S_{n+2,n+2} \right) + S_{n+2,i} \left(1 - S_{n+2,n+1} + S_{n+1,n+1} \right) \right]}{\left(1 - S_{n+1,n+2} \right) \left(1 - S_{n+2,n+1} \right) - S_{n+2,n+2} S_{n+1,n+1}} \cdot a_i. \tag{4}$$

The S_{n+2}, S_{n+1} coefficients in the expressions (1, 2) are defined by cyclic algorithms given in (Gostev, 1997). For their use it is necessary to make the scheme which will be replaced by the multi-pole circuit. It is compiled on the basis of a multipole electrical circuit.

For example, in the case shown in the Fig. 1, we can make calculations from the block diagram shown in Fig. 3.

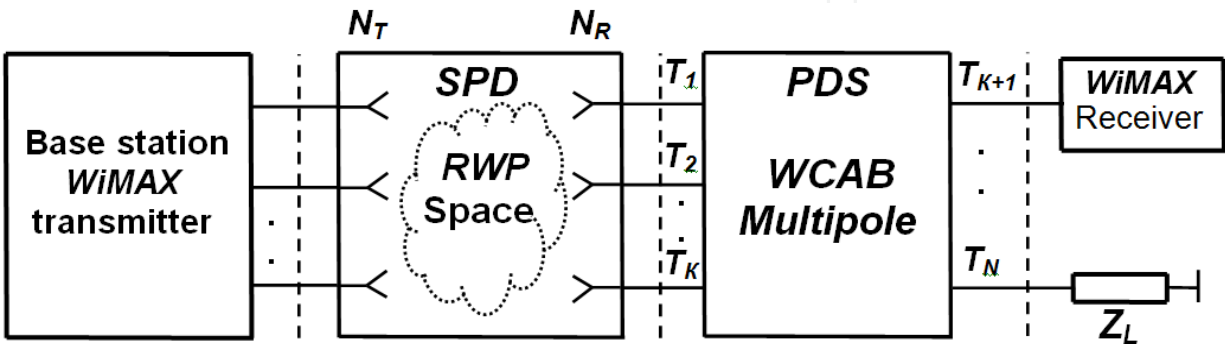


Fig. 3. WCAB block diagram

The scheme consists of a base station transmitter which is connected through its antenna, which has N_T emitters, with a spatial power distributor (SPD). On the SPD outputs there are the N_R receiving antennas, connected by the corresponding transitions to the equivalent line of PDS in the $T_1...T_K$ reference plane. Other reference planes are connected to the channel receiver, as well as loads of equivalent lines Z_L , equal to their characteristic impedance.

Amplitudes a_i in the $T_1...T_K$ reference plane depend on the relative position of the transmitting and receiving antennas and their radiation patterns. The coordinates of the receiving antennas in the cross sections of streets determine the positions of longitudinal sections of the streets along which the attenuation calculations are carried out. Let us represent the equivalent circuit for a part of urban area (Fig. 1). We assume that each segment of the street with length of r_i may be substituted by a segment of an ideal two-wire line, that is connected with the attenuator in cascade, its damping value α_i at RWP is equal to the damping on the street segment with length r_i .

The scattering matrix of quadripole equivalent to a cascading line connection and the attenuator is given by:

$$[S(r_i)] = \begin{bmatrix} 0 & \sqrt{\alpha \left(\frac{r_i}{r_0} \right)} \\ \sqrt{\alpha \left(\frac{r_i}{r_0} \right)} & 0 \end{bmatrix} e^{-i\beta r_i}. \tag{5}$$

The matrix is written on the assumption that the quadripole is consistent with the characteristic impedance of free space and reciprocal. Further let us assume that we need to determine signal strength along the street 2 (Fig. 1). To simplify the calculations, we assume that the wave processes occurring along the street 2, will be affected only by the adjacent streets 1, 3, 5 and 6. Then the electrical circuit of the equivalent multipole will have the form shown in Fig. 4, a.

It is easy to see that the diagram in Fig. 4, consists of the three basic elements: quadripole – cascade connection of attenuator and the ideal line segment - the ideal six-pole and the ideal eight-pole. We assign respectively, numbers 1, 2, 3 for the above basic elements and depict the equivalent circuit of the equivalent multipole (Fig. 4, b).

From the above equivalent circuit, it follows that the scattering matrix of the equivalent multipole can be obtained by applying the cyclic algorithms for cascade connection of quadripole 1 and six pole 2, and also quadripole 1 and eight-pole 3.

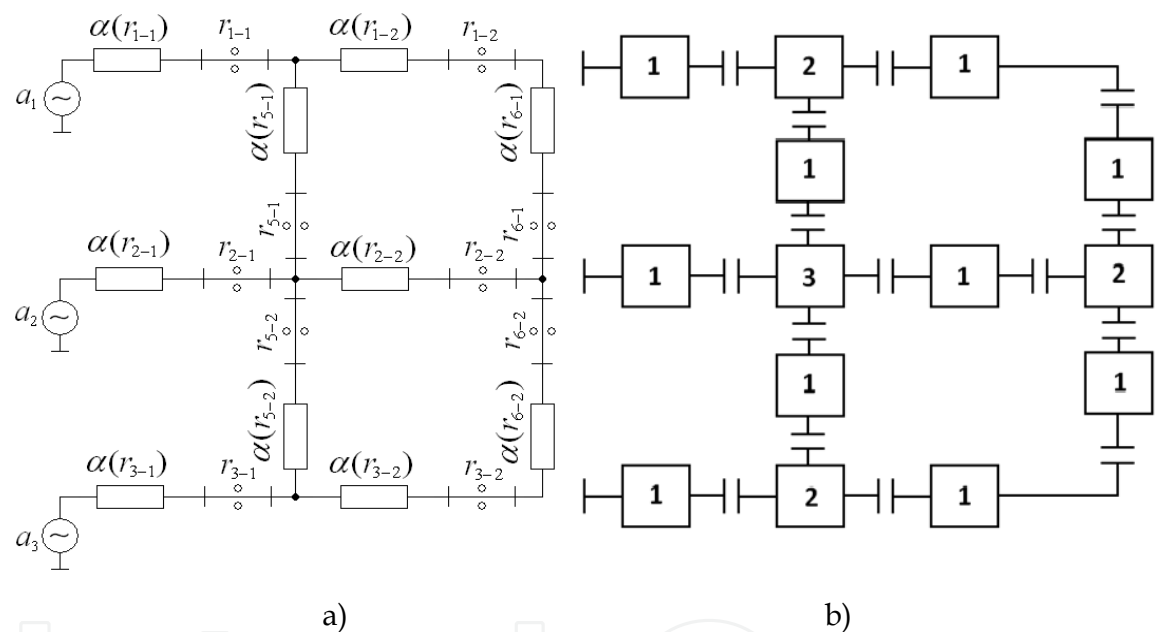


Fig. 4. The electric circuit (a) and equivalent circuit (b) of WCAB multipole

Let's give the formula for calculating the scattering parameters of the quadripole 1 and eight-pole 2 (Gostev, 1997)

$$S_{11} = S_{11}^{(1)} + \frac{(S_{12}^{(1)})^2 S_{11}^{(2)}}{A}, S_{12} = \frac{S_{12}^{(1)} S_{12}^{(2)}}{A}, S_{13} = \frac{S_{12}^{(1)} S_{13}^{(2)}}{A}, S_{22} = S_{22}^{(2)} + \frac{S_{22}^{(1)} (S_{12}^{(2)})^2}{A}, \tag{6}$$

$$S_{33} = S_{33}^{(2)} + \frac{S_{22}^{(1)} (S_{13}^{(2)})^2}{A}, S_{23} = S_{23}^{(2)} + \frac{S_{22}^{(1)} S_{12}^{(2)} S_{13}^{(2)}}{A}, A = 1 - S_{22}^{(1)} S_{11}^{(2)} \tag{7}$$

where $[S_{ij}^{(1)}]$, $[S_{ij}^{(2)}]$ – scattering matrixes of quadripole and eight-pole.

The formulae describing connection of the quadripole 1 and eight-pole 3 (Gostev, 1997)

$$\hat{S}_{11} = S_{11}^M + \frac{4S_{12}^M S_{21}^M S_{11}}{1 - S_{11}(S_{22}^M + \sum_{N=2}^N S_{2,N+1})}, \hat{S}_{21} = \frac{S_{21}^M S_{21}^M}{1 - S_{11}(S_{22}^M + \sum_{N=2}^N S_{2,N+1})}. \quad (8)$$

Let is denote

$$S_{11}^M = S_{11}^\ominus, S_{21}^M = S_{21}^\ominus, 4S_{12}^M = S_{12}^\ominus, S_{22}^M + \sum_{N=2}^N S_{2,N+1} = S_{22}^\ominus. \quad (9)$$

Considering notation (9) expression (10) can be written this way

$$\hat{S}_{11} = S_{11}^\ominus + \frac{S_{12}^\ominus S_{21}^\ominus S_{11}}{1 - S_{11} S_{22}^\ominus}, \hat{S}_{21} = \frac{S_{21}^\ominus S_{21}}{1 - S_{11} S_{22}^\ominus}. \quad (10)$$

The scattering matrix of an equivalent quadripole of i -row of the schema will be:

$$[S^{\ominus(i)}] = \begin{bmatrix} S_{11}^{(i)} & N_i S_{12}^{(i)} \\ S_{21}^{(i)} & S_{22}^{(i)} + \sum_{N_i=2}^{N_i} S_{2,N_i+1} \end{bmatrix}, \quad (11)$$

where $S_{i,j}^{(i)}$ – are the scattering coefficients of the divider or quadripole of i -row; N –amount of inputs of i - row element.

The above formulae (1) - (11) constitute a WCAB mathematical model.

3. Model of street wave channels formed by architectural buildings when WiMAX system works in the city

In this section, the general WCAB model developed in Section 2 is refined for the case of outdoor radio channels taking in consideration the characteristics of WiMAX antenna systems and RWP canyon model.

This section also describes the attenuation of radio waves along the street radio channels of the central district of Kharkov. The measurements were made at 3.5 GHz with the WiMAX base station and a created mobile laboratory. A comprehensive analysis of the results is completed - the mechanism of formation of field distribution along the streets is elucidated. Comparative results of calculations and experiments are presented. Practical suitability of the created model in the problems of forecasting of attenuation in outdoor WCAB is proved.

3.1 Experimental studies of attenuation in the street wave channels formed by architectural buildings when WiMAX system works in the city

The design of digital wireless communication systems is based largely on the design of the radio channel. The accurate model of radio channel as we know from (Hata, 1980), is always based on the experiment.

For the case of digital information transmission system (DITS) with WiMAX-technology there appeared a number of articles (Fabricio, 2005); they highlight some issues of radio

wave propagation in urban environments. In the end, for example, modulation types are revealed which are peculiar to one or another level of signal/noise (S/N) ratio at the reception point. However, the experimental results described in the mentioned works are of particular nature. They cannot be used to construct a general *RWP* model of *WiMAX* wireless channels, both because of the limited number of experimental studies, and because of the lack of their systematization on any grounds. In particular, the mechanism of wave propagation along urban wave channels formed by the architectural building is not studied.

Increased knowledge of the laws of propagation of *WCAB* wireless networks with *WiMAX* technology, especially in city streets, is important in connection with putting into operation mobile *WiMAX* systems at the present time and requires conducting extensive experimental work. Some of the experiments are done within the present study.

The purpose of the work in this subsection was to conduct experiments and analyze their results in the propagation of *DITS* signals with *WiMAX* technology along the street *WCAB* in a large industrial city (Kharkov). The map of the part of Kharkov where the investigations were made is shown in Fig. 5.

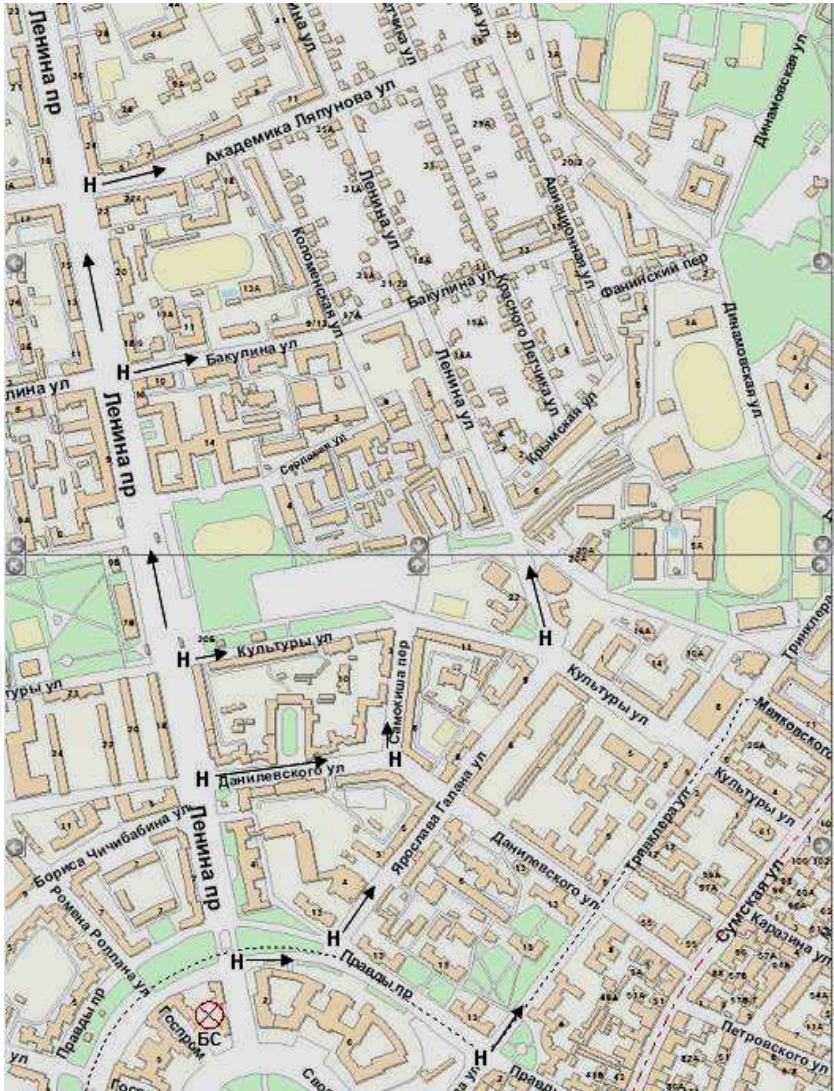


Fig. 5. The Map of the study area in Kharkov (BS - base station location)

For measurements a mobile laboratory was created, its general form is shown in Fig. 6, and its structure in Fig. 7.



Fig. 6. General view of the mobile laboratory

The mobile laboratory is equipped as follows: *WiMAX Breeze-Max 3500 (Alvarion)* subscriber station, «Asus» notebook, NovAtel SS-11 GPS receiver, voltage transformer VT – 12V/220V and storage battery SB-12V. To measure the signal/noise ratio (S/N) and signal level (S) we used special software interface that was provided by «Alternet». *WiMAX* base station (BS) was placed at the altitude of $h_{BS} = 80$ m. (Gasprom building, Fig. 6, right picture).

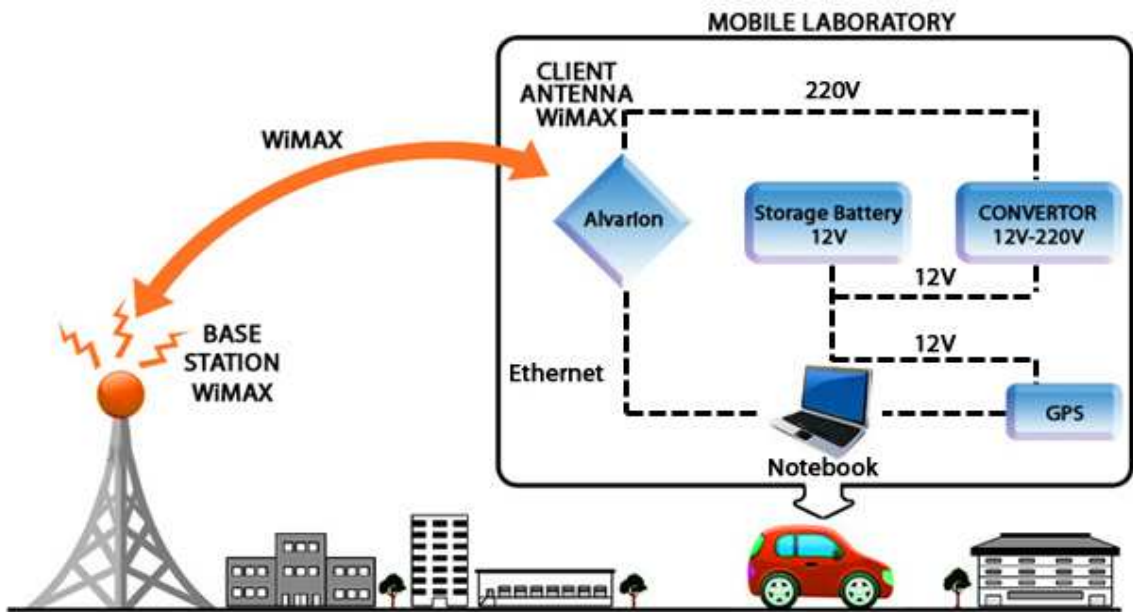


Fig. 7. The structure of the mobile laboratory

In the BS four quadrant antennas is used. One of the sectors of the polar pattern (PP) (Fig. 8, a) serves the area shown in the map (Fig. 5), the direction of maximum radiation is almost identical with the direction (orientation) of Lenin Ave.

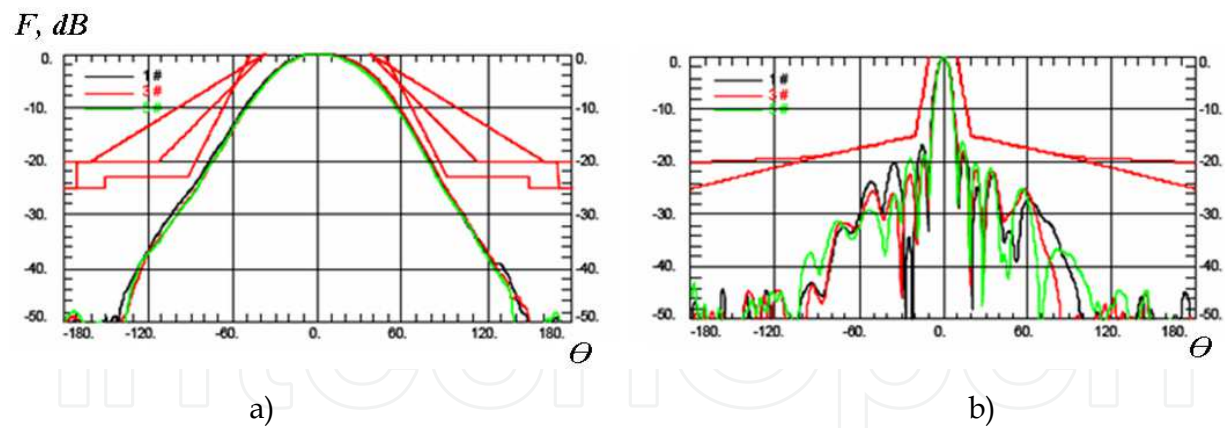


Fig. 8. Polar patterns: a) for BS antennas; б) for subscriber station (SS) antennas

Let us describe the experiments conducted, their results are shown in Fig. 9-13. The first experiment is to measure the radiation pattern along the maximum base station (along Lenin Ave). The results of the experiments in the form of dependency of $S(r)$ and $S/N(r)$ are shown in Fig. 9 a, b. In the experiments, the maximum distance r was equal to 4 km, which corresponded to the maximum range of confident communication. In the figure dots

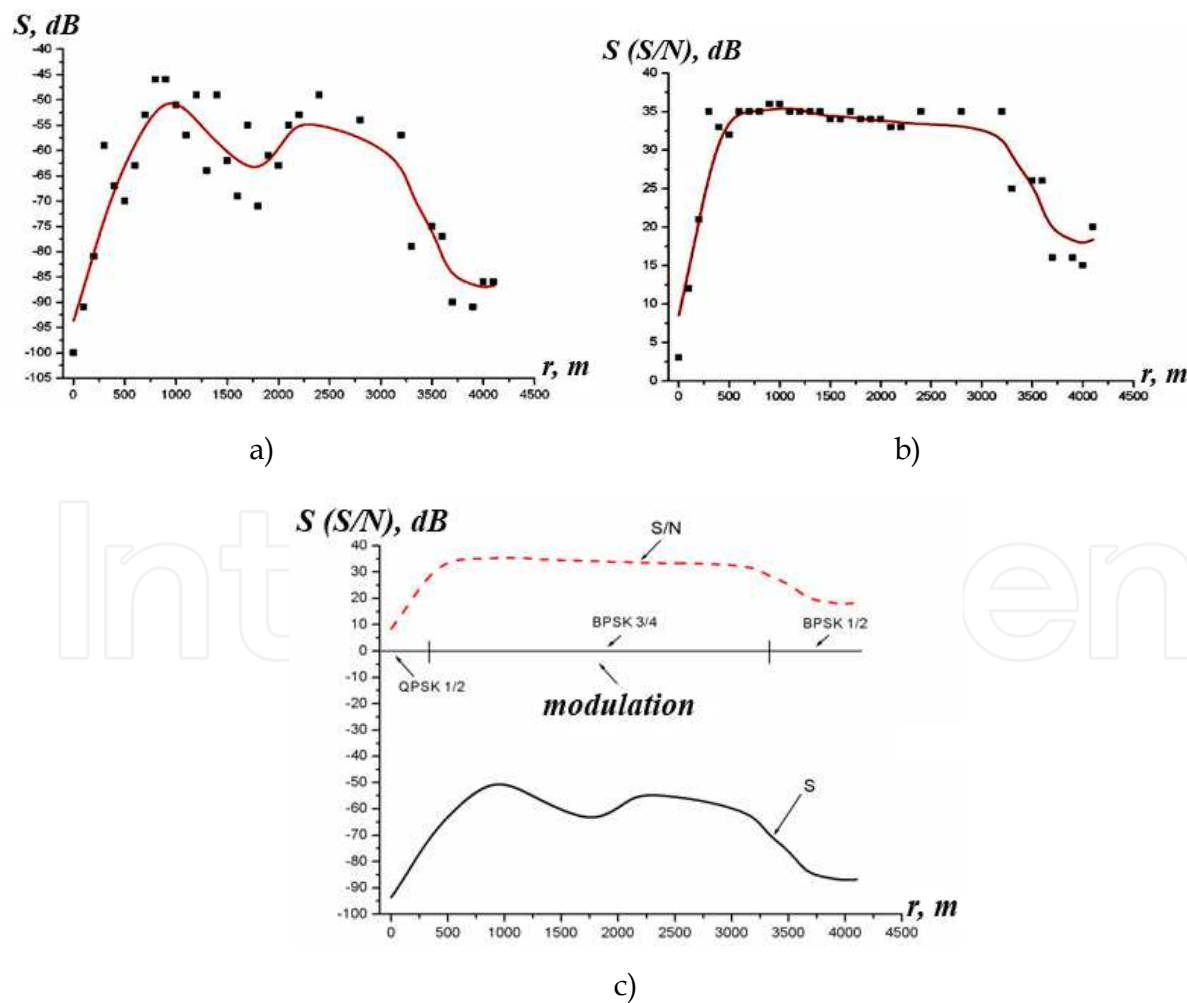


Fig. 9. The measurement data on Lenin Avenue

represented the data of single measurements at the reference distance $r_0 = 100\text{ m}$ and with 100 m step. At each point of measurement the aperture of subscriber station (SS) antenna, fixed on a tripod (Fig. 6), was placed perpendicular to the direction of maximum reception at the height of 1.5 m above the street cover. Initial measurements were averaged and smoothed using the «Origin 6.1» software. The processed results as solid curves are shown in Fig. 9 a, b. The same curves are shown in conjunction in Fig. 9, c. The fig shows the pattern of change of modulation type along the route. On the distances axis segments with one or another kind of modulation (QPSK 1/2, BPSK 3/4, and BPSK 1/2) are shown.

It is known that the WiMAX equipment is adaptive and allows you to maintain a constant transmission rate (or S/N level) of digital stream with a decrease in the signal (Fabricio, 2005).

From the presented data it follows that when $S < -65\text{ dB}$ the adjustment does work and the S/N ratio decreases with the distance at the same rate as the signal level. This result significantly refines the capabilities of WiMAX for adaptation, since in (Balvinder, 2006) it is shown that the lower limit of adaptation is the -75 dB signal level.

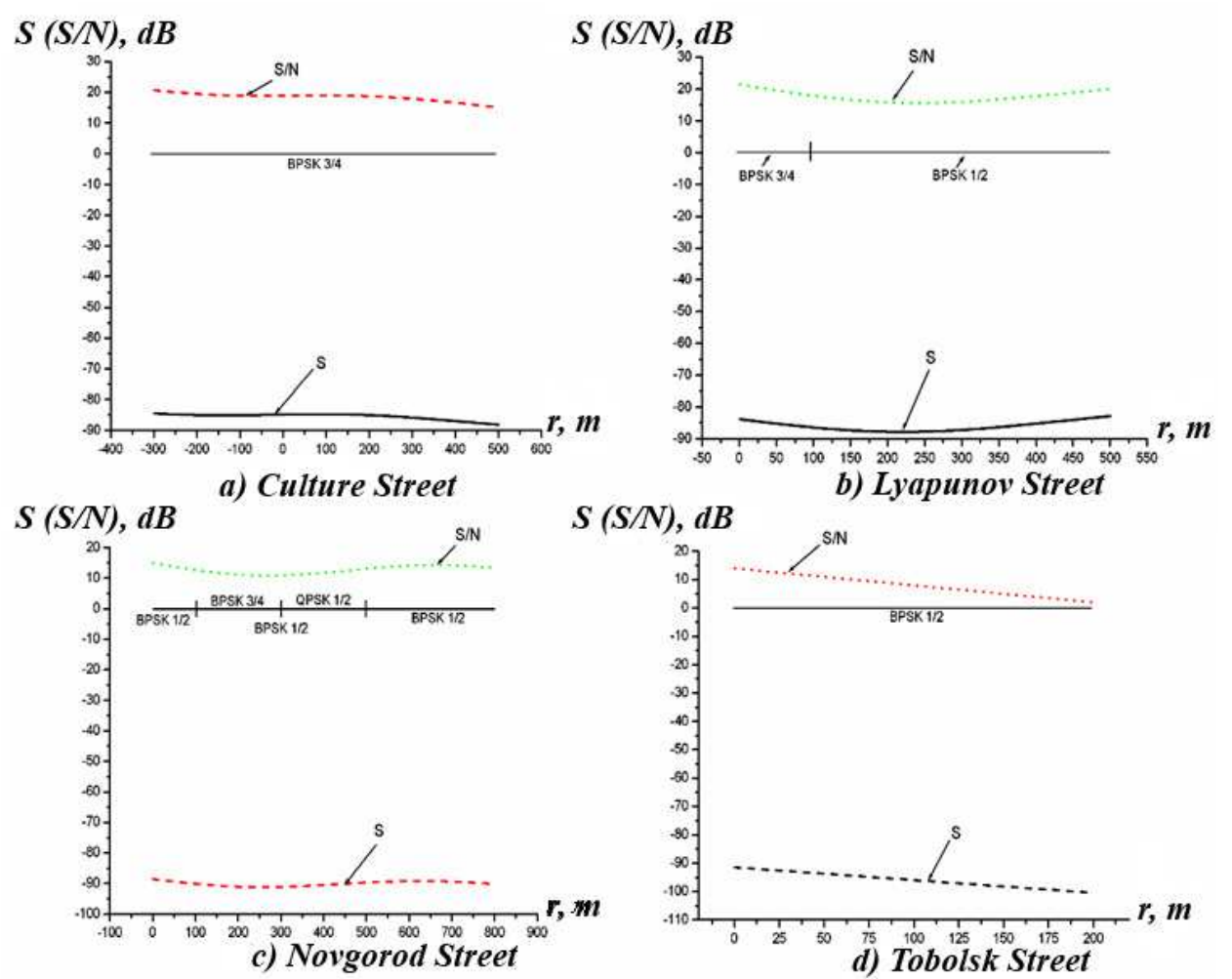


Fig. 10. Measuring the level of S , S/N values and modulation types outside the main lobe of PP of base station antenna

At the same time the data received are well correlated with the results presented in (Porrat, 2002) (Fig. 10, c and Fig. 11) in changes of modulation types on the track. Analyzing them together with the data of the experiment, we can conclude that in the tested part of Kharkov the transfer of information with WiMAX wireless communication system is carried out with the rate of 1-2 Mbps.

The distances shown in Fig. 11, a-d, were measured from H points in the direction of arrows (Fig. 5). In this case the main maximum PP of subscriber station (Fig. 8, b) was set along the street axis (approximately at the angle of 90° to the direction of maximum BS radiation). For this reason the signal level decreased by 30 dB compared to its level on Lenin Ave, which corresponds to PP value at $\Theta = 90^\circ$.

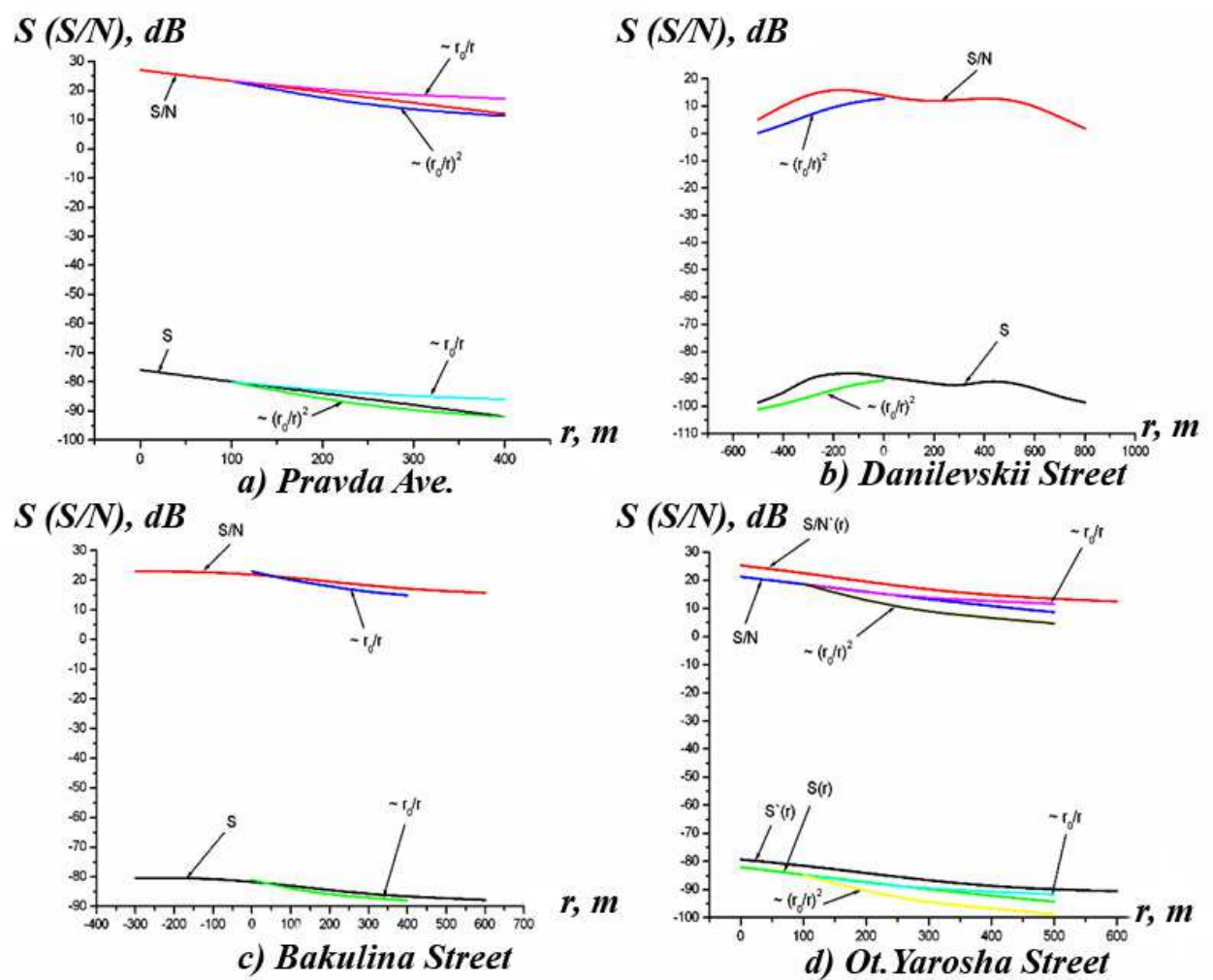


Fig. 11. Approximation of the measured distributions of fields are known functions

According to WiMAX radio access technology on the base station sector antennas with wide PP are used (Fig. 8, a), but subscriber stations have embedded antenna with narrow PP and low level of back lobe reception (Fig. 8, b).

This feature of the WiMAX apparatus allows us to offer a new method of experimental evidence for the existence of the wave channels and comparison of the signal levels S and signal/noise S/N ratio, created at the receiver due to different mechanisms of propagation.

Let us consider Fig. 12. Here BS is located on the longitudinal pattern of the street. Then, under the assumption that there exist wave channels, at the cross street, formed by ensembles of buildings $D1$ and $D2$, two streams of energy should appear (indicated by arrows in Fig. 12). These streams are running waves moving toward each other. They interfere, forming a mixed wave.

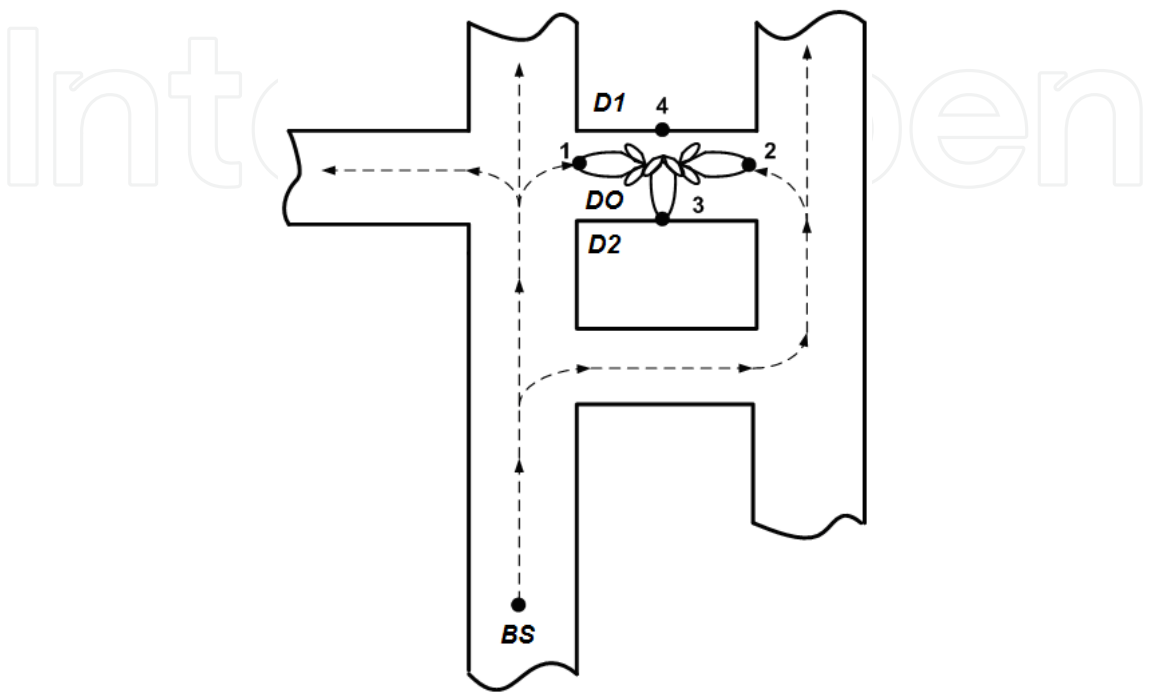


Fig. 12. WCAB structure

From the above description, we get the following method of experimental proof of the existence of the wave channel. The polar pattern of the receiving antenna is sent to a maximum PP to point 1 (Fig. 12), thus recording the flow of energy moving from point 1 to point 2. Then PP maximum goes to point 2 and a reverse flow of energy is recorded. The presence of both flows indicates the existence of a wave channel. Orienting the PP maximum to point 3 (points on the walls of houses ensembles), we can detect the intensity of the signal formed by the diffraction of radio wave propagation (from BS through the roofs of the D2 ensemble of houses).

The novelty of the proposed method in comparison with known works (for example, (Volkov, 2005)) is that using the antenna with a narrow PP one can detect the direction of energy flow along the streets and separate the contributions of different RWP mechanisms to the received signal level.

The experimental studies by the proposed method were performed in one of the four sectors of BS.

The results of measuring the levels of signal S and signal/noise S/N are shown in Fig. 10. Here curves 1 and 3 - shows the dependence of the ratio S/N and S signal levels, respectively, along the street when moving from point 1 to point 2, and curves 2 and 4 - are the same curves, only measured when the vehicle was moving in the opposite direction (i.e. the aperture of the receiving antenna was rotated at 180°).

Based on the above reasoning, we can easily conclude that in this case the *RWP* mechanism by *WCAB* acts. As before, the measurements were made at the height of the receiving antenna $h_{AC} = 1,5M$ over the street surface. Further experiments showed that the intensity of the signals at points 1 and 3 differ in $-(10 \div 15)$ dB, i.e. contribution of diffraction mechanism to the intensity of the signal is more than an order of a magnitude smaller than the *RWP* mechanism by *WCAB*.

The established fact of the interference of counter propagating waves in the street channels in the presence of diffraction field component can explain the pattern of change in signal attenuation along the streets. Fig. 11 shows the measured signal and signal/noise levels for a number of streets in conjunction with the curves of decrease of S and S/N under the laws of $(r_0/r)^2$ or r_0/r . It is easy to see that the experimental curves fall off more slowly than $(r_0/r)^2$ (Fig. 11, a, b, c) or even than r_0/r (Fig. 11, b). These dependencies as it is known from (Grudinskaya, 1967), are characteristic for Fresnel and Relay zones at the *RWP* over the reflecting surface.

The reducing of the extent of decrease of the power flux density of the signal P in the experiment compared with the above case we explain as follows. For simplicity, we assume that the phasing of the two interfering flows in a street corridor, and the diffraction component of the field is such that the vector sum can be replaced by algebraic one. Then the expressions for the damping power of the street channel from the normalized distance k can be easily written as:

$$\alpha\left(\frac{r_0}{r}\right) = \frac{PD(r)}{PD_{\max}} = \left[\frac{1}{k^n} + \frac{M(l)}{[l - (k-1)]^n} + L(r) \right]. \quad (12)$$

In (12) it is indicated: $PD_{\max}$ – is the maximum power flux density at the point 1, when $r = r_0$ and the energy moves in the direction of point 2 (Fig. 12); $k = 1, 2 \dots l$, where l – number of sections the street of length $l \cdot r_0$ was divided into; $M(l) = PD_{\max}(l) / PD_{\max}(r_0)$, where $PD_{\max}(l)$ – maximum power flux density at point 2 when energy moves in the direction of point 1 (Fig. 14); $L(r) = PD_d(r) / PD_{\max}$, where $PD_d(r)$ – power flux density in the street due to diffraction of the radio channel.

In Fig. 13 calculations of value $\alpha(r)$ at $l = 10$, $M = 0,1$, $r_0 = 100$ m are given assuming that $L(r) = \text{const} = 0,1$, and $n = 2$.

Curve $\alpha(r)$ at the decreasing site is well described by the function $(r_0/r)^{1.5}$. Depending on the values of $M \in [0,1]$ and l the pattern of measuring the field distribution along a particular street can be described either by the inverse power function (Fig. 11,a), or by polynomial of n power (Fig. 10,a).

We obtained experimental field distributions along the street *WCAB* that well match with the data in (Porrat, 2002). Here they also conducted measurement of radio waves attenuation in street channels (Ottava), only at 900 MHz frequency and with the help of nondirectional antennas.

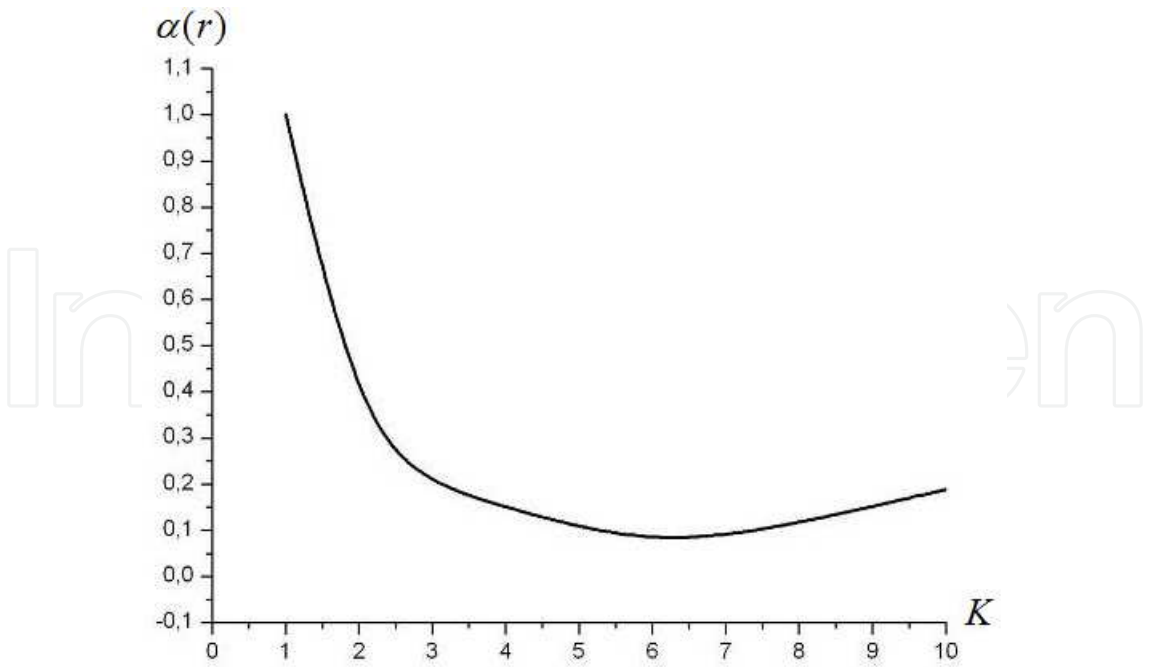


Fig. 13. Calculation results for formula (8)

Another proof of the validity of the results of the experiment is the data of repeated measurements shows in Fig. 11 d. These experiments were conducted one week after the first experiments. The qualitative nature of the curves is identical in both cases.

Thus, for WCAB of different frequencies of microwave range interference is inherent leading to the formation of mixed waves. The mathematical description of these waves is well developed in the theory of microwave circuits which is recommended for the calculation of street WCAB without diffractive component of the field. Another proof of the feasibility of the approach investigated to the WCAB analysis is presented in (Waganov, 1982).

3.2 Theoretical research of attenuations in the street wave channels formed by architectural buildings at the example of WiMAX system

When applying the WCAB model worked out in section 2, in the case of functioning of WiMAX systems, we must know the architectural features of the area where the measurements were done.

For the analysis area (Fig. 5) the following data were obtained. Height above the sea level for most of the analysis area varies smoothly from 135 to 145 m, which allows us to characterize the underlying surface as slightly undulating. The area is characterized by high building density, which makes it possible to approximate the lateral surface of wavelengths to a solid wall. Studies have shown that the material of the walls of most buildings in this case is brick. All the streets have asphalt as the underlying surface. Electrical parameters of brick can vary greatly enough and, according to the paper (Volkov, 2005), for this frequency range they are: specific permittivity $\epsilon_1=2..15$, conductivity $\sigma=0,002..0,01$. The conductivity of asphalt is in the same range as for bricks ($\sigma_2=0,002..0,01$), and permittivity $\epsilon_2=2..5$. Data as for the WCAB length and width are given in Table. 1.

Street name	Segment length, m	Width, m
Lenin Ave	4000	50-55
Bakulina	600	25-30
Danilevskii	1000	30-35
Lenin	1200	30-35
Lyapunov	550	30-50
Samokisha	200	25-50
Culture	600	30
Galana	500	30-40

Table 1. WCAB lenght and width

In the case of street branched radio channels general *WCAB* model, created in section 3.1, must be supplemented by the calculated damping ratios for *RWP* taking into consideration characteristics of *WiMAX* antenna system. Thus, the damping on the straight segment of the street should be calculated by the formula

$$\alpha(r_i / r_0) = (D_1 - \Delta D_1) + (D_2 - \Delta D_2) + \frac{PD(r_i / r_0)}{PD_{\max}}, [dB],$$

(13)

where D_1 – maximum directional antenna factor (*DAF*) of base station (14 dB), D_2 – maximum *DAF* of client adapter antenna (16,5 dB); $PD(r_i / r_0) / PD_{\max}$ – relative power flux density, which was calculated using the models described in *RWP LAN-MAN* (Strelnitskiy, 2008); $\Delta D_1, \Delta D_2$ – amendments that allow change of *DAF* in a given direction, calculated from the mentioned considerations.

Antenna parameters significantly affect the nature and level of the signal and noise. The complexity of the problems of determining the signal strength and signal/noise level is that you need to know not only the maximum *DAF* $D_{\max}$, but also *DAF* in a particular direction in azimuth θ and the corner of the place φ – $D(\theta, \varphi)$.

The applied methods of reducing antenna extraneous emission, and side lobe suppression leads to the complication of the analytical description of the antenna as a whole (Wheeler, 1947). In addition, such description often presents a trade secret of manufacturing companies and antenna technical data contain only its simplified polar pattern and basic characteristics. You should also take into account the fact that under real conditions of installation (the roof of a building, an antenna mast), due to the influence of the earth's surface and surrounding objects, the shape of a real PP is different from that calculated. Therefore, considering a large amount of analyzed data based on the information provided by the manufacturer of antennas, in the polar coordinate system we made polar patterns of the base station antenna (Fig. 14, a) and PP of the customer *WiMAX* antennas (Fig. 14, b).

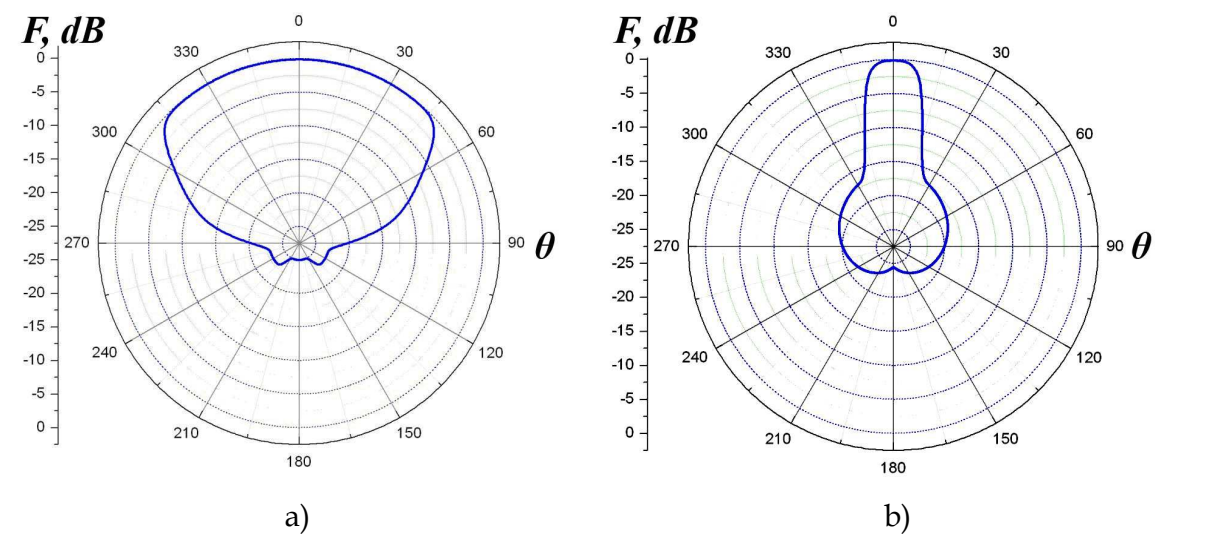


Fig. 14. PP of the base station (a) and customer *WiMAX* antenna (b)

Mutual arrangement and orientation of antennas in the calculation of communication systems can be quite different. Therefore, the actual antenna gain at the base station in the direction of the client adapter interacting with it is defined by the angles that define the direction from the antenna of the transmitter to the receiver antenna, and vice versa, – in horizontal and vertical planes $\theta_{TR}, \theta_{RT}, \varphi_{TR}, \varphi_{RT}$ respectively.

In Fig 15,a relative position of antenna polar patterns in the horizontal plane is given and the same thing is given in a plane passing perpendicular to the plane $\lambda,0,\xi$ through the studied antennas in Fig. 15,b.

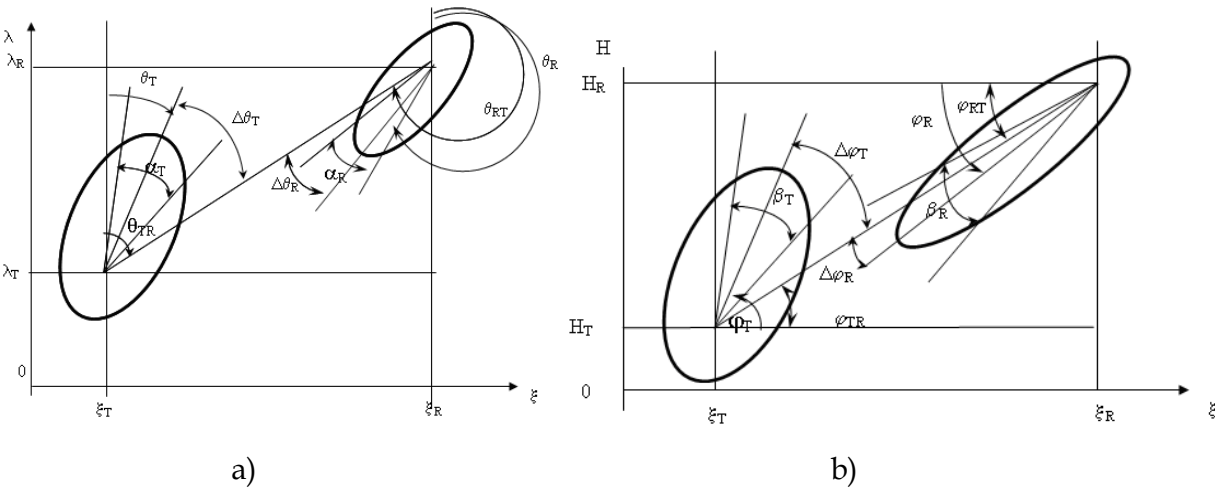


Fig. 15. Parameters of relative positions of antennas in the horizontal (a) and in the vertical (b) planes

In figures the following geographic coordinates are marked: λ_T, ξ_T – latitude and longitude of the location of the transmitter antenna, λ_R, ξ_R – latitude and longitude of the location of the receiver antenna; α_T, β_T – width of the transmitter PP in the horizontal and vertical planes respectively; α_R, β_R – the same for PP of the receiver; θ_T, θ_R – azimuth of maximum

radiation and reception of the transmitting and receiving antennas, respectively; φ_T, φ_R – elevation angles of maximum radiation and reception of the transmitting and receiving antennas, respectively; r_i – distance between the transmitter and receiver; H_T, H_R – height of transmitting and receiving antennas, respectively.

Corners θ_{TR} and φ_{TR} are obtained from the geometrical problem in Fig.15:

$$\theta_{TR} = \arccos \frac{\sin \lambda_R - \sin \lambda_T (\sin \lambda_T \cdot \sin \lambda_R + \cos \lambda_T \cdot \cos \lambda_R \cdot \cos(\xi_R - \xi_T))}{\cos \lambda_T \cdot \sin(\arccos(\sin \lambda_T \cdot \sin \lambda_R + \cos \lambda_T \cdot \cos \lambda_R \cdot \cos(\xi_R - \xi_T)))}, \quad (14)$$

$$\varphi_{TR} = \arctg \frac{H_R - H_T}{r_i}. \quad (15)$$

To determine θ_{RT} and φ_{RT} it is necessary to change indexes T to R and R to T in (14).

The correction that takes into account DAF changes in a given direction of PP, can be found from:

$$\Delta D = \sqrt{D_{\Delta\theta}^2 + D_{\Delta\varphi}^2}, \quad (16)$$

where $D_{\Delta\theta}$ and $D_{\Delta\varphi}$ – coefficients of directional antennas in both horizontal and vertical planes, respectively.

DAF relative to field strength can be calculated by the formula:

$$D_{\Delta\theta}, D_{\Delta\varphi} = 20 \cdot \lg(\tau) \text{ (dB)}, \quad (17)$$

where τ – value, taking into account the reduction in antenna gain in direction $\Delta\theta, \Delta\varphi$ compared to the maximum gain.

Corners $\Delta\theta, \Delta\varphi$ can be calculated by the formulas:

$$\begin{aligned} \Delta\theta_{T,R} &= \left| \theta_{T(R)} - \theta_{TR(RT)} \right|, \\ \Delta\varphi_{T,R} &= \left| \varphi_{T(R)} - \varphi_{TR(RT)} \right|. \end{aligned} \quad (18)$$

The width of base station antenna PP: in the horizontal plane – 90° , in the vertical plane – 8° . The width of customer adapter antenna PP: in the horizontal plane – 20° , in the vertical plane – 20° .

Formulas for calculation τ for different antenna types have the form:

- customer WiMAX adapter antennas:

$$\tau = \frac{4b^2 \cdot \cos^2 \gamma}{(4b^2 - 1) \cos^2 \gamma + 1}, \quad (19)$$

$$b^2 = \frac{1}{2} \cdot \frac{1 - \cos^2 \alpha}{1 - (\sqrt{2} \cos \alpha - 1)^2}, \quad 0^\circ \leq \alpha \leq 65^\circ, \quad -90^\circ \leq \gamma \leq 90^\circ, \quad (20)$$

where γ – corner $\Delta\theta_T, \Delta\theta_R, \Delta\varphi_T, \Delta\varphi_R$ depending on the particular antenna (transmitting - T, receiving - R) and plane (horizontal θ or vertical φ); α – PP width in horizontal (α_T, α_R) or vertical (β_T, β_R) planes;

- WiMAX base station antennas:

$$\tau = \frac{(1-a)\cos\gamma + \sqrt{(1-a)^2 \cdot \cos^2\gamma + 4a}}{2}, \tag{21}$$

where $0 \leq a \leq 1$; at $a = 0$ $-90^\circ \leq \gamma \leq 90^\circ$; $a = 1$ $-180^\circ \leq \gamma \leq 180^\circ$.

Corner γ is calculated by the formula: $\gamma = \arctg\left(\frac{H_T - H_R}{r_i}\right)$ Fig. 16.

Here are some examples of calculations on the proposed model by means of *Microwave Office* application package.

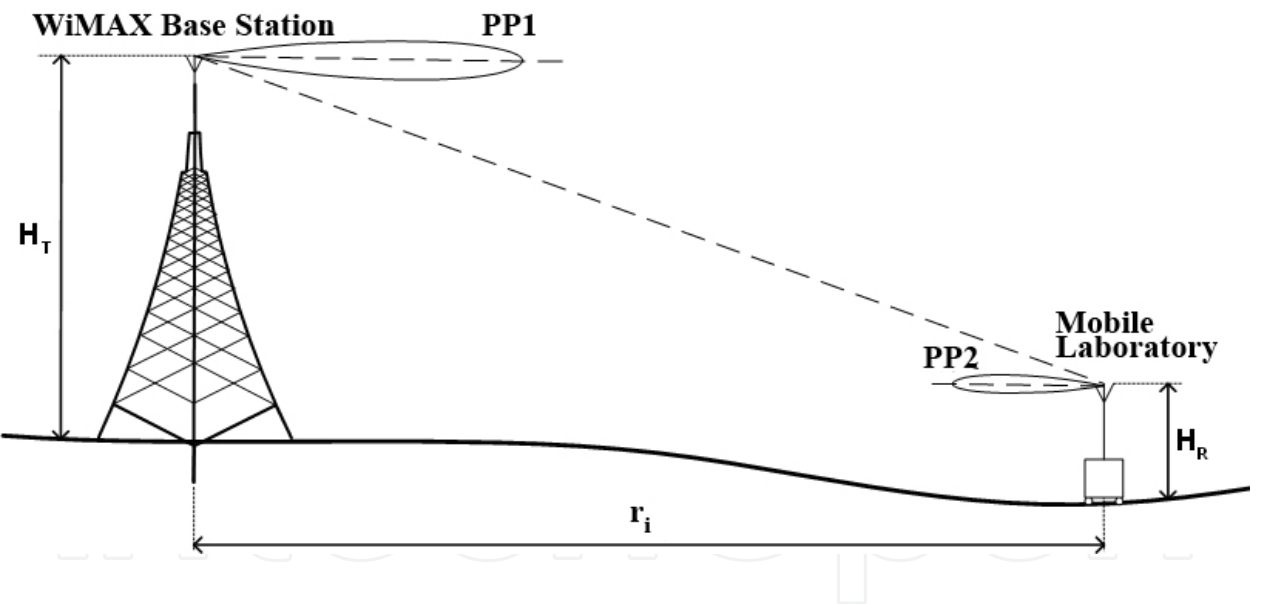


Fig. 16. For the calculation of the angle γ

The example of a streets connection scheme used to calculate the attenuation along Lenin Avenue in the *Microwave Office* application package, is shown in Fig. 17 ($l = r_i$ – line segment length r_i ; $AT(m,n)$ – attenuators (m – street number, n – attenuator serial number for the street with m number); PI – power indicator). The scheme is activated by three sources of locally plane waves from the streets: Romain Rolland, Galana and Lenin Ave.

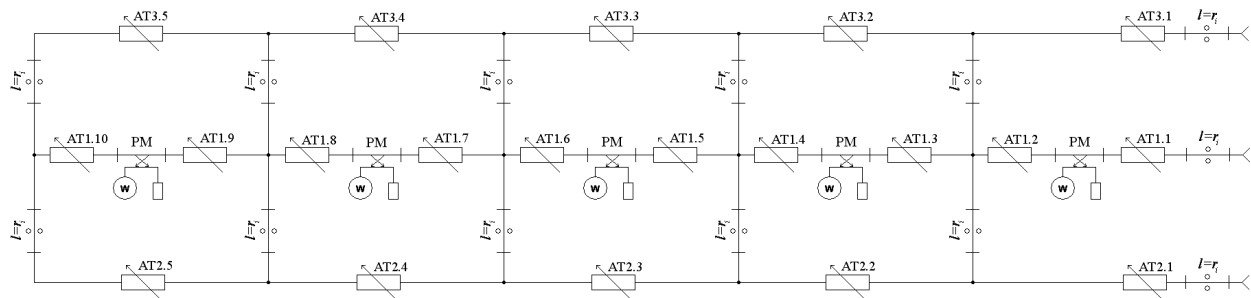


Fig. 17. The scheme for calculating the attenuation along Lenin Avenue ($m=1$ – Lenin Ave, $m=2$ – Romain Rolland street, $m=3$ – Galana street)

For signal level S assessment in r_i points on Lenin Ave. the attenuator AT(1,1) was attributed with the decay $\alpha(r_i / r_0)$, calculated by the formula (9). Summand $PD(r_i / r_0) / PD_{\max}$ in formula (9) is calculated using ratio (10) for a power flux density and the expression (11) for the field strength at the receiver.

$$PD_{\max} = \frac{1}{2} \cdot \frac{|E|^2}{120\pi} . \tag{22}$$

$$\dot{E}(r) = \frac{\sqrt{P \cdot Z_0 \cdot D_2}}{2\pi} \cdot \left[\frac{1}{r} \cdot \left(1 + R_B \cdot e^{-k \cdot r \cdot i} + R_{\Gamma} \cdot e^{-k \cdot r \cdot i} + R_{\Gamma} \cdot e^{-k \cdot r \cdot i} \right) \cdot e^{-k \cdot r \cdot i} \right] , \tag{23}$$

where P – emitting power at the point of transfer; Z_0 – impedance of free space; D_2 – directional antenna factor; R_B , R_{Γ} – reflection coefficients for vertical and horizontal polarizations. Similarly, attenuation for all other attenuators AT(2,n) and AT(3,n) were calculated. At the same time power meter in the lines that imitate the streets 2 and 3, were excluded and were attributed to the attenuator loss distribution over the entire length of the segments. Comparative data on the results of the calculation according to the method described and experimental results are shown in Fig. 18, 20, 22. Fig. 19, 21 shows a connection diagram of the streets used to calculate the attenuation along the streets in the *Microwave Office* application package.

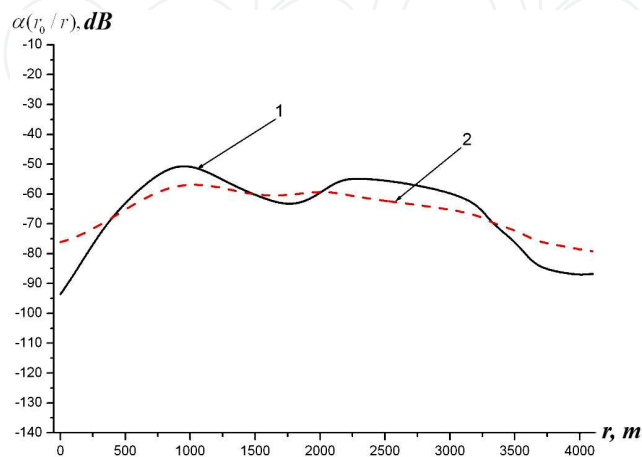


Fig. 18. Attenuation along the Lenin Ave (1 – experiment, 2 – calculation)

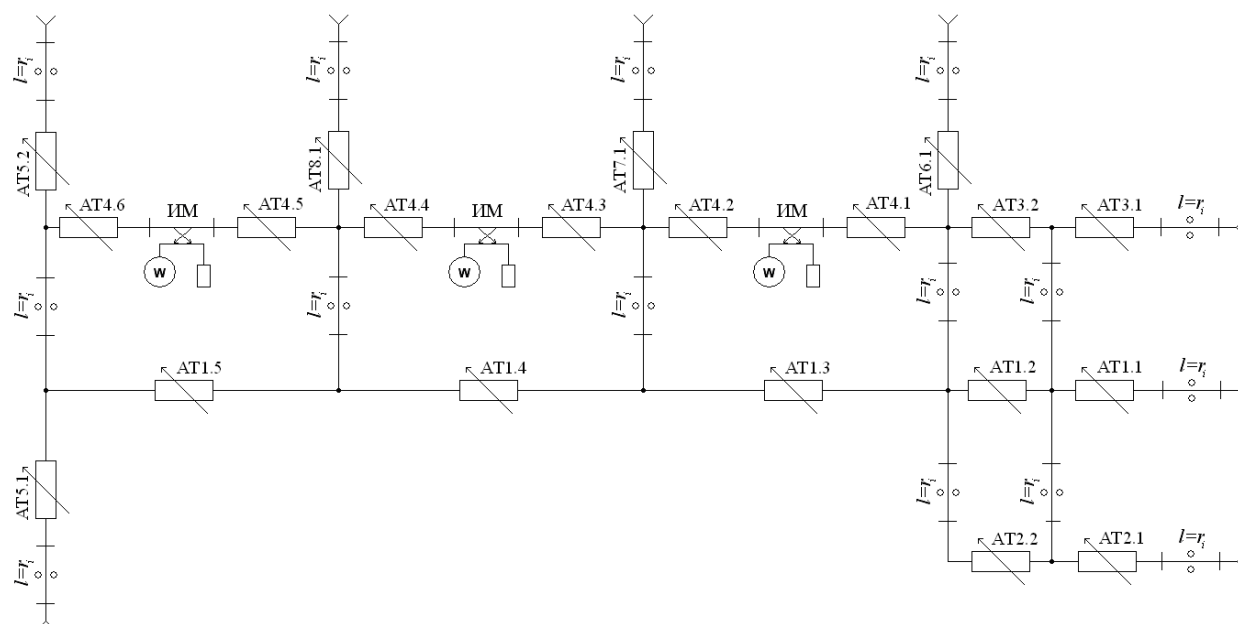


Fig. 19. The scheme for calculating the attenuation along Lenin street ($m=1$ - Lenin Ave., street ($m=1$ - Lenin Ave., $m=2$ - Romain Rolland street, $m=3$ - Yaroslav Galan street, $m=4$ - Lenin street, $m=5$ - Novgorod street, $m=6$ - Culture street, $m=7$ - Baculina street, $m=8$ - Ak. Lyapunov street)

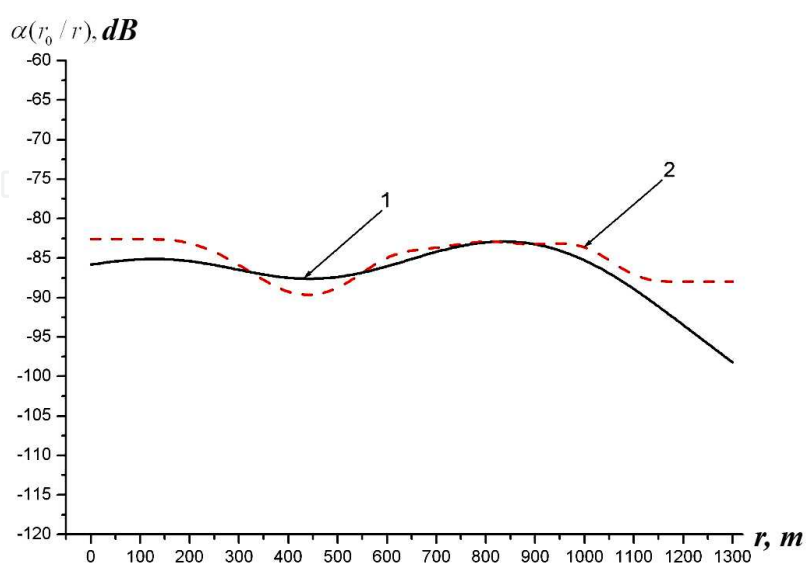


Fig. 20. Attenuation along Lenin street (1 – experiment, 2 – calculation)

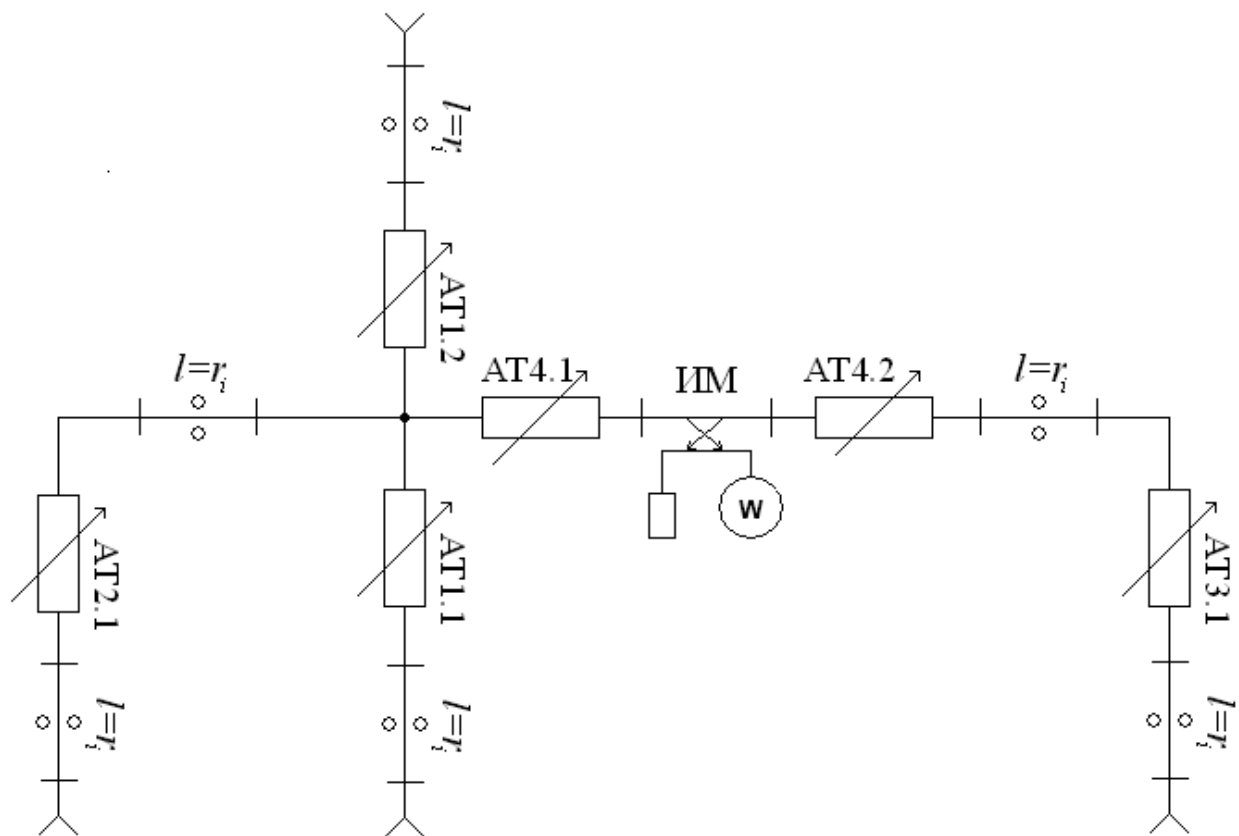


Fig. 21. The scheme for calculating the attenuation along the Danilevskii street (m=1 - Lenin Ave., m=2 - Romain Rolland street, m=3 - Yaroslav Galan street, m=4 - Danilevskii street)

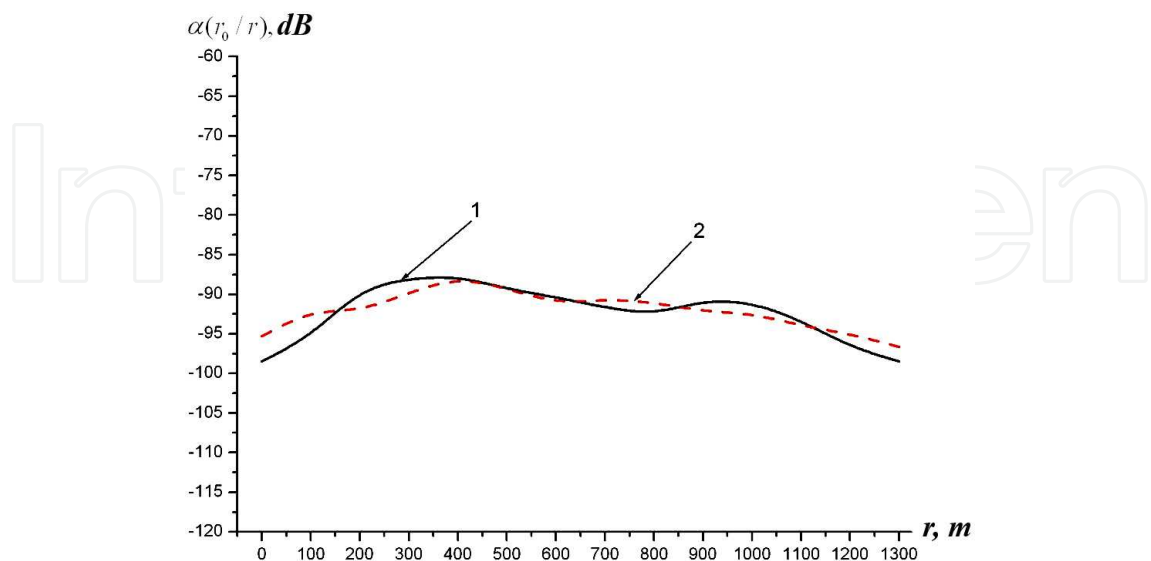


Fig. 22. Attenuation along the Danilevskii street (1 - experiment, 2 - calculation)

It is easily seen that the theoretical curves agree well with experimental data.

4. Assessment of performance and noise immunity of the *WiMAX* system in the city

Let us estimate the performance and security of *WiMAX* channel in the particular example of its operation in the telemedicine system (Fig. 23). It is expedient to consider this example because in constructing the telemedicine system branched channels of street *WCAB* are used.

In this case, the base station and special ambulance are supplied with *WiMAX* equipment. Medical team transfers the data about the patient via *Wi-Fi*. Information comes from the base station to the telemedicine center and providing consultations to the medical team.

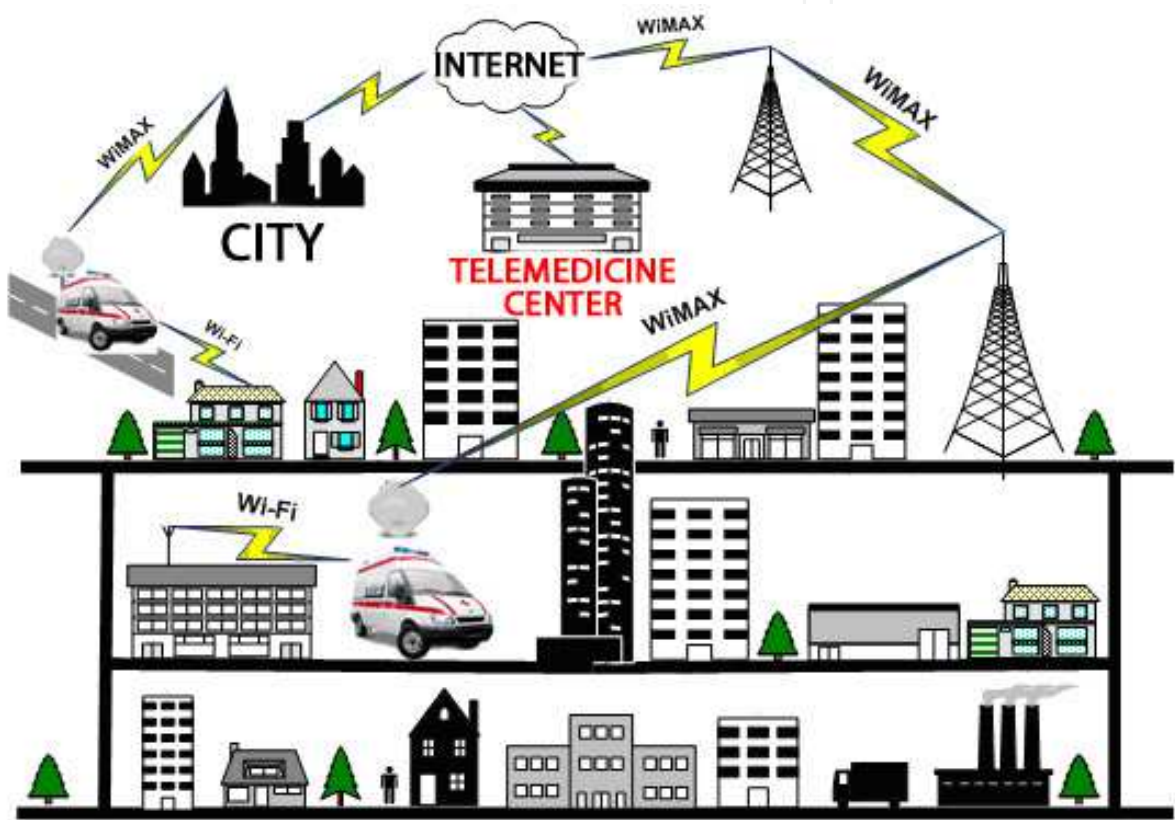


Fig. 23. Configuration of telemedicine network based on *Wi-Fi* and *WiMAX* technologies

Let us define the system efficiency, assuming that the telemedicine system serves population on Lenin Ave. The experimental and theoretical S / N values are shown in Fig. 5.14 (curves 1 and 2). From the comparison of these two curves it follows that the proposed model can be applied to calculate the performance of branched *WCAB* of *MAN* level (Strelnitskiy, 2009).

The rate of information transmission in *WiMAX* channel can change significantly (Fig. 24) depending on their bandwidth, which varies according to (IEEE Standard, 2004) from 1,7MHz (curve 1) to 3,5 7MHz (curve 2).

Comparing our results with the standards, we conclude that in the absence of interference in branched *WiMAX* channels, multimedia data can be transferred with high quality, which is very important during, for example, medical operations (Strelnitskiy, 2008).

Let us plot the graphs of the packet errors probability versus interference level for networks such as MAN (Fig. 25).

Analyzing the results in Fig. 25 with the recommendations of the video transmission standards, we conclude that the presence of noise value less than $P_j / P_s = 0,4$ in branched WiMAX channels, multimedia data can be transferred with high quality at a distance of 3 km, that is very important in the construction of telemedicine networks in big cities.

The model examined in this chapter can be used not only to assess the performance and noise immunity of WiMAX radio channel on WCAB conditions, but also to forecast its physical level security [Strelnitskiy, 2011].

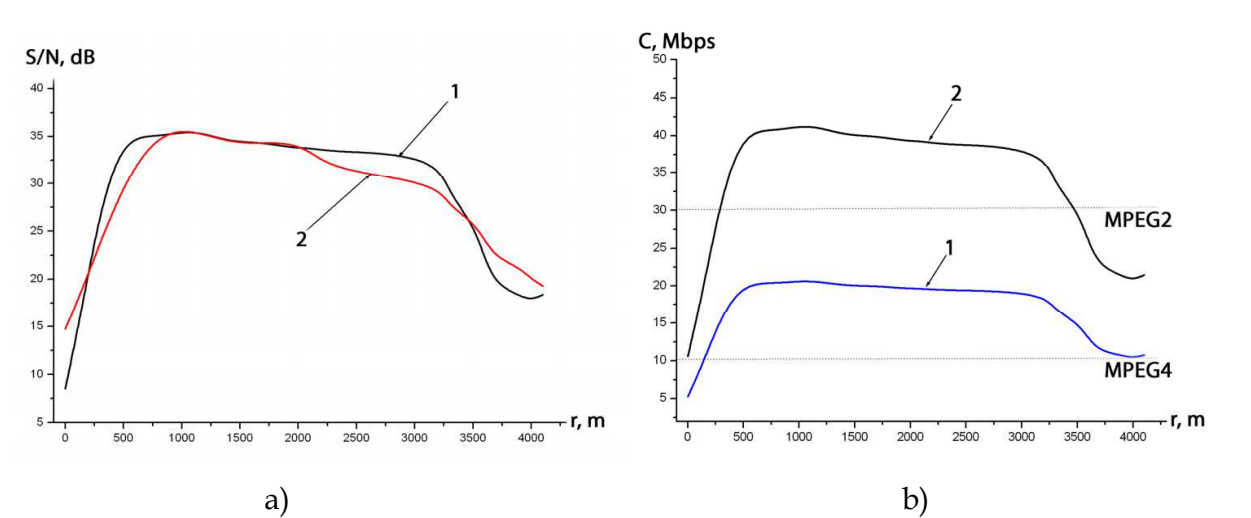


Fig. 24. Dependency of S / N to distance (a) and transmission rate (b) for Lenin Ave.

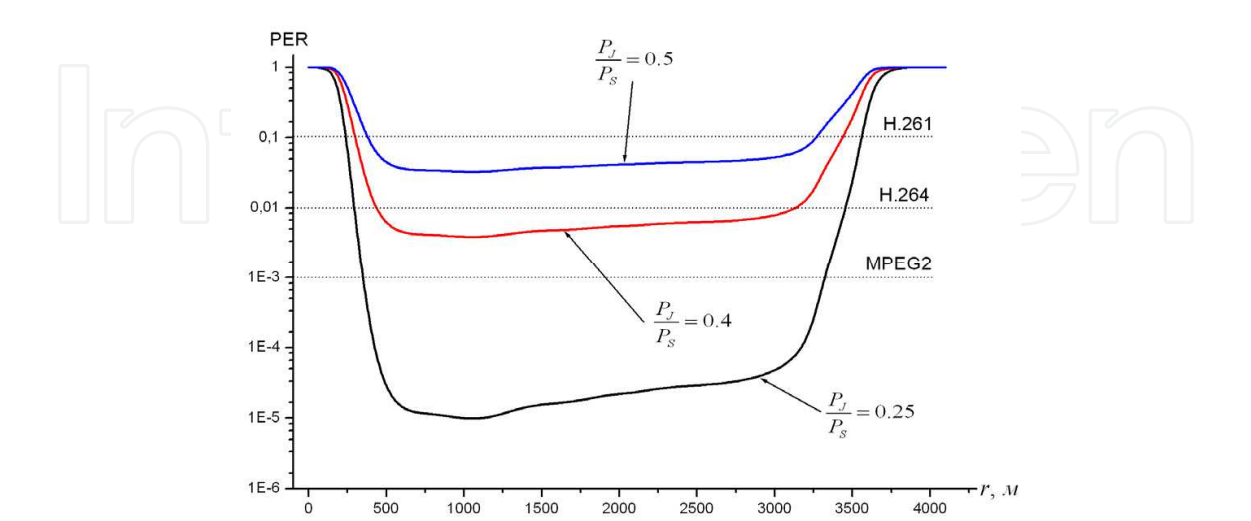


Fig. 25. The dependence of the probability of packet errors on the distance for different values of noise for Lenin Ave. (P_j – interference power, P_s – signal power)

5. Conclusion

1. The approach is developed to create a simplified *WCAB* model, which is based on the idea of representation branched wavelengths in the form of two-wire lines segments connected to one multipole and equivalent in the level of transmission power of street wavelengths. We propose a model to calculate the S-parameters of such multipole-based on using known cyclic algorithms and on registered losses equal to the *WRP* attenuation along *WCAB*.
2. Version of a mobile laboratory on the basis of *WiMAX* subscriber station was created and the *WRP* patterns of street *WCAB* were measured. From the comparison of the data we obtained in the signal/noise ratio with the data of *WiMAX* standard we discovered that the speed of information transmission by the *WiMAX* system operating in the city is less than 2 Mbps at a distance of 4 km.
3. New data on the possibilities of adapting the *WiMAX* system to maintain constant transmission speeds were obtained. It is shown that the adaptation of this system is realized if the signal level is above -65 dB (the lower limit declared before was -75 dB (Balvinder, 2006)).
4. Using the property of high antenna directivity of *WiMAX* client adapter we offer a new method of detection the street wavelengths and reception of the diffraction component of the field. Using this methodology, we proved the dominant existence of *WCAB* in the central area of the city of Kharkov and showed that the level of the diffraction component does not exceed - 10 dB at the chosen measurement conditions ($h_{BC} = 80\text{ m}$, $h_{AC} = 1,5\text{ m}$ and low-rise building of analysis area).
5. It is shown that the patterns of distribution of the field along the city streets are largely predetermined by the interference of waves. A verbal description of this process is given and by comparing with the results (Porrat, 2002) a conclusion is made that it is valid for the cases of measurements in different cities and different frequencies of microwave range.
6. It is concluded that *WRP* dependencies along the street channels identified in the analysis of experimental results are characteristic of microwave circuits, which suggests the possibility of using their well-developed theory to create a *WCAB* model.
7. The ability to predict the attenuation in branched outdoor radio channels using the proposed *WCAB* model was proved.
8. The formula was derived for the calculation of the channel performance and the functional dependence of attenuation on the track was found, which allow to determine the performance of communication systems not worse than previously known mathematical models, but with much less time-consuming. Good agreement between calculated and experimental data gives the right to recommend the above model to calculate the performance and speed of information transmission in wireless access systems of *MAN* level.
9. The assessment of communication system noise immunity on *MAN* level has been given by the wave propagation in the channels formed by buildings. Comparing these results with the standards of video transmission, it was concluded that the presence of noise of less than $P_f / P_s = 0,4$ in branched *WiMAX* channels multimedia data with high quality can be transferred at a distance of 3 km, which is very important in the construction of telemedicine networks in major cities.

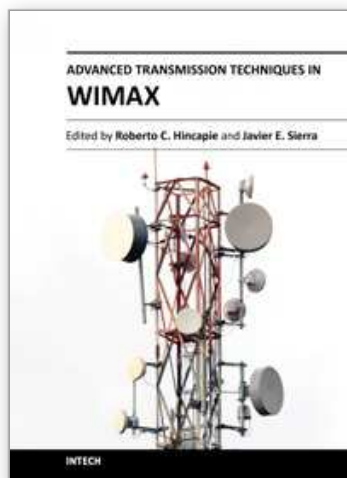
6. Acknowledgment

These studies were supported by the grant from the State Foundation for Fundamental Research, Ministry of Science and Education of Ukraine (#F25/217-2008).

7. References

- Balvinder, B.; Eline, R. J., and Franca-Neto, L. M. (2006), RF System and Circuit Challenges for WiMAX. *Intel® Technology Journal*, Vol.08, Issue 03, (August 2004). pp. 189-201, ISSN: 1535-864X
- Fabricio, L. F., and Cardieri, P., (2005), Coverage Prediction and Performance Evaluation of Wireless Metropolitan Area Networks based on IEEE 802.16. *Journal of communication and information systems*, Vol.20. No.3, (2005), pp. 132-140, ISSN: 1980-6604
- Gostev, V.I., Konin, V.V., and Matsepura, A.L., (1997), Linear multichannel microwave devices, Radio amator Publishing house, Kiev: 315 p. (in Russian)
- Hata, M., (1980), Empirical formula for propagation loss in land mobile radio service, *IEEE Transactions on Vehicular Technology*, Vol. 29, No. 3, (Aug 80), pp. 317-325.
- IEEE Standard, (2004), Standard for Local and metropolitan area networks. Part 16: Air Interface for Fixed Broadband Wireless Access Systems. IEEE P802.16-REVd/D5-2004, 915 p.
- Porrat, D. (2002). PhD Thesis: Radio Propagation in Hallways and Streets for UHF Communications.
- Strelnitskiy, O.O.; Strelnitskiy, O.E.; Tsopa, O.I., and Shokalo, V.M., (2011), Prediction Model of Energy Security for the Systems of Subscriber Radio Access with Branched Street and Corridor Communications Channels. *International journal «Radioelectronics and Communications Systems»*, Allerton Press, Inc., Springer, Vol. 54, No. 2, (2011), pp. 61-68, ISSN: 0735-2727.
- Strelnitskiy, O.O.; Tsopa, O.I. and Shokalo, V.M., (2009), Approximate Model for Estimation of Efficiency and Noise Immunity of Branched Street and Corridor Wi-Fi and WiMAX Communication Channels. *International journal «Telecommunication and Radio Engineering»*, Begell House, Vol. 68(17), (2009), pp. 1511-1528, ISSN: 0040-2508
- Strelnitskiy, O.E.; Tsopa, O.O.; Tsopa, O.I., and Shokalo, V.M. (2008), The variant of quality increasing of video information transmission via WIMAX fixed connection radio channel. *Proceeding of IX International Conf. Modern problems of Radio Engineering, Telecommunications and Computer Science /TCSET'2008/*, Lviv-Slavsko, Ukraine, (February 2008), pp. 388-389, ISBN: 978-966-553-678-9
- Strelnitskiy, A.A., Strelnitskiy, A.E., Tsopa, O.I., and Shokalo, V.M., (2008), Version of the model of the wideband signal attenuation in radio link when calculating the local communication networks protection, *Scientific Journal Information Protection*, Vol. 3(39), pp. 38-43 (in Russian).
- Strelnitskiy, A.A.; Strelnitskiy, A.E.; Tsopa, O.I., and Shokalo, V.M., (2007), The Model of the Multiterminal Network for Attenuation Calculation of the Radio Waves in the Wave Channels of the Architectural Buildings (KNURE - WCAB Model). *Microwave & Telecommunication Technology, CriMiCo2007*. 17th International Crimean Conference Publication, (September 2007), pp. 213-214, ISBN: 978-966-335-012-7

- Volkov, L.N., Nemirovsky, M.S., and Shinakov Y.S., (2005), Digital communication systems: basic methods and characteristics, Eco-Trends, Moscow: 392 p. (in Russian)
- Waganov, R.B., and Katseneleybaum, B.Z. (1982), Fundamentals of diffraction theory. Science, Moscow: 272 p. (in Russian)
- Grudinskaya, T.P., (1967), Wave propagation, High school, Moscow: 244 p. (in Russian)
- Wei, Z., (2007), Capacity analysis for multi-hop WiMAX relay. *Proceeding of the International Conference on Wireless Broadband and Ultra Wideband Communication*, (Mar. 2007), University of Technology Sydney, Sydney, pp. 1-4



Advanced Transmission Techniques in WiMAX

Edited by Dr. Roberto Hincapie

ISBN 978-953-307-965-3

Hard cover, 336 pages

Publisher InTech

Published online 18, January, 2012

Published in print edition January, 2012

This book has been prepared to present the state of the art on WiMAX Technology. The focus of the book is the physical layer, and it collects the contributions of many important researchers around the world. So many different works on WiMAX show the great worldwide importance of WiMAX as a wireless broadband access technology. This book is intended for readers interested in the transmission process under WiMAX. All chapters include both theoretical and technical information, which provides an in-depth review of the most recent advances in the field, for engineers and researchers, and other readers interested in WiMAX.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Oleksii Strelnitskiy, Oleksandr Strelnitskiy, Oleksandra Dudka, Oleksandr Tsopa and Vladimir Shokalo (2012). Performance Analysis and Noise Immunity WiMax Radio Channel, Advanced Transmission Techniques in WiMAX, Dr. Roberto Hincapie (Ed.), ISBN: 978-953-307-965-3, InTech, Available from: <http://www.intechopen.com/books/advanced-transmission-techniques-in-wimax/performance-analysis-and-noise-immunity-wimax-radio-channel>

INTECH
open science | open minds

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2012 The Author(s). Licensee IntechOpen. This is an open access article distributed under the terms of the [Creative Commons Attribution 3.0 License](https://creativecommons.org/licenses/by/3.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

IntechOpen

IntechOpen