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DEVISING A TECHNIQUE TO EVALUATE FLUCTUATIONS IN THE MAIN PARAMETERS OF A WIRELESS CHANNEL OF THE 802.11 STANDARD

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This paper reports the technique devised to evaluate fluctuations in the main parameters for a wireless channel of the 802.11 standard based on the confidence regression interval. Underlying such a technique is the use of mathematical ratios of the relationship among the statistical probability, variance, and fluctuation level. It should be noted that this technique could be used when technically diagnosing the 802.11x standard wireless networks at the stages of their design and operation. Applying the proposed technique for the estimation models of the main channel parameters makes it possible to derive an estimate of fluctuation intervals without the need to process large arrays of measurement results. This greatly reduces the time of obtaining the result from diagnosing by involving monitoring algorithms.

An expression for the statistical relation between fluctuations in the main parameters of the 802.11 standard wireless channel was obtained on the basis of the proposed mathematical ratios, which makes it possible to evaluate fluctuations of the information parameter based on the fluctuations of an energy one and vice versa. This is relevant when assessing the effective speed of information transmission based on measuring the signal strength at the receiver input using monitoring algorithms.

The analysis of the reported results and their comparison with empirical studies have shown that based on the interrelation between the main channel parameters with a regression confidence interval it is possible to determine the level of fluctuations based on the confidence probability. The dependence of a fluctuation level on the variances and confidence intervals of regression models has also been established. With a probability of 0.85, the fluctuations have been obtained for direct visibility and at a minimum number of interferences while a probability of 0.97 shows the impact of a multipath wave propagation factor in the premises

Keywords: wireless channel, 802.11 standard, effective speed of information transfer, signal strength, fluctuations, statistical relation

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1. Introduction

The 802.11x standard wireless networks have been increasingly used in today's world [1]. Such networks are not expensive to maintain, they possess a rather high channel throughput, and are characterized by simple design. The range of their use is quite wide: from combining devices within the "Internet of Things" concept [2] to providing access to tele- and info-communication services [3]. A feature of the 802.11 standard networks is low-power transmitters with a low level of radiation, as well as their application inside the premises. This leads to the emergence of fluctuations in the main parameters of wireless channels, which are clearly visible in the construction of signal distribution and by the effective speed of information transmission in the space of premises [4]. Such fluctuations manifest themselves in empirical studies by the existence of maxima and minima when assessing characteristics along a channel length. In such circumstances, the greatest reliability degree of the assessment of channel parameters could be obtained with the help of models built on the basis of the empirical studies. This is relevant when technically diagnosing wireless channels, which makes it possible to take into consideration the maximum possible number of factors of influence based on a statistical relation between the main channel parameters. However, the issue of assessing the fluctuations themselves is given quite a little attention, and their evaluation requires a significant number of observation periods and additional statistical processing of the results. In addition, observations should be carried out for different standards and, to improve the reliability and take into consideration all factors of influence, the time between observation periods may cover days, weeks, and months. Therefore, it is a relevant task to find mathematical ratios that could produce, based on them, such an assessment of the level of fluctuations in the basic channel parameters that would be similar to that obtained from empirical studies at a lower time cost.

2. Literature review and problem statement

A study reported in work [5] shows that obtaining access to the Internet requires that a signal level should not be lower than 60 dBm. With an increase in the channel length and the presence of architectural obstacles, the signal strength level decreases. However, it is known that in a separate network each measurement at the same point in the room could yield a deviation of up to ±5 dBm, depending on the number of impact factors [4]. This is mostly due to the effect of multipath wave propagation, the presence of a moving person in the room, the displacement of antenna systems during re-study, a change in the number of reflective surfaces, etc. As a result, if one uses the specified threshold of 60 dBm when assessing the coverage of a network, one could detect zones with low throughput. It is also possible to add a factor that depends on the energy parameter of a particular manufacturer of the 802.11 standard equipment due to the different frequencies of quantification and sampling, which was established in the research reported in work [6]. It was investigated that the different position of a device changes the signal level by 2 dBm, while a deviation in the space of 1 m adds 6 dBm to the fluctuations. Such a factor could introduce even greater unevenness into the projected network coverage map.

In work [7], during the sessions of video frame transmission applying the 802.11 standard to determine objects in the premises, the authors detected several peaks of signal strength in the distribution diagrams. When parsing a session of frame transfer into smaller parts, they determined the existence of time factors of influence on the signal level at the receiver input at the constant power of radiation. As a result, the signal strength at the receiver input acquires a chi-square distribution, thereby confirming the existence of random-character fluctuations. The presence of fluctuations in the signal distribution depending on the channel length was confirmed in work [8]. In addition, fluctuations are present when examining the channel bandwidth dependences based on MCS schema parameters. Experimental studies into the throughput of the 802.11ac, 802.11, and 802.11a standards with the application of various configurations and protocols were reported in paper [9]. It was found that theoretical throughput is unattainable when using MIMO technology because of the existence of various types of impact factors. In addition, the TCP protocol demonstrates a 50 % efficiency, indicating the influence of factors on the effective speed of information transmission and the emergence of fluctuations. Similar studies of the 802.11n and 802.11ac standards were conducted in [10]. A bandwidth study for different MCS scheme configurations, taking into consideration spatial flows, showed the emergence of fluctuations while increasing the number of subscribers on the network for both standards. Additionally, one can note work [11], which focuses on the impact of interference. In all such cases, there is an uneven bandwidth due to the modulation index and the appearance of fluctuations in characteristics due to the mechanism of the struggle for the frequency resource.

Work [12] proposed a reliable technique to evaluate fluctuations in the main parameters of wireless channels based on the statistical assessment of empirical studies. That could be carried out on the basis of the following expressions:

$$\Delta P \approx \frac{1}{2}\left(\frac{1}{n}\sum_{j=1}^{n}\max\left\{P_{m.i}\right\}_j - \frac{1}{n}\sum_{j=1}^{n}\min\left\{P_{m.i}\right\}_j\right),$$

$$\Delta V \approx \frac{1}{2z}\sum_{i=1}^{n}\left(\max\left\{V_{eff.i}\right\}_j - \min\left\{V_{eff.i}\right\}_j\right), \quad (1)$$

where ΔP is the signal strength fluctuation interval; ΔV is the fluctuation interval of the effective speed of information transmission; n and z are the number of observation periods to obtain experimental characteristics $P_m(l)$ and $V_{eff}(l)$, respectively.

Consequently, the analysis of the above studies reveals the presence of various kinds of influence factors, due to which there are fluctuations in the basic parameters of wireless channels of the 802.11 standard. This, in turn, may lead to incorrect estimation of bandwidth when designing networks as there can be areas in the premises with the signal' maxima and minima. In addition, there is no general theoretical mechanism that would combine the effect of all impact factors with the effectiveness parameters of the 802.11 standard channels.

On the other hand, in order to obtain a reliable result of the assessment of the main channel parameters, there is an issue related to conducting a large number of empirical studies, which would require significant time spent observing and statistical processing of the results of the experiment.

To resolve this issue, it is possible to propose a technique to determine the level of fluctuations by using the spread interval of the average values of the basic channel parameters, taking into consideration the empirical research and the statistical processing of results based on regression methods. The result would be the ratios of the assessment of fluctuations of the main channel parameters based on the averaged regression models.

3. The aim and objectives of the study

The aim of this study is to develop a technique to evaluate fluctuations in the main parameters of a wireless channel of the 802.11 standard based on a spread interval of the regression analysis of empirical studies. This technique should reduce the time when the evaluation results are received.

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

– to construct general mathematical ratios of the basic parameters of the 802.11 standard wireless channel to the level of fluctuations based on a spread interval of the regression model;

– based on the ratios derived, determine the statistical relationship between the fluctuations in the main parameters of the 802.11 standard wireless channel;

– to analyze and compare the results obtained with those from empirical studies and determine the permissible boundaries.

4. Constructing the mathematical ratios between the basic parameters of the 802.11 standard wireless channel and the level of fluctuations

It is known [12] that the basic parameters of a wireless channel could be evaluated on the basis of linear regression models, which could be written in the following form:

$$P_m(l) \approx al + P_0, \quad V_{eff}(l) \approx bl + V_0, \quad (2)$$

where a and b are the regression decline factors; P_0 and V_0 are the initial levels.

One could calculate the regression coefficients in the following way [13]. Regression parameters could be estimated on the basis of random point values that are written in the following form:

$$a_m=\frac{\sum_{i=1}^{n}P_{m.i}\sum_{i=1}^{n}l_i^2-\sum_{i=1}^{n}l_i\sum_{i=1}^{n}P_{m.i}l_i}{n\sum_{i=1}^{n}l_i^2-\left(\sum_{i=1}^{n}l_i\right)^2},$$

$$P_0^m=\frac{n\sum_{i=1}^{n}P_{m.i}l_i-\sum_{i=1}^{n}l_i\sum_{i=1}^{n}P_{m.i}}{n\sum_{i=1}^{n}l_i^2-\left(\sum_{i=1}^{n}l_i\right)^2}, \qquad (3)$$

$$b_m=\frac{\sum_{i=1}^{n}V_{eff.i}\sum_{i=1}^{n}l_i^2-\sum_{i=1}^{n}l_i\sum_{i=1}^{n}V_{eff.i}l_i}{n\sum_{i=1}^{n}l_i^2-\left(\sum_{i=1}^{n}l_i\right)^2},$$

$$V_0^m=\frac{n\sum_{i=1}^{n}V_{eff.i}l_i-\sum_{i=1}^{n}l_i\sum_{i=1}^{n}V_{eff.i}}{n\sum_{i=1}^{n}l_i^2-\left(\sum_{i=1}^{n}l_i\right)^2}, \qquad (4)$$

where l is the length of a wireless channel.

The assessment of the variance of regression analysis could be calculated in the following way [14]:

$$\sigma_P^2=\frac{n}{n-2}\sum_{i=1}^{n}\left(P_{m.i}-a_m l_i-P_0^m\right)^2,$$

$$\sigma_V^2=\frac{n}{n-2}\sum_{i=1}^{n}\left(V_{eff.i}-b_m l_i-V_0^m\right)^2.$$

Then the variance of regression parameters is written in the following form:

$$\sigma_a^2=\frac{\sigma_P^2}{\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2},$$

$$\sigma_{P_m}^2=\left(\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i^2}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}\right)\sigma_P^2,$$

$$\sigma_b^2=\frac{\sigma_V^2}{\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2},$$

$$\sigma_{V_{eff}}^2=\left(\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i^2}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}\right)\sigma_V^2.$$

Given the random nature of the regression parameters, confidence intervals can be written in the following form [15]:

$$a_m-\frac{t\sigma_P^2}{\sqrt{\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)}}<a<a_m+\frac{t\sigma_P^2}{\sqrt{\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)}},$$

$$P_0^m-t\sigma_P^2\sqrt{\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i^2}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}}<P_0<P_0^m+$$

$$+t\sigma_P^2\sqrt{\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i^2}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}},$$

$$b_m-\frac{t\sigma_V^2}{\sqrt{\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)}}<b<b_m+\frac{t\sigma_V^2}{\sqrt{\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)}},$$

$$V_0^m-t\sigma_V^2\sqrt{\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i^2}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}}<V_0<V_0^m+$$

$$+t\sigma_V^2\sqrt{\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i^2}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}}.$$

where t is the Laplace coefficient at a known variance or a Student coefficient at unknown variance.

The confidence intervals of the variances are:

$$\frac{n\sum_{i=1}^{n}\left(P_{m.ii}-a_m l_i-P_0^m\right)^2}{\chi_{\frac{\gamma}{2},n-2}}<\sigma_{P_m}^2<\frac{n\sum_{i=1}^{n}\left(P_{m.i}-a\ \ l\ \ -P_0^m\right)^2}{\chi_{1-\frac{\gamma}{2},n-2}},$$

$$\frac{n\sum_{i=1}^{n}\left(V_{eff.i}-b_m l_i-V_0^m\right)^2}{\chi_{\frac{\gamma}{2},n-2}}<\sigma_{V_{eff}}^2<\frac{n\sum_{i=1}^{n}\left(V_{eff.i}-b_m l_i-V_0^m\right)^2}{\chi_{1-\frac{\gamma}{2},n-2}},$$

where χ^2 is the distribution of the *chi*-square; γ is the distribution quantile of the *chi*-square.

Thus, expressions (2) are the mathematical expectation of regression of the main channel parameters or their average value [16], which shows the overall evaluation model. Taking into consideration the confidence intervals of the regression parameters, we obtain:

$$\left(a_m-\frac{t\sigma_P^2}{\sqrt{\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)}}\right)l+P_0^m-$$
$$-t\sigma_P^2\sqrt{\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i^2}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}}<P_m(l)\approx al+P_0<$$
$$<\left(a_m+\frac{t\sigma_P^2}{\sqrt{\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)}}\right)l+P_0^m+$$
$$+t\sigma_P^2\sqrt{\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i^2}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}},$$

$$\left(b_m-\frac{t\sigma_V^2}{\sqrt{\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)}}\right)l+V_0^m-$$
$$-t\sigma_V^2\sqrt{\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i^2}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}}<V_{eff}(l)\approx bl+V_0<$$
$$<\left(b_m+\frac{t\sigma_V^2}{\sqrt{\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)}}\right)l+V_0^m+$$
$$+t\sigma_V^2\sqrt{\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i^2}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}}.$$

Fluctuations in the signal parameters occur when there are various kinds of impact factors in a wireless channel. For the conditions of the premises, the most significant of them is the multipath wave propagation, depending on the material and the number of reflective surfaces in the room. In addition, interfering and noise interference, positions of the transmitter and receiver in the space of the premises, the number of active subscribers in the network, etc. could have a significant impact. The fluctuations appear as the maxima and minima on the time and spatial characteristics of the channel parameters [4]. The fluctuation level can then be defined as the difference between the maximum and minimum deviation from the average values of the channel parameters. Then we obtain:

$$\Delta P\approx 2t\sigma_P^2\left(\frac{l}{\sqrt{\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)}}+\sqrt{\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i^2}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}}\right), \quad (5)$$

$$\Delta V\approx 2t\sigma_V^2\left(\frac{l}{\sqrt{\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)}}+\sqrt{\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i^2}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}}\right). \quad (6)$$

If the dependence of the fluctuation level on a channel length, which, for short channels, is insignificant for direct visibility [4], is disregarded, the boundaries of the confidence intervals of the regression would depend on the variances and confidence probability. This can be written in the following form:

$$\Delta P\approx 2t\sigma_P^2\sqrt{\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i^2}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}}, \quad (7)$$

$$\Delta V\approx 2t\sigma_V^2\sqrt{\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i^2}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}}. \quad (8)$$

In the simplest case, the ΔP and ΔV parameters would represent the equivalent of the difference between the maximum and minimum value of the confidence interval of the initial regression values [17]. Expressions (5)–(8) are the mathematical ratios of the main parameters of the channel to the average fluctuation values. In addition, the expressions show the spread interval for regression parameters, where, when accepting a hypothesis about the normal distribution law, it would be most appropriate to use the Student criteria or "chi"-square. Such criteria make it possible to derive the confidence intervals of regression models, which would acquire close values to the fluctuation level of the main parameters of the 802.11 standard wireless channel.

5. Determining the statistical relazztionship between fluctuations in the basic parameters of the 802.11 standard wireless channel

The statistical relationship between the main diagnosing parameters can be determined based on a channel length [12]. Considering expressions (2), we obtain:

$$\frac{P_m(l)-P_0}{b}\approx\frac{V_{eff}(l)-V_{0.}}{a}. \qquad (9)$$

Equation (9) can be used to define one of the channel parameters based on another in the following way:

$$P_m(l)\approx\frac{a\left(V_{eff}(l)+V_0\right)}{b}+P_0,$$

$$V_{eff}(l)\approx\frac{b\left(P_m(l)+P_0\right)}{a}+V_0. \qquad (10)$$

By substituting (3) and (4) in (10) and confidence intervals (7) and (8), we obtain:

$$P_m(l)\approx$$
$$\approx\frac{\sum_{i=1}^{n}P_{m.i}\sum_{i=1}^{n}l_i^2-\sum_{i=1}^{n}l_i\sum_{i=1}^{n}P_{m.i}l_i\left(\left(n\sum_{i=1}^{n}l_i^2-\left(\sum_{i=1}^{n}l_i\right)^2\right)V_{eff}(l)+n\sum_{i=1}^{n}V_{eff.i}l_i-\sum_{i=1}^{n}l_i\sum_{i=1}^{n}V_{eff.i}\right)}{n\sum_{i=1}^{n}l_i^2-\left(\sum_{i=1}^{n}l_i\right)^2\left(\sum_{i=1}^{n}V_{eff.i}\sum_{i=1}^{n}l_i^2-\sum_{i=1}^{n}l_i\sum_{i=1}^{n}V_{eff.i}l_i\right)}+$$
$$+\frac{n\sum_{i=1}^{n}P_{m.i}l_i-\sum_{i=1}^{n}l_i\sum_{i=1}^{n}P_{m\,i}}{n\sum_{i=1}^{n}l_i^2-\left(\sum_{i=1}^{n}l_i\right)^2}\pm t\sigma_P\sqrt{\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}}, \qquad (11)$$

$$V_{eff}(l)\approx$$
$$\approx\frac{\sum_{i=1}^{n}V_{eff.i}\sum_{i=1}^{n}l_i^2-\sum_{i=1}^{n}l_i\sum_{i=1}^{n}V_{eff.i}l_i\left(\left(n\sum_{i=1}^{n}l_i^2-\left(\sum_{i=1}^{n}l_i\right)^2\right)V_{eff}(l)+n\sum_{i=1}^{n}P_{m.i}l_i-\sum_{i=1}^{n}l_i\sum_{i=1}^{n}P_{m.i}\right)}{n\sum_{i=1}^{n}l_i^2-\left(\sum_{i=1}^{n}l_i\right)^2\left(\sum_{i=1}^{n}P_{m.i}\sum_{i=1}^{n}l_i^2-\sum_{i=1}^{n}l_i\sum_{i=1}^{n}P_{m.i}l_i\right)}+$$
$$+\frac{n\sum_{i=1}^{n}V_{eff.i}l_i-\sum_{i=1}^{n}l_i\sum_{i=1}^{n}V_{eff\,i}}{n\sum_{i=1}^{n}l_i^2-\left(\sum_{i=1}^{n}l_i\right)^2}\pm t\sigma_V\sqrt{\frac{1}{n}+\frac{\sum_{i=1}^{n}l_i}{n^2\sum_{i=1}^{n}\left(l_i-\frac{1}{n}\sum_{i=1}^{n}l_i\right)^2}}. \qquad (12)$$

Expressions (11) and (12) show a statistical relationship between the main channel parameters. However, such expressions include the components of the fluctuation assessments that do not take into consideration such a relationship. As shown in [4], a fluctuation interval ΔP, under certain conditions of wireless channel operation and the existence of influence factors, can be assigned with the matching ΔV interval. Then, such fluctuations determine the boundaries of fluctuation of one parameter, which leads to changes in another, within the permissible limits, which would not affect the delay in the transfer of frames. In this case, one can argue about the correspondence between the ΔP and ΔV intervals, which could be described as the coefficient of fluctuation dependence, which, based on expressions (5) and (6), could be written in the following form:

$$k\approx\frac{\Delta P}{\Delta V}\approx\frac{\sigma_P^2}{\sigma_V^2}=\frac{\sum_{i=1}^{n}\left(P_{m.ii}-a\ l-P_0^m\right)^2}{\sum_{i=1}^{n}\left(V_{effii}-b\ l-V_0^m\right)^2}. \qquad (13)$$

Expression (13) shows that a fluctuation dependence coefficient demonstrates the dependence between the average statistical values of the ΔP and ΔV fluctuation intervals in empirical studies and depends on the variances of the initial levels of regression models.

6. The analysis and comparison of the study findings with empirical studies and determining permissible boundaries.

Using ratios (5) and (6), or (7) and (8), it is planned to determine the average statistical fluctuation level values based on regression models (2) for any 802.11 standard along the channel length. In this case, by setting the probability parameter, one can determine the level of fluctuations for a certain type of impact factor. To prove this, the fluctuations were calculated on the basis of the proposed ratios, as well as compared with empirical studies. The empirical research results are borrowed from work [12] for the following channels: 802,11n, 40 MHz, 2.4 GHz; 802,11ac, 80 MHz; 802,11n, 20 MHz, 5 GHz. The study was conducted in a room, involving the 802.11 wireless network, which included one wireless channel up to 80 m long with a minimum number of impact factors. The fluctuation intervals are based on expressions (1) and divided into short channels up to 16 m long (can be described as linear regression) and long ones up to 80 m (a logarithmic regression model). The results are given in Table 1.

Table 1

Comparative table of the measured and estimated fluctuation intervals

Parameter	Formula 1 for l=16 m	Formula 11 for p=0.85	Formula 1 for l=80 m	Formula 11 for p=0.97
Channel 802.11n, 40 MHz, 2.4 GHz				
ΔP	4± dBm	3± dBm	6± dBm	5± dBm
ΔV	5.0± Mb/s	7.0± Mb/s	2± Mb/s	4.1± Mb/s
Channel 802.11ac, 80 MHz				
ΔP	5± dBm	4,5± dBm	8± dBm	9± dBm
ΔV	5.1± Mb/s	2.1± Mb/s	2± Mb/s	8.1± Mb/s
Channel 802.11n, 20 MHz, 5 GHz				
ΔP	2± dBm	3± dBm	4± dBm	5± dBm
ΔV	1.0± Mb/s	13.0± Mb/s	3.0± Mb/s	2.0± Mb/s

Table 1 shows that at a probability of 0.85, the average value of fluctuation results for direct visibility and with a minimum number of interferences closely consistent with experimental measurements was obtained. With a greater length of the channel, there is an increase in the influence exerted by the factor of multipath-wave propagation in the room, which, as a result, corresponds to the probability of 0.97. These results are a confirmation of the relationship between the main channel parameters and the confidence interval of the regression with the possibility of determining the level of fluctuations based on the confidence probability.

The dependences of the relationship of the confidence probability, variance, and a fluctuation level of the main channel parameters are shown in Fig. 1.

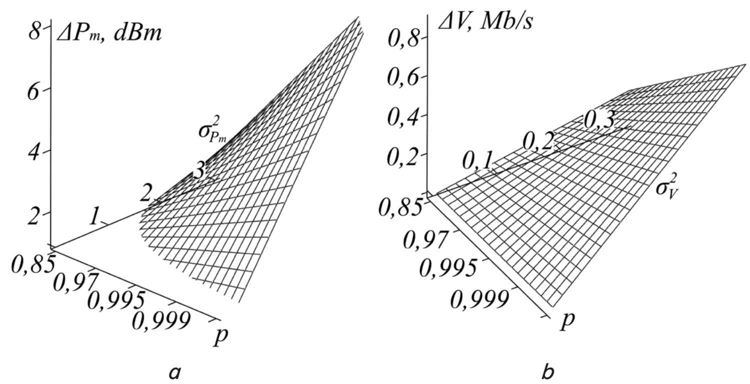

Fig. 1. Dependences of the relationship of the confidence probability, variance, and fluctuation level for: *a* — signal strength at the receiver input; *b* — effective speed of information transmission

Fig. 1 shows that when taking into consideration the significant effect of influence factors, at fluctuations of up to ±5...10 dBm, which lead to the fluctuations in the effective speed of information transmission of up to ±0.1...0.5 Mb/s, the equivalent of confidence intervals would be determined by the probability of 0.999. Deviations in the ΔP and ΔV parameters from the average statistical value is insignificant, in the worst cases, it is possible to obtain approximately ΔP±1.5 dBm and ΔV±0.5 Mb/s for the chi-square distribution, which is a rather high result. Such deviations are relatively small for fluctuations obtained empirically and can be automatically taken into consideration when setting a certain margin under bitrate control conditions and assessing channel capabilities [12, 18].

7. Discussion of results of studying the proposed technique for evaluating fluctuations in the main channel parameters

The essence of the technique implies using the resulting ratios (5) and (6) as an extension for the models that evaluate the main channel parameters. In this case, one can obtain an estimate of fluctuation intervals without the need to process large arrays of measurement results. If the confidence intervals for the coefficients of regression decline are ignored, it is possible to apply ratios (7) and (8), which would yield an insignificant error while greatly simplifying the assessment of confidence intervals.

When using the fluctuation assessment of the main channel parameters based on expressions (1), that would lead to significant time cost and additional processing of data arrays. Here, when evaluating the main channel parameters, the fluctuation assessment operations are additionally added at each measuring point of the channel. Given that it is necessary to use an observation period of 360 s with a monitoring cycle of 1 s [4], then for a channel with a length of 16 m, the required time to obtain a reliable result would be at least 96 minutes. Given the impact of random factors, such an operation would require even more time. The use of ratios (5) and (6), or (7) and (8) significantly speeds up obtaining the result of technical diagnosing since the approximate result is derived on the basis of spread intervals of the regression models. In this case, one evaluation operation would produce an assessment of the channel's capabilities and the level of existing fluctuations. Taking into consideration the similar construction of all types of wireless channels of the 802.11 standard [19], then, based on the database of regression model coefficients, such diagnosing could also be performed simultaneously [20].

The biggest problem will be the creation of a separate base of the correspondence between the values of the confidence probability for setting various types of impact factors in the wireless channels of the 802.11 standard, which is supposed to be performed in the following studies.

8. Conclusions

1. A technique to evaluate fluctuations in the main parameters of the 802.11 standard wireless channel based on the confidence interval of regressions has been devised. Underlying such a model is the use of the relationship between the statistical probability, variance, and the interval of fluctuations.

2. On the basis of the constructed mathematical ratios, an expression for the statistical relation between fluctuations in the main parameters of the 802.11 standard wireless channel was derived, which makes it possible to evaluate the fluctuations in the information parameter based on the fluctuations in the energy parameter, and vice versa. This is relevant when assessing the effective speed of information transmission based on measuring the signal strength at the receiver input using monitoring algorithms.

3. The analysis of the reported results and the comparison with empirical studies have shown that, based on the relationship between the main channel parameters and the regression confidence interval, it is possible to determine the level of fluctuations based on a confidence probability. The dependence of fluctuation levels on the variances and confidence intervals of the regression models has been also established.

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