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Method for estimating the effective data rate in 802.11 channels by using a monitoring algorithm

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Abstract: The rapid spread of 802.11 wireless technologies and the emergence of a significant number of networks leads to a large number of negative factors that can significantly impair the transmission characteristics of wireless transmission channels. The aim of this research is to develop a method estimating the effective rate of information transmission in 802.11 channels using a monitoring algorithm to improve the design efficiency of wireless networks. During the study, statistical processing models and methods for averaging research results were used. Novel mathematical models have been developed to estimate the effective rate of information transmission, taking into account monitoring parameters and destabilizing factors for 802.11 wireless channels. Models allow us to estimate the effective rate of information transmission at any location of user device in the coverage area of the network in real-time. The peculiarity of such models is consideration of fluctuations in monitoring parameters, which is estimated by the confidence interval between changing the primary informational parameter to determine the suitability of the channel to transmit any type of traffic. Based on the mathematical models obtained, the provisions of a new method for estimating the effective rate of information transmission in the channel of standard 802.11 were formed using a monitoring algorithm, which has high estimation, ease of implementation, taking into account the maximum possible number of destabilizing factors and possibility of adaptation for any other wireless channel standards.

Keywords: wireless channel, bandwidth, evaluation method, mathematical modeling, monitoring

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1. Introduction

Modern multiservice networks, providing access to communication services, in most cases use TCP / IP family of protocols, and the principle of transparent transfer of traffic, which from the point of view of user does not depend on the type of transmission channel (Barachi, Kara, Rabah, & Forgues, 2015). One of the common channel building technologies is the 802.11 standard , which includes the function to quickly deploy local area networks in corporate and home sectors, easy connection of user equipment, and low cost of equipment (Perahia & Stacey, 2013). The development of the 802.11 standard made a contribution to widespread introduction of the concept of Internet of Things and increasing the requirements for bandwidth channels. Nonetheless, the rapid spread of 802.11 wireless technologies and the emergence of a large number of networks results in a large number of negative factors that can significantly impair the transmission characteristics of wireless transmission channels (Mykhalevskiy & Horodetska, 2018; Diagilev et al., 2019). They cause the delays in the channel and errors in accepted packages. This results in an increase in the amount of service information and, as a result, a significant impairment in the bandwidth of the channel. It becomes unacceptable for high-quality telecommunication and info communication services. These factors need to be taken into account at design stages of wireless networks. And the most reliable estimation of such factors can be obtained only by applying methods for evaluating network parameters and wireless channels developed on the basis of experimental research.

The bandwidth of the wireless channel is conditioned by channel, physical and application level parameters. The most commonly used estimations of this parameter are provided by the analytical calculation models based on the specifications of the channel construction standard. One of such studies is the work (Mykhalevskiy & Kychak, 2019) where it is proposed to use new mathematical models for estimation of information and energy efficiency of 802.11x family standard wireless channels. These models give possibility to evaluate the transmission efficiency of the block of information taking into account the full cycle of packet and frame transmission when errors occur in frames. In addition, the model accounts for the existence of other subscribers in the network and the mechanism of competition for the physical resource of the frequency channel. Another model helps to calculate the maximum bandwidth, taking into account delays, microgeneration certification scheme (MCS) circuit parameters and channel length according to 802.11g (Barbosa, Caetano, & Bordim, 2011; Shevgunov, 2019). But such models use the parameter of probability of occurrence of errors in the channel, which will not always take into account presence of various destabilizing factors.

In work (Kim, Park, Lee, & Hu, 2011), to evaluate the parameters of a wireless network, it was proposed to use transformation of the physical network into a model with smaller number of nodes. This approach makes it possible to evaluate the parameters with fewer mathematical calculations for the totality of subscribers in the network. The model operates with probabilistic characteristics of time slot selection, and is characterized by the complexity of setting the initial conditions (Mustafin & Kantarbayeva, 2019; Skvortsov, Orlov, Frolov, Gonchar, & Litvinenko, 2000).

The objective of this work is to develop a method estimating the effective rate of information transmission in 802.11 channels using a monitoring algorithm to improve the design efficiency of wireless networks.

To achieve this objective, the following tasks need to be addressed:

a) developing models for evaluating the effective speed of information transfer, taking into account monitoring parameters and destabilizing factors;

b) performing mathematical modeling using the obtained models to determine the limits of change of destabilizing factors;

c) developing a new method for estimating the effective rate of information transmission in 802.11 channels using a monitoring algorithm that will determine the channel's suitability for transmitting different types of traffic.

2. Materials and methods

The evaluation of 802.11 wireless bandwidths is a complex process. This work can be distinguished among the methods of estimating the speed of information transmission (Khan & Qiu, 2016). Here are two methods suggested for using bandwidth estimation using packet error estimation with the new interleave algorithm. These methods have advantages over conventional signal/noise estimation methods and improve the power and bandwidth parameters of 802.11 wireless networks. Another method (Sen, Santhapuri, Choudhury, & Nelakuditi, 2010; Shevgunov, Efimov, & Kirdyashkin, 2019) involves determining the optimal bandwidth of the channel based on an estimate of the level of variance between packet symbols. In this case, the packet simulation can be performed on different parameters of MCS scheme. The result determines the optimal transmission mode. The proposed methods use frame error estimation and, based on this, choose the optimal mode of operation of MCS scheme. This, in turn, does not provide complete information about existing processes, obstacles and hindrances in the wireless channel.

Analyzing the results, we can say that, as a rule, all existing studies are aimed at obtaining a common information model of the wireless channel or to evaluate the parameters of the channel and physical level of standard 802.11. But the effective baud rate is directly dependent on destabilizing factors in the channel that change over time. Thus, it is possible to formulate an urgent task about the need to develop a new method for estimating the effective rate of information transmission, which will allow evaluating the information efficiency of the channel, taking into account the maximum possible number of destabilizing factors, for transmitting any traffic.

The use of monitoring algorithms involves using statistical processing models and methods of averaging research results. Monitoring provides opportunity to obtain information on: the number of N^{Tx}MSDUs transmitted and N^{Rx}MSDUs received per unit time; the number of requests to retransmit frame Nr; the number of successfully transmitted frames for which more than one N_{mr} request was completed , the number of lost frames N_f .The general block diagram for estimating such parameters during the monitoring is presented in Fig. 1.

During the channel transfer process, all service information that adds the channel and physical levels of 802.11 can be ignored, as the number of frames received and transmitted can be counted. Confirming a successful or false transmission using the ACK frame. When an error occurs, the loop is retransmitted, which is fixed by the parameters N_r and N_{mr}. It creates delays in the channel for transmitting of subsequent frames. When exceeding the maximum number of cycles of retransmission N_{max}, the frame is considered lost, which is fixed by the parameter N_f . As an example, we can provide a timeline snippet for the parameters of the received and transmitted frames with query cycles. The results of the study are demonstrated in Fig. 2.

Monitoring was done for 802.11n standard channel, with 40 MHz channel bandwidth of 2.4 GHz. The length of wireless channel was 5 m. In addition, there were: architectural obstacle of brick and interference hindrances as in apartment building, where there can be 20-30 networks within the reception range of the subscriber's receiving module.

3. Results

Development of the mathematical model for the estimation of the effective speed of information transfer.

The total effective speed of transmission of information on the channel will depend on the number of frames received and transmitted without errors, taking into account the re-query cycles. Then, considering the statistical results of the studies, the effective transmission rate can be expressed as the number of successfully transmitted frames transmitted in the channel over a specified period of time t:

$$V_{eff} = \frac{N_{eff}\,L}{t} \tag{1}$$

where N_{eff} – is the number of successfully transmitted and received frames; L – is the length of the frame.

Analyzing Fig. 2, for coherence with monitoring data, the unit of assessment time can be set at 1 s. But the graphs show significant fluctuations in number of frames at different points in time. From the user's point of view, the average value of receiving useful information per unit of time will be of interest, where there will be no delay in telecommunication and info communication services. The average amount of information received can be obtained based on evaluation period, through successfully received MSDU packages or frames:

$$N_{MSDU} = \frac{1}{T}\sum_{i=1}^{T} N_{MSDU.i,}\ where\ i = 1,2,3 \ldots T, \tag{2}$$

where $N_{MSDU.i}$ – is the number of packets received per unit time; T – is the evaluation period, to obtain the average value (in this case it is determined in times).

Frame transmit errors and lost frames reduce the amount of useful information per channel transmitted per unit of time. Since temporal characteristics of the parameters are also random, the expression for estimating the maximum number of rewriting cycles for successful frame transmission can be written as follows:

$$N_r^m = \frac{1}{T}\sum_{i=1}^{T}(N_r + N_{m.r.})_i,\ where\ i = 1,2,3..T, \tag{3}$$

If the limit of allowed requests is exceeded, the frame is considered lost. For lost frames we get:

$$N_f = \frac{1}{T}\sum_{i=1}^{T} N_f^i\ ,\ where\ i = 1,2,3 \ldots T \tag{4}$$

where N^i_f– is the number of frames lost per unit time.

Given expressions (2), (3) and (4), the average number of successfully sent and received frames per unit of time can be calculated as follows:

$$N_{eff} = \frac{1}{T}\sum_{i=1}^{T}(N_{MSDU}^{Tx} + N_{MSDU}^{Rx} - (N_r + N_{m.r.})_i - N_f^i - N_d^i), \tag{5}$$

where N^i_d – is the number of frames identified as duplicate and, in most cases, neglected.

Given construction of the package (Mykhalevskiy & Kychak, 2019), the amount of useful information is expressed through an MPDU or MSDU frame:

$$L = L_{MPDU} - L_{s.MPDU} - L_{s.TCP/IP} = L_{MSDU} - L_{s.TCP/IP} \tag{6}$$

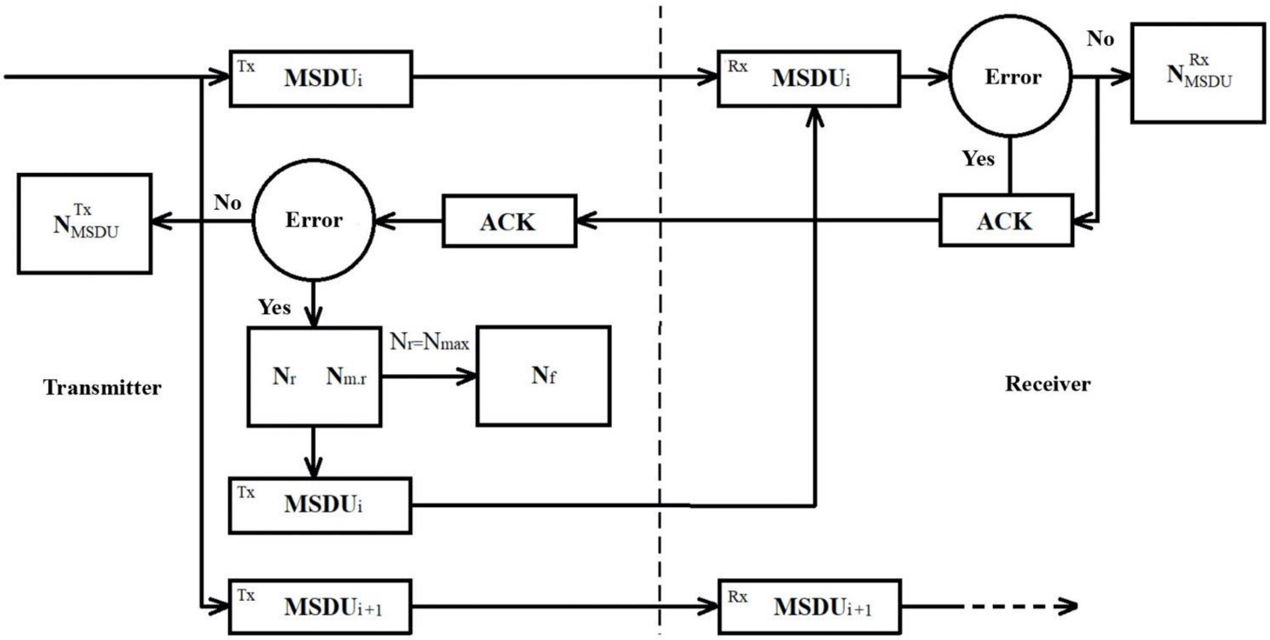


Figure 1. Structure of estimation of useful information parameters in 802.11 standards when transmitting frames.

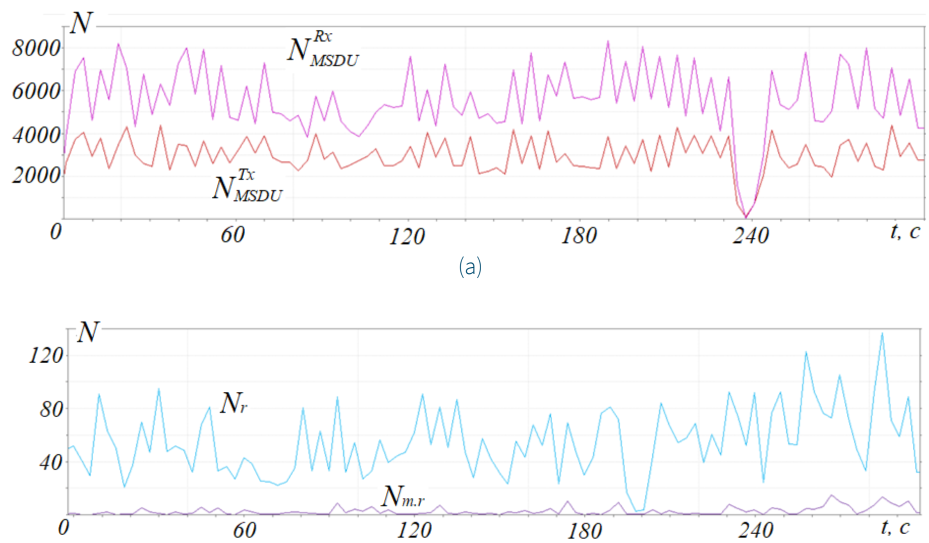


Figure 2. Fragment of time distribution for a) transmitted and received frames MSDU; b) for re-query cycles.

where $L_{s.MPDU}$ – is length of service information in the MPDU frame; L_{MSDU} – is MSDU frame length; L_{MPDU} – is MPDU frame length; $L_{s.TCP / IP}$ – is the length of TCP / IP protocol stack of service information.

Substituting expressions (5) and (6) into expression (3), we get a model for estimating the total effective data rate in wireless channel 802.11:

$$V_{eff} = \frac{K(L_{MDSU}-L_{s.TCP|IP})}{tT}\sum_{i=1}^{T}(N_{MSDU}^{Tx} + N_{MSDU}^{Rx} - \left(N_r + N_{m.r.}\right)_i - N_f^i), \quad (7)$$

where K – is the channel load factor of the service information that generates the monitoring algorithm and in this case is 1.5.

The obtained model makes an opportunity to estimate the effective speed of information transmission at any point of location of subscriber device in coverage area of the network in real time. This takes into account all negative factors of influence in the information transmission path.

Consideration of channel length for the model for estimating the effective data rate

The basic parameters of wireless channel are randomly distributed over time, and their characteristics can have pronounced fluctuations (Mykhalevskiy, 2019; Mykhalevskiy & Horodetska, 2019). Let's research typical cases of wireless channel operation in real conditions. The studies are shown in the following diagrams: 1 – direct visibility between the transmitter and receiver without interference; 2 – there is an architectural obstacle of tree type in the channel; 3 – there are two obstacles in the channel, such as "tree"; 4 – there is one "brick" obstacle in the channel; 5 – there are two obstacles of the type "brick" in the channel; 6 – there is an interference obstacle in the channel; 7 – there is interference obstacle in the channel and there is one obstacle such as "tree"; 8 – there is an interference obstacle in the channel and two "tree" obstacles; 9 – there are two interference obstacles in the channel with direct visibility; 10 – there are two interference obstacles and the first type interference in the channel; 11 – there are two interference obstacles and two obstructions of the tree type in the channel. For obstructions of the type "brick" with interference obstacles, the results have a similar distribution. The graphs of the number of received and transmitted frames by the length of channel are shown in Fig. 3.

Architectural interferences of different types have an impact that depends on the thickness and density of material, and interference obstacles – on the level of radiation and the amount of information generated by subscribers of other networks. If we do not consider the maximums near the access point, then using the regression methods we can get a reliable average dependence of the number of received and transmitted frames on the length of channel. Therefore, a common mathematical model for estimating the number of successfully transmitted and received frames for 802.11 wireless channel can be written as follows:

$$N_{MSDU} = N_{MSDU}^{Tx} + N_{MSDU}^{Rx} = 2a_1 l + N_0^{Tx} + N_0^{Rx} + \Delta N, \quad (8)$$

or:

$$N_{MSDU} = 2a_2 \ln l + N_0^{Tx} + N_0^{Rx} + \Delta N, \quad (9)$$

where a_1 and a_2 – are the regression coefficients obtained from experimental data (Mykhalevskiy & Horodetska, 2019); N_0 – is the initial level of regression; ΔN – is the confidence interval of the estimation showing fluctuations of time characteristics; ln – is applied in presence of high density interference.

On the basis of the mechanism of creation of re-query (Perahia & Stacey, 2013), we will consider the results of researches for successfully sent frames taking into account the retransmission cycles, which are demonstrated in Fig. 4.

The results of the regression analysis demonstrate a gradual increase in the number of re-query cycles with increasing channel length. This is especially true for high density architectural obstacles. But for all cases the dependence of the number of retransmission cycles of the frame on the length of the channel can be described as follows:

$$N_r = N_{0r} e^{(kl)} + \Delta N_r, \quad (10)$$

where k – is the regression growth factor, N_{0r} – is the initial regression level.

Similar dependencies were obtained for parameters N_{mr} and N_f:

$$N_r = N_{0m.r} e^{(k_1 l)} + \Delta N_{m.r}, \quad (11)$$

$$N_f = N_{0f} e^{(k_2 l)} + \Delta N_f. \quad (12)$$

where $N_{0m.r}$ and N_{0f} – are the initial regression levels; $\Delta N_{0m.r}$ and ΔN_{0f} – are the confidence intervals of the estimate.

Further analysis of research results made it possible to establish the following relationships:

$$N_{0r} \approx 4N_{0m.r} \approx 20N_{0f}, \quad (13)$$

$$k \approx k_1 \approx 2{,}5k_2 \quad (14)$$

The regression coefficient k indicates presence of architectural obstacles and density of the material. For the accomplished studies, k = 0.1…0.3 is set, where the lower value is straight line of sight and the upper one is brick.

We substitute the obtained dependences of estimation of parameters of the effective speed of information transmission from the channel length into mathematical model (9). Given that the regression models are obtained as average values; we get a model for estimating the effective speed of information transmission along the entire length of channel:

$$V_{eff} = \frac{K(L_{MSDU} - L_{s.TCP|IP})}{t} F(l) + N_0^{Tx} + N_0^{Rx} - \\ -\frac{5}{4} e^{kl} + \frac{1}{20} e^{0.4kl}) N_{0r}) \pm \Delta V \quad (15)$$

$$F(l) = \begin{cases} (a_1^{Tx} + a_1^{Rx}) l, for\ 0.1 \leq k \leq 0.2, \\ (a_2^{Tx} + a_2^{Rx}) ln\ l, for\ 0.2 < k \ \leq 0.3, \end{cases} \quad (16)$$

where ΔV – is the confidence interval of the effective data rate.

In this case, the confidence interval of the effective data rate can be calculated as follows:

$$\Delta V = (\Delta N_0^{Tx} + \Delta N_0^{Rx} - \Delta N_r - \Delta N_{m.r} - \\ \Delta N_f) \frac{K(L_{MSDU} - L_{s.TCP/IP})}{t} \quad (17)$$

The mathematical model (10) makes it possible to estimate effective transmission speed over the entire length of 802.11 wireless channel based on parameters that are fairly easy to obtain using monitoring algorithms. The parameter ΔV indicates fluctuations of monitoring parameters over time. This lets us determine the limits of change in the effective rate of information transmission for transmissions of any type of traffic.

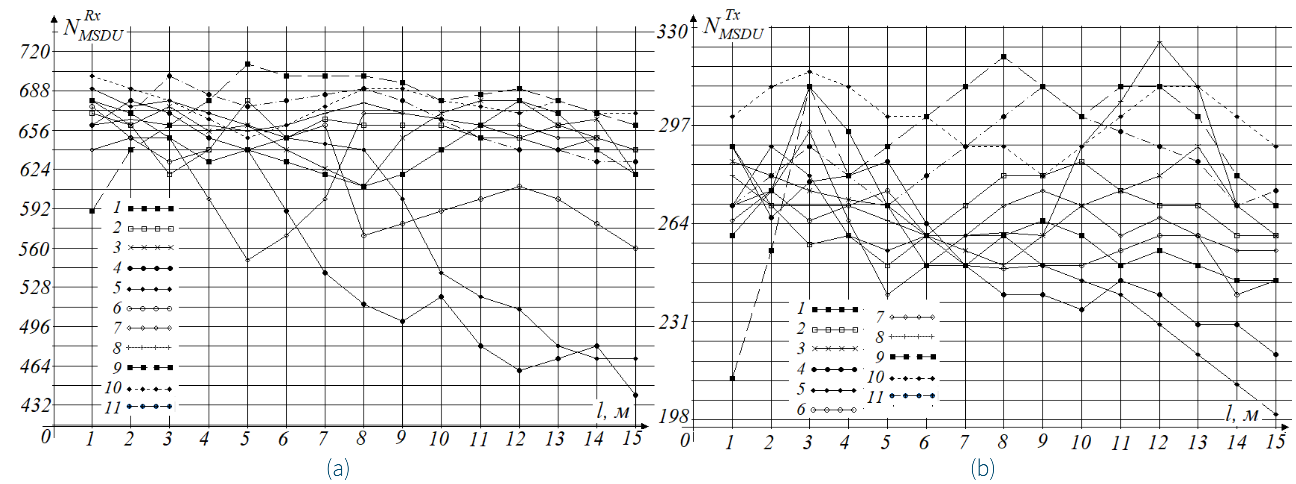


Figure 3. Graphs of the dependence of parameter N_{eff} on the channel length for: a) received frames; b) frames sent.

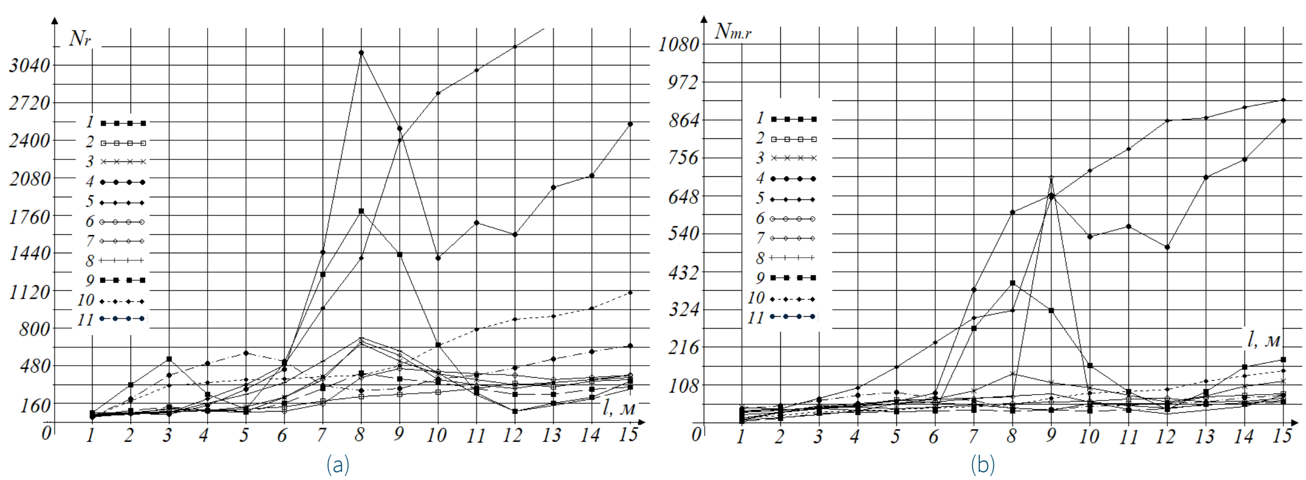


Figure 4. Graphs of the number of retransmission requests from the channel length for: a) N_r; b) N_{mr}.

4. Discussion

Two mathematical models were obtained to estimate the effective rate of information transmission in 802.11 channels. Model (9) estimates the average value for period T and does not have channel length parameter. This makes it possible to evaluate at any point in coverage of the network, taking into account the maximum possible number of destabilizing factors.

Model (10) contains a length parameter that allows the estimation of the effective speed of traffic transmission over the whole possible channel length where there may be architectural obstacles and interference hindrances. The impact of interference and obstacles reduces the effective rate of transmission of information by coefficients a_1, a_2, and k. These coefficients demonstrate how the basic information parameter changes in the event of significant interference or obstacle with the channel. Using mathematical modeling, you can get graphs of impact of destabilizing factors on the main informative parameter. The results are demonstrated in Fig. 5.

The other parameters N_0 and N_{0r}, which can be obtained experimentally, are the most accurate consideration of destabilizing factors in real time that affect all network coverage. The fluctuations of these parameters are provided by confidence intervals ΔN_0 and ΔN_{0r}. The simulation results for the specified intervals are demonstrated in Fig. 6.

As it can be seen from the results obtained in Fig. 5 and Fig. 6, the mathematical model for estimating the effective transmission rate takes into account the maximum number of destabilizing factors in the channel. The reliability of results is ensured by the choice of an estimation period for the informative parameter using a monitoring algorithm. It greatly simplifies the obtained information about the ability to transmit different types of traffic in 802.11 wireless channels. Similar results can be received for any channel and frequency band. Based on the obtained models, a method for estimating the effective speed of information transmission using monitoring algorithms was suggested, which allows obtaining information about the channel capacity for transmitting different types of traffic. The essence and consistency of the assessment method are as follows:

In the first stage, monitoring determines the basic parameters of transmission of frames in the wireless channel. It is necessary to exchange the test information and obtain the time distribution of parameters N^{Tx}_{MSDU}, N^{Rx}_{MSDU}, N_r, N_{mr} and N_f. As a rule, it can be done as access to an information service.

In the second step, the effective rate of information transmission in the channel is calculated using the formula (9). The parameters for incoming packets must be separately evaluated; thus:

$$V^{Rx}_{eff} = V_{eff} - \frac{1}{T}\sum_{i=1}^{T}(N^{Tx}_{MSDU} - (N_r + N_{m.r.})_i - N^i_f), \qquad (18)$$

If the formula (10) is used, then it is also necessary to determine the initial regression levels and confidence intervals of the estimate: N_0, N_{0r}, ΔN, ΔNr, ΔN_f, $\Delta N_{m.r}$. The initial level N_0 can be determined at distance of two meters from the access point (Mykhalevskiy, 2018). Considering that at this distance the influence of interference hindrance is minimal, then it can be assumed that for any transceiver equipment, the following inequality will be valid:

$$N^{Rx}_0 + N^{Tx}_0 = N_{eff} \qquad (19)$$

The estimation intervals can be obtained from the time distribution over period T on the basis of the following condition:

$$\Delta N \quad = \frac{1}{T}\sum_{i=1}^{T}(min\, N\,(t); max\, N\,(t)). \qquad (20)$$

At the third stage, the result of evaluation of the effective speed of information transfer and the magnitude of impact of destabilizing factors are obtained. As a result, the obtained data can be written as follows:

$$V_{eff} - \Delta V \le V_{eff} < V_{eff} + \Delta V\ . \qquad (21)$$

The criteria for assessing the level of destabilizing factors can be recorded as follows:

$$K^T_r = \frac{N^{Rx}_{MSDU} + N^{Tx}_{MSDU}}{N_r + N_{m.r}} = \frac{2a_1 l + N^{Rx}_0 + N^{Tx}_0}{1{,}25 N_{0r} e^{kl}}, \qquad (22)$$

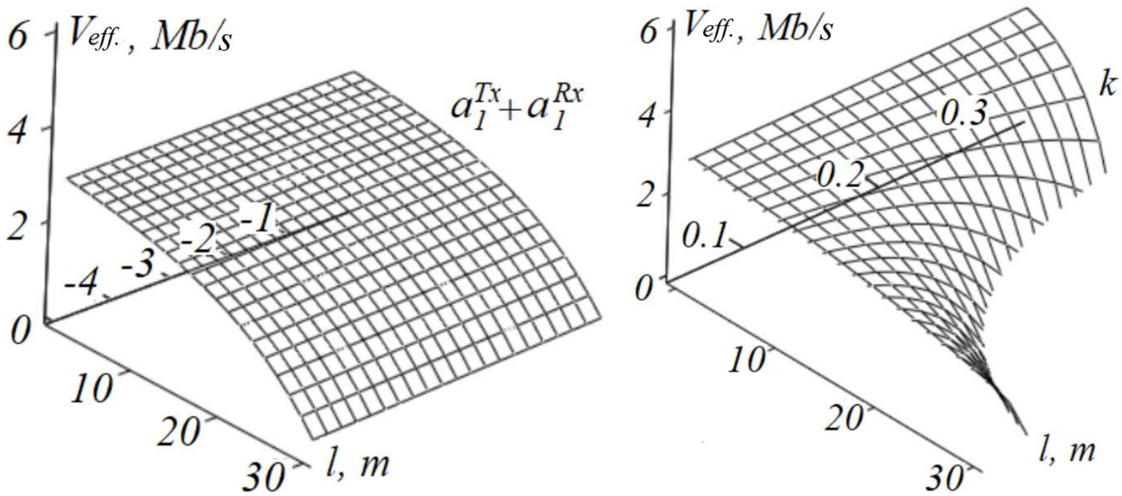
$$K^T_f = \frac{N^{Rx}_{MSDU} + N^{Tx}_{MSDU}}{N_f + N_d} = \frac{20(2a_1 l + N^{Rx}_0 + N^{Tx}_0)}{N_{0r} e^{0{,}4kl}} \qquad (23)$$

The fourth step is to establish the current state of the wireless channel to transmit different types of traffic. As practice shows, for receiving high quality info communication service without delay, the bit rate V_b should satisfy the following condition:

$$V_b \le (0.8..0.7) V^{Rx}_{eff} \qquad (24)$$

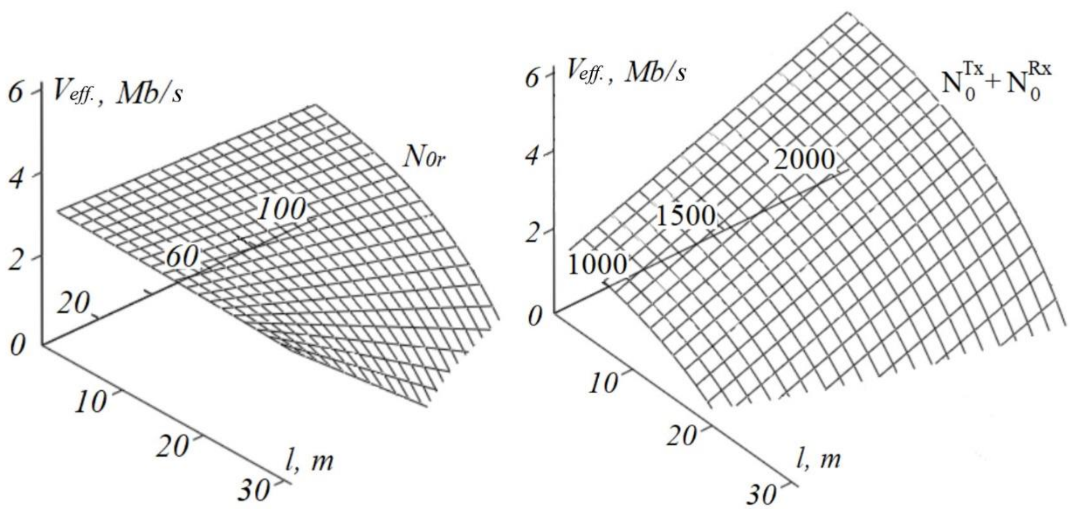
Excluding fluctuations in the effective rate of information transmission, we obtain the condition that the 802.11 wireless channel is suitable for transmitting certain types of traffic, which can be written as follows:

$$V_b \le (0{,}8..0{,}7)\left(V_{eff} - \frac{1}{T}\sum_{i=1}^{T}(N^{Tx}_{MSDU} - (N_r + N_{m.r.})_i - N^i_f\right) - \Delta V) \qquad (25)$$



(a) (b)

Figure 5. The dependence of V_{eff} on attenuation coefficients: a)for transmitted and received frames MSDU;b) for re-query cycles.



(a) (b)

Figure 6. Dependence of V_{eff} on initial levels for: a) for transmitted and received MSDU frames; b) for re-query cycles.

The obtained inequality makes it possible to evaluate the usability of 802.11 wireless channels to transmit any traffic where the bit rate V_b is known. Using the developed method, it is possible to get maximum channel efficiency when designing a network or when tuning a wireless channel for maximum performance (Faraday, 1822; Oersted, 1820;Tesla, 2008). The disadvantages include not enough widespread equipment that supports the estimation of frames, for high reliability it is necessary to have a base of certain regression coefficients and criteria for estimation of destabilizing factors.

5. Conclusions

As a result of the study, two models of estimation of the effective speed of information transfer with the parameters of monitoring and destabilizing factors were obtained. Such models make it possible to estimate the informative parameter based on statistics of the monitoring algorithm taking into account the maximum number of destabilizing factors.

It was established that parameters N_0 and N_{0r}, which can be obtained experimentally, are the most accurate consideration of real-time destabilizing factors that affect all network coverage. The fluctuations of these parameters can be provided by the confidence intervals ΔN_0 and ΔN_{0r} .In the absence of interference hindrance, the ratio of number of lost packets N_f to number of successfully transmitted ones when rewriting N_r is approximately 1: 3, and relative to the parameter N_{mr} is approximately 1: 2. All confidence intervals can be reduced to a single parameter ΔV, which estimates admissible limits for changing the main informative parameter to determine the suitability of a channel to transmit any kind of traffic.

The authors obtained a novel method for estimating the effective speed of information transmission in an 802.11 standard channel using a monitoring algorithm that has high estimation reliability, ease of implementation, taking into account the maximum possible number of destabilizing factors, and the possibility of adaptation for any wireless channel of other standards.

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