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Запропоновано математичні моделі просторової оцінки потужності сигналу на вході приймача для сімейства стандартів 802.11x для діапазону 5 ГГц. Моделі отримані на основі експериментальних досліджень розподілу сигналу для кутового та центрального розміщення точки доступу.

Особливістю даних моделей є оцінка основного енергетичного параметра в реальному часі та врахування максимально-можливої кількісті факторів впливу. Також для даних моделей було визначено допустимі межі, що мають мінімальний вплив на ефективну швидкість передачі інформації.

Було встановлено, для стандарту 802.11 у частотному діапазоні 5 ГГц, існують досить значні флуктуації сигналу. В залежності від заповнення приміщення різнорідними об'єктами рівень флуктуацій може становити δ=±4..8 дбм, при наявності системи MIMO. Найбільша концентрація енергії випромінювання спостерігається безпосередньо біля передавальних антен на відстані до двох метрів, що в подальшому затухає на 10…20 дбм.

Встановлено, що наявність технології MIMO вносить певну неоднорідність у просторовий розподіл. При цьому існують зони із меншим рівнем сигналу та зони-смуги із вищим за рахунок існування декількох антен. Ефективність такої системи є максимальною у площині розміщення антен.

До переваг отриманих моделей оцінки просторового розподілу сигналу можна віднести: оцінка рівня сигналу у просторі для будь-якого приміщення; врахування флуктуацій основного енергетичного параметра та параметрів середовища передачі; врахування параметрів приміщення та заповнення простору об'єктами. Такі моделі є найбільш ефективними для застосування у методах діагностики та контролю безпровідних мереж та каналів сімейства стандартів 802.11x

Ключові слова: безпровідний канал, стандарт 802.11, розподіл сигналу, потужність сигналу, частотний діапазон 5 ГГц

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CONSTRUCTION OF MATHEMATICAL MODELS FOR THE ESTIMATION OF SIGNAL STRENGTH AT THE INPUT TO THE 802.11 STANDARD RECEIVER IN A 5 GHZ BAND

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1. Introduction

Given the relative ease in constructing high-speed access channels to modern telecommunication and info-communication services, networks from the 802.11x family of standards have become very popular [1]. In addition, such networks are actively used in the concept of the Internet of Things [2] as a technology of the channel and physical levels of information transfer.

Networks from the 802.11x family of standards are characterized by constant development in the direction of improving the main quality criterion – the effective rate of information transfer. This criterion depends on energy parameters of a wireless channel and on the large number of destabilizing factors. The main energy parameter that determines a signal quality is the level of signal strength at the input to a receiving device [3]. The main destabilizing factors include the widespread deployment of wireless networks. That leads to overloading the frequency resources, which significantly impairs the transmitting characteristics of wireless channels. It can be observed using as an example the range of 2.4 GHz in densely populated areas.

In order to unload the frequency resource, other ranges are employed: 5 GHz, and 60 GHz in future. Each such range has differences in the mechanism of wave propagation and is less common at present. However, in order to derive more reliable models for the estimation of a signal's energy parameters, an independent research is needed for each such range. Therefore, it is a relevant task to investigate a 5 GHz range that provides for a possibility to obtain more channels with a high throughput. It would be also appropriate to construct an effective mathematical model for the estimation of signal strength in the space of premises, taking into consideration all the destabilizing factors.

2. Literature review and problem statement

The level of signal strength at the input to a receiving device is a quite sensitive parameter in terms of many destabilizing factors. The most effective estimation of this parameter is to apply the methods of experimental research with a simulated impact of each type of a destabilizing factor, both individually and comprehensively. One of such studies is paper [4], in which authors established the influence of a receiver's location in space, the distance between a receiver and a transmitter, the time of measurement, an interference from other devices, the presence of architectural obstacles, on the primary energy parameter of the channel – a signal strength at the input to a receiver. They revealed the presence of significant fluctuations and the dependence of energy parameter on a specific equipment ,manufacturer due to different frequencies in quantization and discretization. It is shown that the different location of a device changes the level of signal by 2 dBm, while a deviation in space to 1 m adds 6 dBm to fluctuations. However, the algorithm, constructed in the study, does not take into consideration the geometrical dimensions of premises.

As shown in paper [5], the estimation of RSSI parameter (signal strength at the input to a receiver) can be asymmetric in nature when applying the normal distribution law. This factor admits different variations for different manufacturers of receiving equipment, which would ultimately increase an error in estimation.

Paper [6] reports results of research aimed at obtaining the best energy characteristics for wireless channels at optimal location of an access point in the premises. The presence of signal fluctuations within a range of ±5 dBm was revealed. Similar signal fluctuations were identified in studies [3] and [7] for direct visibility. In the presence of reflective surfaces in premises, the level of fluctuations grows. As shown, the presence of signal fluctuations exerts a significant influence on the parameter of signal strength at the input to a receiver, creating a heterogeneous distribution in the space of the premises. However, the results were derived based on the channels in a frequency range of 2.4 GHz.

The estimation of influence of destabilizing factors on the throughput of a 802.11 standard channel for smaller premises in a 5 GHz range was addressed in paper [8]. The study was based on mathematical modeling in line with the Monte Carlo method, which in turn imposes significant limitations in terms of accounting for the random factors within a transmission environment. In contrast, paper [9] reported quite a significant number of results regarding RSSI parameter for six multistoried buildings in two EU countries. That has made it possible to establish that the waves in a 5 GHz range have much greater attenuation along a wireless channel. The biggest manifestation is observed in the vertical direction where materials with higher density are applied. This shows that waves in a 5 GHz range have a higher attenuation coefficient when passing through architectural obstacles than that in the range of 2.4 GHz.

The results obtained give grounds to assert that the estimation of signal strength at the input to a receiver in premises is an important problem. Evaluation process is accompanied by a considerable number of random factors that affect accuracy. Therefore, there is a task to construct new models, aimed at improving the accuracy of signal strength assessment at the input to a receiver, and taking into consideration the maximum number of destabilizing factors.

3. The aim and objectives of the study

The aim of this work is to construct mathematical models for estimating the signal strength at the input to a receiver of the 802.11 standard for a central and a corner arrangement of an access point in a 5 GHz range.

To accomplish the aim, the following tasks have been set:

– to obtain the spatial distribution of the signal in premises for a central and a corner arrangement of an access point in a 5 GHz range based on experimental research;

– based on the experimental research, construct new mathematical models for the estimation of signal strength at the input to a receiver, taking into consideration the coordinates of premises and the maximum number of impact factors;

– to assess permissible boundaries in the obtained mathematical models.

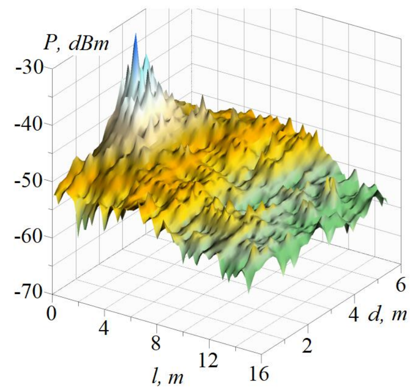
4. Construction of experimental mathematical models for estimating the signal strength at the input to a receiver for a 5 GHz range

4. 1. Spatial distribution of signal based on experimental research

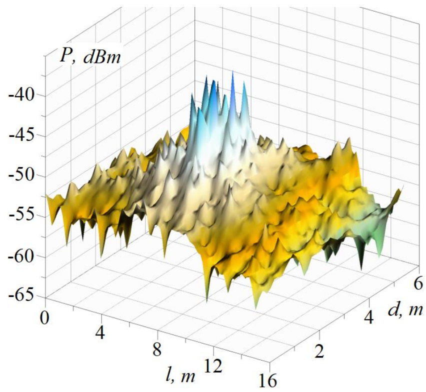
In order to obtain the spatial distribution of the signal, a wireless channel of the 802.11ac standard was built, with a movable subscriber based on the access point (AP), equipped with the technology MIMO 3×3, in line with the circuit reported in paper [3]. Such a setup implies accounting for the most common structure in the receiving-transmitting equipment commercially available at present. The study was conducted under the following conditions: a corner arrangement of the access point, a central arrangement of the access point, the presence of a small number of reflective surfaces, the presence of a considerable number of reflective surfaces. Length of the channel is defined by the geometrical dimensions of premises: length l is up to 15 m, width d is to 6 m. The main criterion to assess spatial distribution of the signal is the signal strength at the input to a receiver (RSSI). The study was performed in the frequency range of 5 GHz. The patterns in wave propagation in a 5 GHz range imply a two-time lower capability to bend around obstacles. Therefore, in the presence of a large number of objects in the premises, the level of attenuation will be higher. To this end, the resolution was increased two-fold compared to a 2.4 GHz range. The 153 frequency channel was selected in the upper range with a band of 20 MHz.

The result of conducting an experimental research is the derived spatial distributions of signal at the input to a receiver for the following cases. First, consider the case when a room has a small number of objects. Based on this, one can assume that the space in the room is filled by less than 30 %. Most premises belong in this group: educational, home, offices, etc. The results of experimental research into the signal strength distribution at the input to a receiver, based on coordinates (l, d) for the premises, are shown in Fig. 1.

Diagrams in Fig. 1 show that the main energy of radiation is concentrated at a distance of two meters from AP. This agrees with the results derived for the range of 2.4 GHz. The difference between this region and the subsequent distribution is approximately 10...20 dBm, with respect to the signal fluctuations. This phenomenon is independent of the number of antennas used since the overall level of radiation is constant.

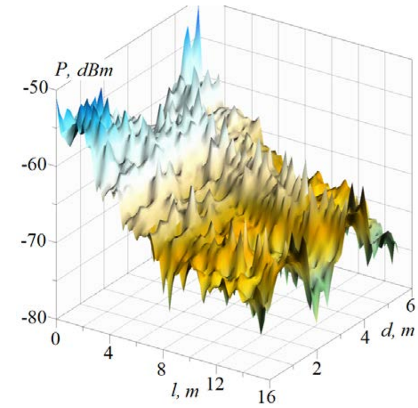


a

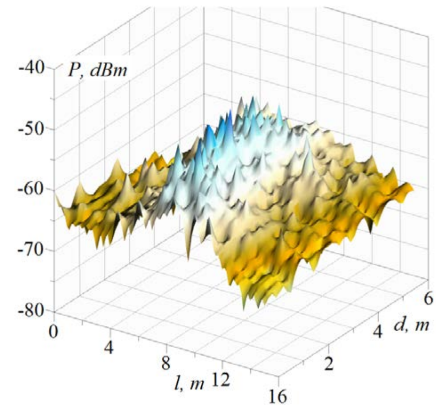


b

Fig. 1. Distribution of signal strength for premises filled by less than 30 %: *a* – for the corner arrangement of AP; *b* – for the central arrangement of AP



a



b

Fig. 2. Distribution of signal strength for the premises filled by more than 30 %: *a* – for the corner arrangement of AP; *b* – for the central arrangement of AP

The presence of three antennas at AP imposes certain features on its location in the premises. The surfaces acquired show that the antenna system was located for radiation at coordinate *l*. As a result, the distribution reveals zones with a lower level of the signal, as well as three zones-bands with a higher level, which is clearly visible at the corner arrangement. This indicates that the presence of multiple antennas forms a heterogeneous orientation diagram, whose effectiveness is maximal in the plane of antenna arrangements.

At the corner arrangement of an access point, the signal fluctuations are not larger than ±4 dBm, which is a good indicator of stability in the radiating system.

Another case simulates a room in which there are many reflective surfaces, or the space is filled by more than 30 %. Such premises include: classrooms with educational equipment, laboratories, engineering facilities, warehouses, shops, etc. The results of examining this case are shown in Fig. 2.

In this case, one observes rather significant fluctuations, especially close to the walls of the room. This is explained by the formation of a fairly complex interferential pattern due to the large number of reflective surfaces. And, as expected, the presence of architectural obstacles in the premises provides for a fairly high degree of attenuation. In addition, the signal distribution shows that there is a fairly strong narrowly directed part of the orientation diagram for coordinate *d*. This creates rather significant fluctuations, especially in the presence of walls near the radiating antennas.

4. 2. Construction of mathematical models for estimating the signal strength at the input to a receiver

Similarly to paper [7], I shall apply a method of mathematical regression to treat the results obtained in chapter 4. 1. Signal strength has a significant concentration of energy close to TA, which considerably decreases at a distance larger than two meters from the emitting antenna unit. When considering its impact on the effective transfer rate, it was established that such a maximum produces no negative changes, so it can be neglected. Thus, the signal strength at the input to a receiver can be considered without the energy maximum, and the distribution can be regarded as two components, which are determined based on two coordinates *l* and *d*.

$$\begin{cases} P_l = cl^2 + gl + k, \\ P_d = ad^2 + bd + z, \end{cases} \tag{1}$$

where *c*, *g*, *a*, *b* are the coefficients of signal attenuation along the respective coordinate, determined based on the statistical results of regression; *k*, *z* are the initial levels.

Any static and random destabilizing factor exerts an impact on the value for signal strength. In order to account for the cumulative effects of factors, it is sufficient to estimate strength in real time. This can be done using the receiving equipment of the subscriber and the time interval of assessment. The measured value for the signal strength can be then written in the form:

$$P_m = \frac{1}{n}\int_0^t \sum_{i=1}^{n} P_{r.i},$$

where $P_{r.i}$ is the i-th measured value of power; n is the number of measurements to derive the required reliability in estimation; t is the time interval of estimation.

Such an assessment of the measured value makes it possible to take into consideration parameters of any equipment and premises, as well as all changes along the channel in real time. Thus, a change in parameter P_m accounts for the impact of all static and random factors during existence of the wireless channel.

By neglecting the factor of maximum energy, initial levels k and z can be determined at a distance of two meters from AP. It is possible to assign a starting coordinate for any AP location, which depends on the geometrical dimensions of the premises ($l/2+2$; $d/2$). With respect to expression (1), the initial levels can be written in the form:

$$\begin{cases} k = P_m - c\dfrac{l^2}{4} - 2cl - g\dfrac{l}{2} - 4c - 2g, \\ z = P_m - a\dfrac{d^2}{4} - b\dfrac{d}{2}. \end{cases}$$

If one considers any point in the premises (l, d), then, for expression (1) to hold, a condition for $P_l = P_d$ must be met. A mathematical model for the estimation of spatial distribution for any premises can be written as the average value for signal strength along two coordinates. Given the initial levels, we obtain:

$$P = \frac{5}{8}\left(cl^2 + ad^2\right) + \frac{1}{4}\left(gl + bd\right) - c(l+2) - g + P_m. \qquad (2)$$

The expression above makes it possible to derive an estimate for signal strength at any point in the premises, taking into consideration all the destabilizing factors that exist within the coverage of the access point.

Based on experimental data, define the coefficients of signal attenuation for all conditions assigned in the study. For premises filled by less than 30 %, expression (2) takes the following form:

– at the corner arrangement of AP:

$$P = -0{,}02l^2 - 0{,}2l \mp 0{,}2d \pm 0{,}2d - 0{,}25 - P_m;$$

– at the central arrangement of AP:

$$P = -0{,}08l^2 + l \mp 0{,}2d \pm 0{,}2d - 1{,}16 - P_m.$$

For premises filled by more than 30 %, expression (2) takes the following form:

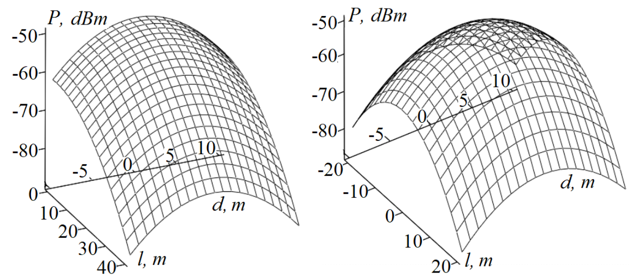
– for the corner arrangement of AP:

$$P = -0{,}04l^2 + 1{,}5l \mp 0{,}35d \pm 0{,}5d - 1{,}6 - P_m; \qquad (3)$$

– for the central arrangement of AP:

$$P = -0{,}1l^2 + 1{,}5l \mp 0{,}55d \pm 0{,}5d - 1{,}7 - P_m. \qquad (4)$$

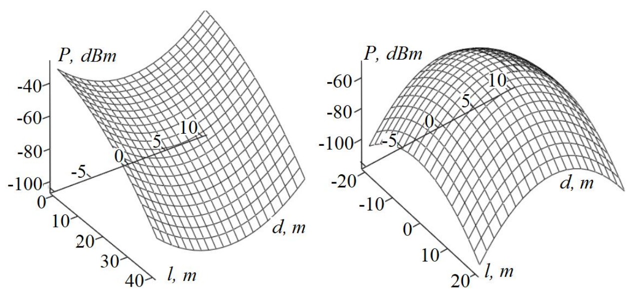
The proposed models would require assigning the size of the premises. Assume that AP is at the beginning of the coordinate grid. Then, in a room with dimensions (l, d), the AP coordinates' origin is at point (0, $d/2$) for the angular position, and ($l/2$ $d/2$) – for the central position. Graphical representation is shown in Fig. 3.



a *b*

Fig. 3. Graphical representation of the signal strength distribution model for premises filled by less than 30 %: *a* – for the corner arrangement of AP; *b* – for the central arrangement of AP

Graphical representation of expressions (3) and (4) is shown in Fig. 4.



a *b*

Fig. 4. Graphical representation of the signal strength distribution model for premises filled by more than 30 %: *a* – for the corner arrangement of AP; *b* – for the central arrangement of AP

The surfaces constructed in Fig. 3, 4 show that the mathematical models hold for premises with dimensions l to 40 m and d to 20 m. The "±" sign at coefficients a and b indicates the presence of maxima and minima in the fluctuations in spatial distribution, which can be seen by comparing Fig. 3, *a*, 4, *a*.

If one takes into consideration the factor of maximum energy concentration close to TA, it is possible to construct a model for the estimation of signal strength at the input to a receiver based on length of the wireless channel. Thus, one obtains:

– for premises filled by less than 30 %:

$$P = -4{,}5\ln(l) - 0{,}01l^2 - 0{,}1l + P_m + 8;$$

– for premises filled by less than 30 %:

$$P = -6\ln(l) - 0{,}9l + P_m - 2.$$

The dependences constructed can be termed as a model of signal attenuation in the premises space. Such a model holds in any direction from AP, but it does not take into consideration the fluctuations from objects and architectural obstacles with a high density of a material in the room.

5. Estimation of permissible boundaries in the constructed mathematical models

The presence of signal fluctuations puts certain requirements to mathematical models for estimating signal strength at the input to a receiver. The accuracy of assessment will depend on the correct determination of permissible boundaries within which the impact of destabilizing factors on the effective rate of information transfer would be minimal.

Permissible boundaries can be estimated as the interval that is defined by the level of signal fluctuations. It depends on the external and internal destabilizing factors. The simplest and optimal parameter is the coefficient of signal strength fluctuations, which is denoted δ. The permissible interval of signal strength at the input to a receiver can then be recorded in the form:

$$P-\delta < P_d < P+\delta.$$

Coefficient δ is to determined based on experimental data. For a wireless 802.11 channel in a 5 GHz range with the active MIMO system 3×3, δ=±4 dBm for premises filled by less than 30 %, and δ=±8 dBm for premises filled by more than 30 %. Thus, the expression, taking into consideration the permissible boundaries, will take the form:

$$\left.\begin{matrix} P-4\ \text{dBm, at } k<30\,\% \\ P-8\ \text{dBm, at } k>30\,\% \end{matrix}\right\} < P_d < \left\{\begin{matrix} P+4\ \text{dBm, at } k<30\,\%, \\ P+8\ \text{dBm, at } k>30\,\%. \end{matrix}\right.$$

As an example, consider the impact of permissible boundaries on the spatial signal distribution. Diagrams for the premises filled by less than 30 % are shown in Fig. 5.

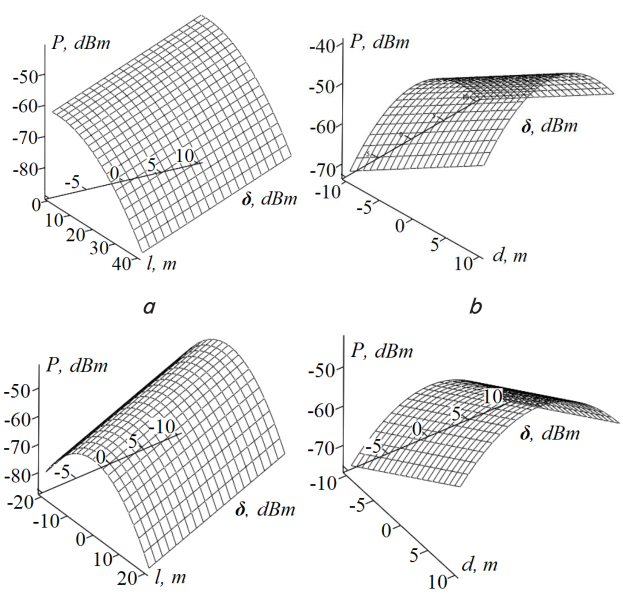


Fig. 5. Dependence of signal strength at the input to a receiver on fluctuations: *a* — for coordinate *l* at corner arrangement; *b* — for coordinate *d* at corner arrangement; *c* — for coordinate *l* at central arrangement; *d* — for coordinate *d* at central arrangement

The results derived, shown in Fig. 5, demonstrate a change in the signal strength at the input to a receiver within the permissible boundaries. And, if the permissible boundaries do not produce a significant impact close to AP, then, at a great length of the wireless channel, there would occur the weakening zones close to 80 dBm. Such a level is quite low, which is a condition for the channel to enter the low-speed mode of information transfer.

In addition, it is appropriate to consider the impact of a fluctuation coefficient on the model of signal attenuation in the premises space. Diagrams are shown in Fig. 6.

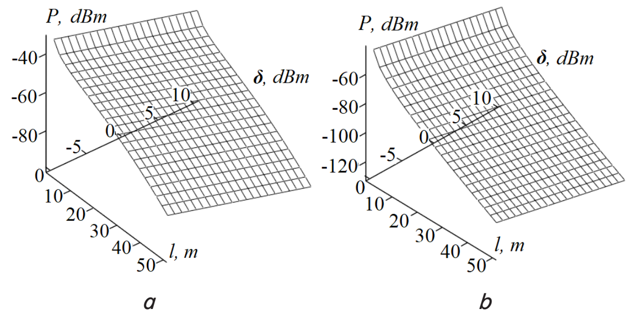


Fig. 6. Dependence of the signal attenuation model in the premises space on fluctuations: *a* — for premises filled by less than 30 %; *b* — for premises filled by more than 30 %

In this case, the presence of signal fluctuations does not have a significant impact on the overall level of power. This suggests that the model, which includes a single coordinate, does not provide for a full estimation of the signal fluctuation level in premises.

6. Discussion of research results and constructed models

When employing classical methods and models for assessment of signal strength in wireless channels, there occurs high complexity while taking into consideration the large number of impact factors. In turn, in order to reduce the complexity, it is possible to apply a multitude of models and methods aimed at solving specific problems [10] or which are used at individual nodes and stages of signal conversion [11]. However, based on the obtained experimental data, on can see that the spatial signal distribution demonstrates fluctuations with typical maxima and minima. The magnitude of such fluctuations increases near architectural obstacles due to the effect of multibeam wave propagation. It degrades the signal/noise ratio and produces a negative impact on the channel's throughput parameter, which is usually not taken into consideration as it is a random magnitude. In addition, in any premises there is a probability of the emergence of a series of other random factors, such as the appearance of a person, the emergence of other networks and emitting devices, taking some objects into the room, etc. Therefore, in contrast to existing models, the proposed models for the estimation of signal strength solve the specified problems comprehensively: taking into consideration the maximum number of impact factors; estimation of the signal fluctuation; accounting for the parameters of premises and equipment. In addition, the models take into consideration any changes in the parameters of a transmission medium in real time, as well as within the permissible boundaries. The presence of boundaries defines the interval over which the influence of random factors is minimal regarding the main criterion of effectiveness of the wireless channel.

The identified advantages make it possible to apply the models constructed for diagnosing and control of wireless channels from the 802.11x family of standards both at network design stages and during operation.

In addition, one should note that the reported models for the estimation of signal strength at the input to a receiver have a shortcoming. It is the accuracy of estimation, which depends on the correct choice of signal attenuation coefficients based on the coordinates of premises and initial values. The accuracy of estimating the coefficients of attenuation directly depends on the signal spatial distribution based on the experimental and statistical studies into wireless channels.

7. Conclusions

1. The signal spatial distribution in premises at the central and corner position of the access point in a frequency range of 5 GHz has been derived. An analysis revealed that the largest concentration of radiation energy is observed directly next to the transmitting antennas at a distance of up to two meters, and subsequently fades on 10…20 dBm. In the absence of obstacles and reflective surfaces, the channel has demonstrated a fairly high stability – the signal fluctuations did not exceed 4 dBm.

In the presence of a large number of objects in a transmission medium the level of fluctuations increases, especially near walls of the room, where there is a high attenuation of the signal. The results obtained provide for a complete representation of the process of wave propagation in premises for channel 802.11 in a 5 GHz range.

2. The new mathematical models have been constructed for the estimation of signal strength at the input to a receiver at the corner and central arrangement of an access point. The models derived make it possible to estimate the signal strength at the input to a receiver for wireless channels directly within the premises space in real time. The models, in contrast to existing ones, take into consideration all the static and random destabilizing factors and could be used for rooms with dimensions of up to 40×20 m.

3. The estimation of dependence of signal strength at the input to a receiv er on the permissible boundaries of signal fluctuations has been performed. The permissible level of fluctuations is $\delta=\pm4$ dBm for direct visibility, and $\delta=\pm8$ dBm in the presence of a considerable number of reflective surfaces in the premises. The presence of fluctuations in the signal strength within the specified range has a minimal impact on the effective speed of information transfer. Assessment of the permissible boundaries has shown that in order to enhance the reliability, it is necessary to use the distribution based on the premises' two coordinates.

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