DOI 10.34185/1562-9945-1-138-2022-19
UDC 681.3.07

V.S. Khandetskyi, D.P. Sivtsov

EFFICIENCY OF FRAGMENTED FRAMES TRANSMISSION IN IEEE 802.11 COPMUTER NETWORKS

Abstract. In an analytical form, the dependence of the MAC efficiency of frames transmission on the coefficient of their fragmentation is obtained, taking into account retransmissions of damaged frames, the number of which changes in accordance with the noise level. When the noise intensity is high, the dependence of transmission efficiency on the fragmentation factor has the extreme character.

Key words: computer networks IEEE 802.11ac/ax, transmission efficiency, frame fragmentation, bit error rate.

Introduction. At the present time, there is an intensive development on fifth and sixth wireless networks generations (IEEE 802.11ac, IEEE 802.11ax) [1]. One of the priorities of these technologies is their use for the automation of production processes in mechanical engineering, metallurgy and a number of other industries. The need arises to safely and conveniently connect hundreds and thousands of electronic devices to corporate network in accordance with their operational and engineering requirements. Traditionally, these needs are met through problem-oriented technologies, but nowadays, corporative Wi-Fi is increasingly been chosen as the internal platform for such networks, due to its significant advantages in speed, scale and ease of management.

A common factor that reduces the efficiency of wireless networks is the increased noise level in the shops of industrial enterprises, due to the operation of technological equipment. In addition, the intensity of thermal noise, which increases with temperature, must also be taken into account [2].

The peak speed of a wireless network is determined by: the channels bandwidth, the density of subcarriers, the number of spatial streams, the amount of housekeeping data per transmitted symbol. Increasing the data transfer rate in the IEEE 802.11ac and IEEE 802.11ax networks to several Gbps necessitates the use of extended channels with a width of 160 MHz, which leads to an increase in the noise

ISSN 1562-9945 (Print)
ISSN 2707-7977 (Online)

power in the channel. Improving the coding, that is, moving from 256 QAM to 1024 QAM increases the data rate. However, being denser, subcarriers are more susceptible to mutual interference. Therefore, 1024 QAM technology provides speed improvements at a shorter distance from the access point and under normal conditions the signal to noise ratio decreases sufficiently fast as the coverage area with a single access point is expanded.

Thus, the use of modern high-speed technologies for wireless data transmission in industrial conditions requires the development of methods and means to increase the noise immunity of computer networks.

Problem statement. It is necessary to determine the possibility of increasing the efficiency of the transmission of fragmented frames in Wi-Fi networks with an infrastructure topology, taking into account the retransmissions of frames distorted by interference.

Main part. We will carry out our research within the framework of using the distributed coordination function (DSF) [3].

For an ideal data transmission channel, when there is no noise and in each cycle only one station transmits a frame, and the ACK receipt from the access point arrives without delay, the throughput S_{id} can be expressed as follows [4]:

$$S_{id} = \frac{L_{data}}{T_{DIFS} + T_{\overline{CW}} + T_{data} + T_{SIFS} + T_{ACK} + 2\delta}, \qquad (1)$$

where L_{data} is the data size of frame in bits ; $T_{\overline{CW}} = \sigma \cdot (CW_{\min} - 1)/2$, where σ is the idle slot duration; $CW_{\min}$ is the minimum (initial value) of the contention window; *SIFS* and *DIFS* are the interframes intervals; *ACK* is the acknowledgment frame; δ is the propagation delay.

It is known that an increase in the noise immunity of transmitted data with a significant noise level is achieved by reducing the size of the frame data field or by its fragmentation. In [5], we modified formula (1) to calculate the transmission efficiency Q of frames fragmented with a coefficient k :

$$Q = \frac{S}{R} = \frac{T_{data}}{T_{in} + k(T_{SIFS} + T_{ACK} + T_{MAChdr} + 2\delta) + T_{data}}, \qquad (2)$$

where $T_{in} = T_{DIFS} + T_{\overline{CW}} + T_{PHYhdr}$, T_{PHYhdr} and T_{MAChdr} are headers of PHY and MAC levels respectively; R is the physical rate.

For the parameters corresponding to the IEEE 802.11ac standard, we calculated the dependences $Q(R,k)$. The results show that the value of the efficiency Q decreases significantly with an increase in physical rate R. This is primarily due to the growth in the contribution of the total duration of the transmitted service information $T_{S\Sigma}$, which does not change with the physical rate increasing, while the transmission time of the actual data T_{data} decreases.

The study carried out in [5] does not take into account the probability of frames distortion and need of retransmission.

For a more objective evaluation of the process of frames transmitting with the possibility of their distortion, we propose, as a first approximation, instead the parameter Q to use the parameter U:

$$U = Q \cdot (1 - P_{fe}), \tag{3}$$

where P_{fe} is the probability of frame distortion during transmission.

$$P_{fe} = 1 - (1 - p_b)^L, \tag{4}$$

where p_b is the bit error rare (BER) for discrete-time memory less Gaussian channel [6], L is the frame data size.

Table 1 shows the values of $U(R,k)$ at BER=10^{-4} and L=12000 bit.

Table 1

Modified parameter of frames transmission efficiency

R, Mbps	*U*				
	k=1	*k*=2	*k*=3	*k*=4	*k*=5
54	0,133	0,200	0,207	0,198	0,187
100	0,091	0,131	0,131	0,124	0,115
200	0,054	0,074	0,074	0,068	0,062
300	0,038	0,052	0,051	0,047	0,043
400	0,029	0,040	0,039	0,036	0,030
600	0,020	0,028	0,027	0,024	0,022
800	0,016	0,021	0,020	0,019	0,017
1000	0,013	0,017	0,016	0,015	0,013
1200	0,011	0,014	0,013	0,013	0,011

Graphs of U versus k at different values of the physical transmission rate R are shown in Fig.1.

ISSN 1562-9945 (Print)
ISSN 2707-7977 (Online)

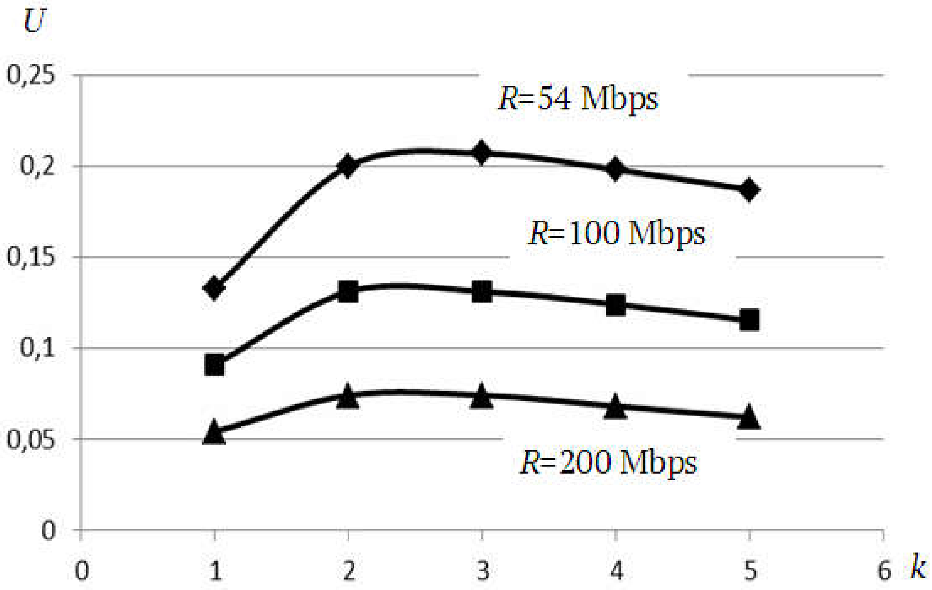

Figure 1 – Dependences of the modified efficiency parameter U on the frames fragmentation coefficient k at different values of the physical transmission rate R

At the next stage of research, we took into account the number of retransmissions of frames, distorted by interference during transmission. With this, we calculated the MAC efficiency of the network Q by the formula:

$$Q = \frac{T_{data}}{T_{\Sigma} + T_x}, \tag{5}$$

where the value of T_{Σ} denotes the denominator (2), and

$$T_x = m(T_{data} + T_{ACKtimeout}), \tag{6}$$

where m is the number of retransmissions, $T_{ACKtimeout}$ is the timeout value of waiting for acknowledgment of data frame successful reception. We took this timeout to be 120 µs.

Let us consider the procedure for determining the number of retransmissions in stages for a given BER level using an array of N_0 frames.

At the first stage (m =1), the average number of successfully transmitted frames will be:

$$N_{S1} = N_0(1 - P_{fe}). \tag{7}$$

At the second stage (m =2):

$$N_{S2} = (N_0 - N_{S1}) \cdot (1 - P_{fe}) = N_0 P_{fe}(1 - P_{fe}). \tag{8}$$

At the third stage (m =3):

$$N_{S3} = [N_0 - (N_{S1} + N_{S2})] \cdot (1 - P_{fe}) = N_0 P_{fe}^2 (1 - P_{fe}). \tag{9}$$

In general

$$N_{Sm} = N_0 P_{fe}^{(m-1)} (1 - P_{fe}) \,, \qquad (10)$$

where N_{Sm} is the number of successfully transmitted frames at the m-th stage of transmission.

The sum of frames successfully transmitted at m stages will be:

$$N_{\Sigma m} = N_{S1} + N_{S2} + N_{S3} + \ldots + N_{Sm} =$$

$$= N_0 (1 - P_{fe})[1 + P_{fe} + P_{fe}^2 + P_{fe}^3 + \ldots + P_{fe}^{(m-1)}] \,. \qquad (11)$$

The expression in square brackets is the sum of the terms of a decreasing geometric progression with the first term a_1=1 and the denominator $q = P_{fe}$. From here:

$$N_{\Sigma m} = N_0 (1 - P_{fe}^m) \,. \qquad (12)$$

The number of retransmission attempts m we can approximately calculate from the condition N_0-$N_{\Sigma m}$=0,01N_0. In this way:

$$m = -\frac{2}{\lg P_{fe}} \,. \qquad (13)$$

Substituting (13) into (5) and taking into account (6), we obtain:

$$Q = \frac{T_{data}}{T_{\Sigma} - \dfrac{2}{\lg P_{fe}} (T_{data} + T_{ACKtimeout})} \,. \qquad (14)$$

Figure 2 shows the graphs of dependences $Q(k)$ at different levels of BER. The physical data transfer rate is equal to R = 54 Mbps.

Comparing the plot in Fig.1 for R = 54 Mbps and the plot in Fig.2 for BER=10^{-4} and the same rate, we see that they are similar.

As follows from the Fig.2, a decrease in the noise intensity not only increases the efficiency of frame transmission Q, but also changes the character of the dependence $Q(k)$ from extreme to monotonically decreasing.

At the same time, the dependence at high noise intensity (BER=10^{-4}) is the greatest practical interest. As can be seen from the corresponding plot, here the maximum value of the transmission efficiency Q is observed when the fragmentation coefficient is k =3 for the standard size of the frame data field.

ISSN 1562-9945 (Print)
ISSN 2707-7977 (Online)

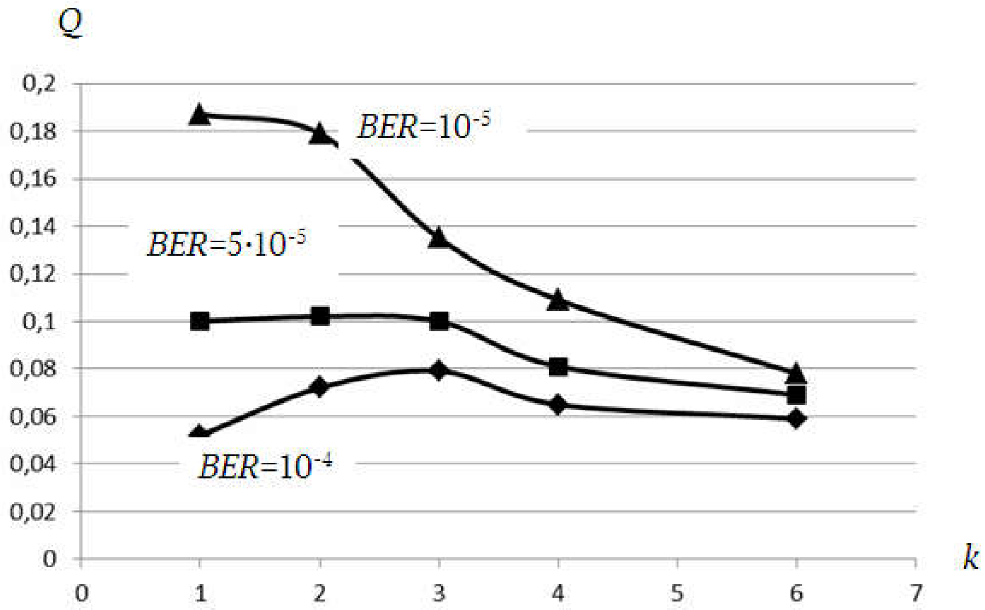

Figure 2 – Dependences of the MAC - efficiency of frames transmission Q on the coefficient of their fragmentation k at different noise level (BER)

Conclusions

1. In an analytical form, the dependence of the MAC-efficiency of frames transmission on the coefficient on their fragmentation is obtained, taking into account retransmissions of damaged frames, the number of which changes in accordance with the noise intensity.

2. At a high noise intensity, corresponding to the level of bit error rate $BER=10^{-4}$, the dependence of the transmission efficiency on the fragmentation factor has the extreme character. The maximum efficiency for a standard frame data field size corresponds to a fragmentation factor of 3.

REFERENCES

1. IEEE 802.11ax: The Sixth Generation of Wi-Fi, White Paper [Electronic resource]. – Access mode: https://www.cisco.com/c/en/us/products/collateral/wireless/white-paper-c11-740788.html.

2. Stallings W. Wireless Communications and Networking / W. Stallings. – Upper Saddle River (N. J.): Prentice Hall, 2003. – 638 p.

3. Kurose J. Computer Networking; A Top-Down Approach / J. Kurose, K. Ross. - 6th ed. – New Jersey: Pearson Education Inc., 2016. - 912 p.

4. Xiao Y. Performance analysis and enhancement for the current and future IEEE 802.11 MAC protocols / Y. Xiao, J. Rosdahl // ACM SIGMOBILE, Mobile Computing and Communications Review (MC2R), special issue on Wireless Home Networks. – Apr. 2003.- Vol.7, No.2.- P.6-19.

5. Khandetskyi V.S. Data transfer rate in noisy channels of wireless networks / V.S. Khandetskyi, D.P. Sivtsov, K.V. Panin // System Technologies. – 2021.- Vol.132, No.1.- P.136-144.

6. Cover T. Elements of Information Theory / T. Cover, J. Thomas. – John Wiley & Sons, 1991. – 328 p.

Received 27.01.2022.
Accepted 31.01.2022.

Ефективність передачі фрагментованих фреймів в комп'ютерних мережах IEEE 802.11

Одним з пріоритетів для Wi Fi мереж п'ятого і шостого поколінь (IEEE 802.11ac,ax) є їх використання для автоматизації технологічних процесів на виробництві. Виникає необхідність безпечного і зручного підключення сотен і тисяч електронних пристроїв до корпоративної мережі у відповідності з їх експлуатаційними та інженерними вимогами. Загальним фактором, який знижує ефективність роботи таких мереж є підвищений рі вень шуму в цехах виробничих підприємств внаслідок роботи технологічного устатку вання, що вимагає розробки засобів підвищення завадостійкості комп'ютерних мереж.

В статті досліджується можливість підвищення ефективності передачі даних за рахунок фрагментації фреймів з урахуванням повторних передач викривлених фреймів, кількість яких залежить від інтенсивності шуму. Доказано, що при збільшенні кількості бітових помилок даних, що передаються (BER), не тільки зменшується ефективність передачі фреймів, але й змінюється характер залежності ефективності від коефіцієнта фрагментації від монотонно спадного до екстремального. При цьому вирішальну роль тут відіграє змінення кількості повторних передач, яка виражена через імовірність ви кривлення фрейму даної довжини. Максимум ефективності для високоінтенсивного шуму (BER=10^{4}), при стандартній довжині поля даних фрейму відповідає коефіцієнту фрагме нтації що дорівнює 3.

Хандецький Володимир Сергійович – доктор технічних наук, професор, завідувач кафедри электронних обчислювальних машин Дніпровського національного університету імени Олеся Гончара.

Сівцов Дмитро Павлович – завідувач лабораторії комп'ютерної інженерії кафедри электронних обчислювальних машин Дніпровського національного університету імени Олеся Гончара.

Khandetskyi Volodymyr Sergievich – Doctor of Sciences, Professor, Head of Computer Systems Engineering Department of the Oles Honchar Dnipro National University.

Sivtsov Dmutro Pavlovich – Head of Computer Engineering Laboratory of Computer Systems Engineering Department of the Oles Honchar Dnipro National University.

ISSN 1562-9945 (Print)
ISSN 2707-7977 (Online)