DEVELOPMENT OF INFORMATION MODELS FOR INCREASING THE
EVALUATION EFFICIENCY OF WIRELESS CHANNEL PARAMETERS
OF 802.11 STANDARD

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The objective of the research is to develop information models in order to improve the efficiency of evaluating the parameters of the wireless channels in 802.11 standard. A feature of the information model of the wireless channel of 802.11 standard is an opportunity to evaluate the efficiency of transferring the information block taking into account the complete packet and frame transmission cycle in the event of errors 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. It has been established that channel efficiency is mostly affected by the presence of destabilizing factors in the channel, which lead to an increase in the number of service information and an increase in the transmission cycle due to the creation of reciprocal queries.

Keywords: *bandwidth, channel level, effective data rate, physical level, 802.11 standard, wireless channel*

1. INTRODUCTION

One of the common channel building technologies is the 802.11 standard, which includes the function to quickly deploy local area networks in the corporate and home sectors, easy connection of user equipment, and low cost of hardware [1]. The development of the 802.11 standard made a contribution to the widespread introduction of the concept of the Internet of Things and increasing requirements for bandwidth channels.

However, the rapid spread of 802.11 wireless technologies and the emergence of a large number of networks lead to the emergence of a large number of negative factors that can significantly hinder the transmission characteristics of wireless transmission channels [2]. 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, in a significant impairment in the bandwidth of the channel. It becomes unacceptable for high-quality telecommunication and information communication services. These factors need to be taken into account at the design stages of wireless networks. 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. On the other hand, for the exchange of information at the application level there is a mechanism for transmission by the channel, which has its own factors to consider. Therefore, in addition to the experimental methods, it is necessary to have models for assessing the transmission of information in the channel, taking into account the parameters of the relevant transmission mechanism.

Analysing the works [3]–[10], one can say that, as a rule, all existing studies were aimed at obtaining a general information model of a wireless channel and determining the software conditions for maximum productivity. However, the actual rate of transmission has a direct dependence on the destabilizing factors in the channel.

2. GENERAL DEVELOPMENT OF INFORMATION MODEL OF THE WIRELESS CHANNEL

The general information model can be constructed using the following expression [10]–[12]. The efficiency ratio of information transmission in the channel can be written as follows:

$$K_{ef} = \frac{V_{ef}}{V_{pl}}, \quad (1)$$

where V_{ef} – the effective rate of information transmission; V_{pl} – the maximum bandwidth of a channel, which is determined by the rate of frame transformation into a bit sequence at the physical layer.

Let us consider options in terms of information transfer. The effective rate of transmission is an amount of information v , which is transmitted in the channel for a certain time interval t (2). At the channel layer, depending on the transmission system standard, the information is divided into frames (3), where N_f – the number of frames; L_f – the length of the frame.

$$V_{ef} = \frac{v}{t}; \quad (2)$$

$$v = N_f L_f. \quad (3)$$

The time for the transmission of information in the channel is determined based on the frame transfer cycle. The transfer time of frames taking into account errors can be calculated using the expression:

$$t = (t_f + t_s)(N_f + N_e), \quad (4)$$

where t_f – frame transmission time; t_s – time of transfer of service information taking into account the frame transmission cycle; N_e – the number of received frames with errors, for which the overwrite procedure is executed.

False frames increase the amount of repeated information transmitted on the channel. They can be expressed via the probability of bit error occurrence. Then the time of the information transfer in the channel can be written as (5), where P is the probability of receiving the error frame:

$$t = N_f(t_f + t_s)(1 + P). \quad (5)$$

In semi-duplex systems, the transfer of a package is carried out in two stages: a request for the transfer of a package in direct T_x channel and reception confirmation in reverse R_x . Thus, taking into account [4], the delay time for one frame transfer frame can be defined as follows:

$$t_s = t_{Tx} + t_{Rx} = \frac{L_{Tx} + L_{Rx}}{V_{pl}} + 2t_{dc}, \quad (6)$$

where t_{Tx} – transmission time of the transfer request frame; t_{Rx} – time to receive a frame confirming the successful transmission of the information frame; L_{Tx} and L_{Rx} – the lengths of the request and confirmation frames, respectively; t_{dc} – the time delay between the frames of the transmission cycle, which is determined by the technical features of the standard.

Considering the transmission cycle of the information frame and the delay in the channel, the effective rate of transmission of information can be calculated by substituting (6), (4) and (3) into (2):

$$V_{ef} = \frac{N_f L_f}{\left(t_f + \frac{L_{Tx} + L_{Rx}}{V_{pl}} + 2t_{dc}\right)(N_f + N_e)} = \frac{L_f}{\left(t_f + \frac{L_{Tx} + L_{Rx}}{V_{pl}} + 2t_{dc}\right)(1 + P)}. \quad (7)$$

Taking into account (7), the efficiency ratio of the channel can be calculated as follows:

$$K_{ef} = \frac{L_f}{(1 + P)((t_f + 2t_s)V_{pl} + L_{Tx} + L_{Rx})}. \quad (8)$$

The resulting expression is a general information model for any wireless channel with a mechanism for retransmission of packets when registering errors. The bandwidth of the channel can be expressed via the signal strength at the receiver input [13].

$$V_{pl} = \Delta F \log_2 \left(\frac{P_{Rx}}{(P_n + P_i)} + 1 \right), \quad (9)$$

where P_{Rx} – signal strength at the receiver input; P_n – a noise level in the channel; P_i – the level of interference noise.

Taking into account [9], signal/noise is the ratio of the energy of the signal E to transmit one bit of information to the noise power density, the following expression can be formed:

$$\frac{E_b}{N_0} = \frac{P_{Rx}}{P_n + P_i} \cdot \frac{\Delta F}{V_{ef}}, \quad (10)$$

where ΔF – the band of the frequency channel; N_0 – the power of white noise in the channel; E_b – the energy to transmit one bit of information.

Then, the bandwidth can be established by the expression:

$$V_{pl} = \Delta F \log_2 \left(\frac{V_{ef} E_b}{\Delta F N_0} + 1 \right). \quad (11)$$

3. DEVELOPMENT OF INFORMATION MODEL OF WIRELESS CHANNEL IN 802.11 STANDARD

To develop an information model of a wireless channel by 802.11 standard, we consider transferring the information in terms of the application layer. Then, first of all, the condition of information exchange without changes and transformations must be fulfilled. After that, for the standard 802.11 channel, information transfer will consist of two stages. Let us consider them on the basis of the complete cycle of transfer of information block DU (Data Unit) between applications at the application level, the scheme of which is shown in Fig. 1.

Fig. 1. The scheme of one cycle of transmission of DU block.

The first stage implies formation of DU data blocks and their transmission in a virtual channel. The DU itself is a useful piece of information used by applications. DU length can be specified by the parameter L . The time of the DU passing through the transmission path from one application to another per unit of time will determine the efficiency ratio of transmission of information. To transmit this block in channels and networks, there are PDAs (Protocol Data Units) that contain the service information of the transfer protocol. The most common is the TCP/IP protocol stack that adds the service information to the DU, which can be specified by length $L_{s,TCP}$ and $L_{s,IP}$. The TCP protocol has a duplex packet transfer mode with reliability control mechanism [14]. This implies a link in the reverse direction of the service information confirming receipt of the package, and in case of an error, the overwrite is done. Therefore, the amount of information per packet cycle can be written as follows:

$$L_{TSP/IP} = L + L_{s,TCP} + L_{s,IP} . \quad (12)$$

The second stage involves transferring the data packet via the media (M) using the hardware-software tools for creating a wireless channel at the channel and physical layers [13]. The data packet is transmitted using internal information unit called the frame.

The frames in 802.11 standard are formed at the channel layer and are called MSDU (Mac Service Data Unit). They are customizable by the size of the PDU and $L_{TCP/IP} = L_{MSDU}$. MSAs are added to the MSDU to provide service information by generating MPDU (Mac Protocol Data Unit) frames [15]. Thus, the amount of information in one frame can be determined by expression (13), where $L_{s,MPDU}$ – the length of the service information in the frame MPDU; L_{MSDU} – the length of MSDU frame.

$$L_{MPDU} = L_{s,MPDU} + L_{MSDU} = L + L_{s,MPDU} + L_{s,TCP/IP} . \quad (13)$$

Let us consider the AMPDU aggregation as applied directly to the 802.11 standard. AMSDU aggregation is inappropriate because, in the presence of even a small number of destabilizing factors, there will be a large number of errors in frames for high-speed modes. Thus, the amount of information, taking into account the cycle of transmission, is defined as follows:

$$v_s = L_{RTS} + L_{s,PPDU} + mL_{MPDU} + L_{CTS} + L_{ACK} , \quad (14)$$

where L_{RTS} – the length of the RTS frame; $L_{s,PPDU}$ – PPDU service information, including preamble and header; L_{CTS} – the length of the CTS frame; L_{ACK} – the length of the confirmation frame; m – the number of MPDU frames in the aggregated frame of the AMPDU.

The time required to transmit the amount of information in the channel, taking into account service information and delays for the full frame of transmission MPDU, can be written as follows:

$$t_s = t_{Difs} + t_{BO} + t_{RTC} + t_{Sifs} + t_{CTS} + t_{Sifs} + t_{MPDU} + t_{Sifs} + t_{ACK} + 2t_{ds}, \quad (15)$$

where t_{BO} – delays in selecting time slots to prevent collisions; t_{Difs} , t_{Sifs} – inter-frame delay and small intercity delay, respectively; t_{RTS} – RTS frame transmission time; t_{CTS} – time of transmission of CTS frame; t_{MPDU} – time of transmission of MPDU frame; t_{ACK} – time of transmission of the ACK frame; t_{ds} – the time delay of the signal.

According to the specification of 802.11 standard [13], the delay for choosing time slots can be determined as follows:

$$t_{BO} = random(0, CW \min) \cdot T_{st}, \quad (16)$$

where $random()$ – a random function of choosing the size of the window of the conflict to prevent overload and collisions in the channel; T_{st} – the length of the time interval in CSMA/CA.

The time of transmission of the information frame will be (17), where $t_{s,PPDU}$ – service information containing a preamble and a physical level (layer) heading.

$$t_{MPDU} = t_{s,PPDU} + \frac{m \cdot L_{MPDU}}{V_{pl}}. \quad (17)$$

Frame transfer time RTC, CTS and ACK can be defined as follows:

$$t_{RST} = t_{s,PPDU} + \frac{L_{RTS}}{V_{pl}}, \quad (18)$$

$$t_{CTS} = t_{s,PPDU} + \frac{L_{CTS}}{V_{pl}}, \quad (19)$$

$$t_{ACK} = t_{s,PPDU} + \frac{L_{ACK}}{V_{pl}}. \quad (20)$$

There are also some delays associated with the formation and transmission of the signal in the environment. After transforming the PPDU frame into a bit sequence in the BRTB (Bit Rate Transform Block), it is possible to select a certain group of delays. Thus, we can write:

$$t_{ds} = t_{QAM}^{Tx} + t_{OFDM}^{Tx} + t_{MIMO}^{Tx} + t_{sp} + t_{QAM}^{Rx} + t_{OFDM}^{Rx} + t_{MIMO}^{Rx} + 2t_{PMD}, \quad (21)$$

where t_{QAM}^{Tx} – the delay in the transmitter modulator; t_{OFDM}^{Tx} – the delay in forming OFDM; t_{MIMO}^{Tx} – the delay to the formation of spatial flows MIMO; t_{sp} – the delay of the signal passing in the medium of transmission; t_{MIMO}^{Rx} – the delay for the integration of spatial flows MIMO; t_{OFDM}^{Rx} – the delay on the inverse transform of OFDM; t_{QAM}^{Rx} – the delay in receiver demodulator; t_{PMD} – the delay for converting a frame to a bit sequence at the PMD sublevel.

Taking into account the useful information in the loop and the time it passes through the wireless channel of the 802.11 standard, the efficiency factor will look like this:

$$K_{ef} = \frac{m(L_{MSDU} - L_{s,TCP/IP})}{(t_{Difs} + t_{BO} + 3t_{Sifs} + 4t_{s,PPDU} + t_{ds})V_{pl+L_{RTS}+L_{CTS}+mL_{MPDU}+L_{ACK}}}. \quad (22)$$

The resulting expression is an information model of a wireless channel of the 802.11 standard and provides an opportunity to evaluate the efficiency of the transmission of the DU information block in the absence of errors in frames. The amount of information in the TCP protocol when errors occur in the virtual channel will be (23), where n – the number of packet reload cycles in case of errors.

$$L_{TCP/IP} = L + L_{s,TCP} + L_{s,IP} + \sum_{i=1}^n (L + L_{s,TCP} + L_{s,IP})_i. \quad (23)$$

The 802.11 standard has a mechanism that defines the number of retransmission requests for well-received frames and the number of well-received frames, where the request for retransmission was sent more than once. Thus, each retransmission cycle is the transmission of the MPDU information frame using the RTS/CTS loop. In this case, it is expedient to apply a period of estimation T , for which a certain number of frames without error N_f and number of frames with errors N_e will be transmitted (24). Then, using expressions (3) and (4) the efficiency of the wireless channel 802.11, taking into account frames with errors, can be determined by expression (25).

$$N = \int_0^T (N_f + N_e) dt. \quad (24)$$

$$K = \frac{N_f}{N_f + N_e} K_{ef}. \quad (25)$$

The number of frames with errors can be determined by the probability of a bit error [9]. Then the probability of receiving an error frame can be determined as follows:

$$P = 1 - (1 - p)^{v_c}. \quad (26)$$

Considering (26) and (5), we can write it as follows:

$$K_{ef,e} = \frac{K_{ef}}{2 - (1 - p)^{v_c}}. \quad (27)$$

The resulting expression takes into account the transmission of the frame for an individual mode of the channel operation when one radio is present in the network. 802.11 standard networks provide more than one subscriber, while they all exchange frames on one frequency channel. The efficiency of the 802.11 standard channel, taking into account the number of subscribers on the network, can be described as follows:

$$K_{ef} = \frac{m(L_{MPDU} - L_{s,MPDU} - L_{s,TCP/IP})}{2 - (1 - p)^{v_c} \sum_{i=1}^k \gamma_i \left((t_{RTS/CTS} + t_{sc}) V_{pl} + L_{RTS} + L_{CTS} + m L_{MPDU} + L_{ACK} \right)}, \quad (28)$$

where $t_{RTS/CTS}$ – time frame transmission in the RTS/CTS cycle; t_{sc} – time of scanning of time slot by a subscriber; γ_i – the probability of receiving a frame from k -th participant in the network.

4. ANALYSIS OF RESEARCH RESULTS

The reliability of the obtained models can be verified by mathematical modelling and compared with the results of experimental studies [16]–[18]. Starting conditions for modelling are selected based on the capabilities of the 802.11 standard. We can perform the mathematical modelling of the information model (8) taking into account expressions (9) and (11). The results are shown in Fig. 2.

Analysis of the results demonstrates that an increase in the effective rate of information transmission in the channel reduces the information efficiency of the channel, since the probability of frames with errors increases. Energy efficiency shows that when reducing errors in the channel, it is necessary to increase the power at the receiver input. The dependence of energy efficiency on the band of the frequency channel was found to be different from the information one.

Fig. 2. Channel efficiency: a – information; b – energy.

To analyse the efficiency model for the wireless channel of 802.11 standard, a high-performance mode with aggregation of frames was selected. The results of mathematical modelling are presented in Fig. 3. Frame aggregation is supported in the 802.11n standard and is mandatory for high-performance modes of 802.11ac standard.

Fig. 3. The ratio of channel efficiency: a – for frame aggregation; b – when receiving frames with errors.

Further, let us consider modelling the efficiency of the channel in the presence of other participants in the network. For this purpose, we will set the maximum loaded mode of the network, in which at the same time everyone is active and forms MSDU frames ($\gamma_i = 1$). From the practical point of view, on average, an access point can support 20–40 users. The results of this simulation are presented in Fig. 4.

Fig. 4. The dependence of the efficiency of the channel on the number of channels:
a – the signal strength at the receiver input;
b – the effective transmission speed.

The obtained results of the analysis coincide with the experimental research data. Namely, the signal strength level has insignificant changes from the number of participants existing simultaneously. The greater the number of active participants in the network, the lower the effectiveness of the physical frequency channel for a single subscriber. For example, the difference in the efficiency rate of information transmission is more than twice between one and two active participants in the network [16]–[19].

5. CONCLUSIONS

1. The information model of the wireless channel of the 802.11 standard has been obtained taking into account the complete packet and frame transmission cycle. The obtained model provides an opportunity to carry out an assessment of the transfer of useful information for both individual mode and a network of several active participants. This model, unlike the other existing models, takes into account the package construction and frame construction, the technology of aggregation of frames.
2. It has been established that channel efficiency is mostly affected by the presence of destabilizing factors in the channel, which lead to an increase in the number of service information and an increase in the transmission cycle due to the creation of reciprocal queries. It has been confirmed that at the level of signal strength, the number of simultaneously existing participants has little effect in contrast to the effective transmission speed where the impact has a directly proportional dependency.

REFERENCES

1. Barachi, M., Kara, N., Rabah, S., & Forgues, M. (2015). An Open Virtual Multi-Services Networking Architecture for the Future Internet. *Journal of Internet Services and Applications*, 6(3), 1–22.
2. Mykhalevskiy, D. (2017). Development of a Spatial Method for the Estimation of Signal Strength at the Input of the 802.11 Standard Receiver. *Easten-European Journal of Enterprise Technologies*, 4/9(88), 29–36.
3. Mussabayev, R.R., Kalimoldayev, M.N., Amirgaliyev, Y.N., Tairova, A.T., & Mussabayev, T.R. (2018). Calculation of 3D Coordinates of a Point on the Basis of a Stereoscopic System. *Open Engineering*, 8(1), 109–117.
4. Nesterenko, S.A., & Ivanova, L.V. (2011). An Analytical Model of the Pass-Through Channel of the Wireless IEEE 802.11 Network Segment. *Works of Odessa Polytechnic University*, 01(35), 146–150.
5. Nesterenko, S.A., & Nesterenko, Yu.S. (2015). Analysis of the Bandwidth of the Wireless Channel in the Accelerated Transmission Modes. *East European Magazine of Advanced Technology*, 3/9(75), 20–24.
6. Kim, H., Park, E.C., Lee, S.K., & Hu, C. (2011). Fast Performance Assessment of IEEE 802.11-based Wireless Networks. *Mathematical and Computer Modelling*, 53, 2173–2191.
7. Yarilovets, A.V., Nazaruk, V.D., & Zaitsev, S.V. (2014). An Evaluation of the Efficiency of Information Technology for Wireless Access Systems Built on the Basis of Optimal Orthogonal Multi-Frequency Signal Constructions. *Mathematical Machines and Systems*, 2, 51–58.
8. Amirgaliyev, B.Y., Kenshimov, C.A., Baibatyr, Z.Y., Kuatov, K.K., Kairanbay, M.Z., & Jantassov, A.K. (2015). Statistical Inference in ALPR System. In *9th International Conference on Application of Information and Communication Technologies, AICT 2015 – Proceedings* (pp. 310–313), 25 November 2015, Article number 7338569.
9. Kychak, V.M., & Tromsyuk, V.D. (2017). Assessment Method of Parameters and Characteristics of Bit Errors. *Journal of Automation and Information Sciences*, 49(5), 59–71.
10. Sharma, R., Singh, G., & Agnihotri, R. (2010). Comparison of Performance Analysis of 802.11a, 802.11b and 802.11g Standard. *International Journal on Computer Science and Engineering*, 02(06), 2042–2046.
11. Mykhalevskiy, D., Vasylykivskiy, N., & Horodetska, O. (2017). Development of a Mathematical Model for Estimating Signal Strength at the Input of the 802.11 Standard Receiver. *Easten-European Journal of Enterprise Technologies*, 4/9(88), 38–43.
12. Gorbaty, I.V. (2017). Research of Technical Efficiency of Telecommunication Systems and Networks Using Different Methods of Data Transmission with Feedback Manager. *Information and Control Systems on the Railway Transport*, 1, 18–23.
13. Prokis, D. (2000). *Digital communication*. Moscow: Radio i svyaz’.
14. Insam E. (2003). *TCP/IP embedded internet applications*. Oxford: Elsevier Ltd.
15. Perahia, E., & Stacey, R. (2013). *Next generation wireless LANs: 802.11n and 802.11ac*. Cambridge: Cambridge University Press.
16. Buyankin, V.M. (2018). Neuroidentification With Neuro-Self Tuning to Ensure the Operation of the Current Loop of the Electric Drive with the Desired Static and Dynamic Characteristics. *Periodico Tche Quimica*, 15(30), 513–520.

17. Mykhalevskiy, D.V. (2018). Construction of Mathematical Models for the Estimation of Signal Strength at the Input to the 802.11 Standard Receiver in a 5 GHz Band. *Easten-European Journal of Enterprise Technologies*, 6/9(96), 16–21.
18. Mykhalevskiy, D.V. (2019). Investigation of Wireless Channels of 802.11 Standard in the 5GHz Frequency Band. *Latvian Journal of Physics and Technical Sciences*, 1, 41–51.
19. Mykhalevskiy, D.V., & Horodetska, O.S. (2019). Investigation of Wireless Channels according to the Standard 802.11 in the Frequency Range of 5 GHz for Two Subscribers. *Journal of Mechanical Engineering Research & Developments*, 42(2), 50–57.

INFORMĀCIJAS MODEĻU ATTĪSTĪBA 802.11 STANDARTA BEZVADU KANĀLA PARAMETRU NOVĒRTĒJUMA EFEKTIVITĀTES PALIELINĀŠANAI

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K o p s a v i l k u m s

Pētījuma mērķis ir izstrādāt informācijas modeļus, lai uzlabotu bezvadu kanālu parametru novērtēšanas efektivitāti standartā 802.11. Standarta 802.11 bezvadu kanāla informācijas modeli raksturo iespēja novērtēt informācijas bloka pārsūtīšanas efektivitāti, ņemot vērā pilnu pakešu un kadru pārraides ciklu kadru kļūdu rašanās gadījumā. Turklāt modelis atspoguļo citu abonentu esamību tīklā un frekvences kanāla fizisko resursu izmantošanas konkurences mehānismu.

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