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DATA TRANSFER RATE IN NOISY CHANNELS OF WIRELESS NETWORKS

Annotation. Analysis of new technologies IEEE 802.11ac/ax of wireless networks showed that increasing their noise immunity is an actual task. The article studies the efficiency of fragmented data frames transmission. Comparison of the efficiencies in the case of retransmission of the corrupted original frame and in the case of its fragmentation in a wide range of the physical data transfer rates is carried out.

Key words: wireless networks IEEE 802.11ac/ax, DCF mode, MAC efficiency, frame fragmentation, noise.

Introduction. Modern data transmission technologies in Wi-Fi networks: IEEE 802.11n, 802.11ac, 802.11ax are currently being intensively developed. Corresponding protocols regulate a number of means for increasing the main indicator of these networks – data transfer rate. The most significant of them are the following.

First, it is the expansion of the channel bandwidth. Instead of channels with a bandwidth $\Delta f = 20$ MHz, which were used in 802.11a/g technologies, channels with $\Delta f = 40$ MHz (802.11n), $\Delta f = 80$ MHz and $\Delta f = 160$ MHz (802.11ac, 802.11ax) are used.

Secondly, it is the decrease in the inter-symbol spacing. In technologies 802.11a/g, for reliable symbol recognition, an inter-symbol interval $\Delta\tau = 800$ ns is used. In 802.11n technology, this interval is reduced to $\Delta\tau = 400$ ns, in 802.11ac/ax even more.

Thirdly, this is the use of the number of antennas (up to 8) for transmitting and receiving data and implementation of transmission using several parallel spatial streams (MU-MIMO technology).

All this, as well as the application of the method of multiple access with orthogonal frequency division of the signal (OFDM/OFDMA), which provides coding the information on several subcarriers frequencies, allows to increase the physical data rate in the channel to approximately 7 Gbps for 802.11ac and 14 Gbps for 802.11ax.

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Let’s consider how the above tools affect the noise immunity of IEEE 802.11 wireless networks.

As noted by US Federal Communications Commission (FCC), an urgent problem for technologies using channels with a width $\Delta f = 160$ MHz, operating in the range with a central frequency $f = 5$GHz, is “clearing the frequency range”. The effect of noise increases as the channel bandwidth expands.

Reducing the inter-symbol interval $\Delta\tau$ in 802.11n technology from 800 to 400 ns allows to increase the transmission rate for channels with a width $\Delta f = 80$ MHz from 135 Mbps to only 150 Mbps. That is, inter-symbol spacing was reduces by 2 times, and the rate increased by only 11%. This is due to the presence of a certain time interval in the physical distribution of the intensity of each symbol. When $\Delta\tau$ decreases, additional signal processing is used to correct the possible intersection of the neighboring symbols intensity distribution intervals in order to improve the recognition of symbols.

Reducing the inter-symbol intervals lowers the noise immunity of the transmitted data.

In the presence of a significant number of obstacles in the signal propagation area, reflected waves enter the receiver antenna. Multiple reflected signal loses its initial energy and arrives with a certain delay. This raises the problem of multipath signal propagation – one of the most significant problems in wireless communication systems.

To struggle the negative influence of multipath propagation, several antennas are used on the sender side and on the receiver side of the channel (MIMO scheme). This also allowed the formation of several parallel spatial data streams. In 802.11ac technology, which uses 8 antennas in the router, a directional signal formation mode (Beamforming) has been created. This mode is used, for example, between two routers in the backbone of the wireless network.

At the same time, the concentration of several spatial streams in one region of the channel, even despite, for example, different polarization of signals transmitted in each stream, leads to an increase in the mutual influence of signals. This effect is further enhanced with an increase in the intensity of external noise, blurring the distinctive features of signals of different streams.

Enhancements of coding when moving to 256QAM in 802.11ac and moving to 1024QAM in 802.11ax increases the peak data rate by increasing the number of data subcarriers. However, being closer to each other adjacent subcarriers frequencies are more sensitive to noise and mutual interference [1].

A very important characteristic of digital communication systems is Signal to Noise Ratio (SNR) [2]. SNR is defined as the ratio of signal energy per bit to noise power density per Hertz (E_b/N_0). For thermal noise

$$SNR = \frac{E_b}{N_0} = \frac{W}{kT \bullet R}, \tag{1}$$

where W is the signal power, k is the Boltzmann constant, T is the absolute temperature, and R is the data transfer rate in bits per second. The E_b/N_0 ratio is of great practical importance, since bit error rate (BER) is a decreasing function of this ratio. With a constant signal power and temperature, an increase in data transfer rate increases the BER value.

Problem statement. Investigate the possibility of improving the efficiency of wireless networks at the MAC level in conditions of increased noise intensity.

Main part. At the MAC layer, the basic scheme of wireless local area networks (WLANs) is distributed coordination function (DCF), which is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism [3,4]. In the case of collisions and noisy channel errors, the access point (AP) in infrastructure topology of WLAN can't decode any frames and do not send back ACKs. The sender (STA) waits for a potential acknowledgment (ACK) until the end of corresponding timeout.

In the ideal case, the channel is regarded as perfect, i.e. neither errors in channel not collisions occur, and in any transmission cycle, there is only one active STA which always has frames to transmit. The AP only responds with ACKs, and the other STAs just sense the channel and wait.

Then the ideal throughput $S_{DCF(id)}$ can be defined as (1) [5]:

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

where L_{data} is the MAC layer frame size in bits; $T_{\overline{CW}} = \sigma \cdot (CW_{\min} - 1)/2$, where σ stands for 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's frame; δ is the propagation delay.

Using (2) in [6] for IEEE 802.11n calculated the MAC efficiency while the physical (PHY) rate is increased from 54 to 432 Mbps. In this work MAC efficiency Q represents the ideal throughput normalized to the PHY rate R.

In this work we assume that all stations generate traffic of the same priority with the same payload size, and hence, they have the same probability of winning the channel contention. –

Our network uses one AP and all stations work in saturated mode, i.e. data frames are always available in their transmission buffers. We also assume that the lifetime of each data frame is infinite, so that a data frame is repeatedly retransmitted until its delivery is successful.

The network performance is affected by two different aspects [7]:

- at first, the probability of having a successful channel access grant;
- at second, the channel's utilization efficiency.

The first aspect, which represents the probability that a single station wins a channel contention, depends on the number of competing stations and the value of frame error rate (FER). The second aspect, which represents the overheads that are required for data delivery, is a function of access mode (i.e. basic or RTS/CTS), acknowledge policy (i.e. immediate or block ACK), block size and FER.

In this work we use basic access mode (DCF), immediate ACK and one frame in block. The effect of number of stations competing for access to the channel on the network throughput is also outside the scope of this article. The next work will be devoted to the study of the join influence of interference and collisions on the data transfer rate.

We use the discrete-time memory-less Gaussian channel. In such a channel, the bit errors independently and identically distributed over a frame [8]. Let L and p_b denote the frame size and the bit error rate (BER) respectively, and p_e denote the frame error rate (FER), then p_e is defined as:

$$p_e = 1 - (1-p_b)^L \tag{3}$$

The results of calculating the p_e value are shown in Table 1.

Table 1

Dependence of frame error rate p_e on BER and the frame fragmentation coefficient k

p_b (BER)	p_e (FER)				
	k=1	k=2	k=3	k=4	k=5
10^{-5}	0,11	0,06	0,04	0,03	0,02
$5\cdot10^{-5}$	0,45	0,26	0,18	0,14	0,11
10^{-4}	0,70	0,45	0,33	0,26	0,21

As follows from Table 1, delivery of a frame of length L = 1500 bytes (k = 1) becomes problematic even at BER = $5\cdot10^{-5}$, and at BER = 10^{-4} the frame error probability reaches $p_e = 0{,}7$. This probability decreases significantly when the frame is fragmented. At the same time, fragmentation reduces the network throughput S due to an increase in overhead when transferring the same amount of data L_{data}.

Let's take a closer look at this process. In the basic DCF scheme, only first fragment in a transmitted frame contends for a channel access, the other fragments are transmitted after deferring a SIFS interval. But after each fragment, an ACK is sent back by the access point (AP).

We define the transmission efficiency Q of fragmented frames in the form:

$$Q = \frac{S}{R} = \frac{T_{data}}{T_{in} + k(T_{SIFS} + T_{ACK} + T_{MAChdr} + 2\delta) + T_{data}}, \qquad (4)$$

where $T_{in} = T_{DIFS} + T_{\overline{CW}} + T_{PHYhdr}$, T_{PHYhdr} and T_{MAChdr} are headers of PHY and MAC levels respectively; k – coefficient of fragmentation.

Development of (4) was made taking into account the materials [5, 9]. When calculating by formula (4) we used the parameters corresponding to the IEEE 802.11ac protocol, collected in Table I of work [10]. In particular: T_{DIFS} = 34 µs, T_{SIFS} = 16 µs, $W_{\min}$ = 15, σ = 9 µs, T_{PHYhdr} = 68,8 µs, L_{MAChdr} = 272bit, $T_{MAChdr} = L_{MAChdr}/R$, $T_{ACK} = T_{PHYhdr} + L_{ACK}/6$ Mbps = 87,5 µs (RTS, CTS and ACK rates is 6 Mbps for 802.11ac), δ = 0,33 µs (the distance between the sender and the receiver was assumed to be100 m), L_{data} = 1500 byte (12000 bit), $T_{data} = L_{data}/R$. The calculation results are given in Table 2 and are shown in Fig.1.

Table 2

MAC efficiency Q of network with varying degrees of data frame fragmentation k

R, Mbps	Q				
	k=1	k=2	k=3	k=4	k=5
54	0,443	0,364	0,309	0,268	0,237
100	0,304	0,238	0,196	0,167	0,145
200	0,179	0,136	0,110	0,092	0,079
300	0,127	0.095	0,076	0,063	0,054
400	0,098	0,073	0,058	0,048	0,041
600	0,068	0,050	0,040	0,033	0,028
800	0,052	0,038	0,030	0,025	0,021
1000	0,042	0,031	0,024	0,020	0,017
1200	0,035	0,026	0,020	0,017	0,014

As follows from the Fig.1, with an increase in the physical rate *R*, the efficiency of the network decreases due to a relative increase in the overhead for data transmission with a decreasing value of T_{data}. For the same reason, due to an increase in the number of headers of transmitted fragments and the number of service frames ACK efficiency decreases with an increase in the fragmentation coefficient *k*.

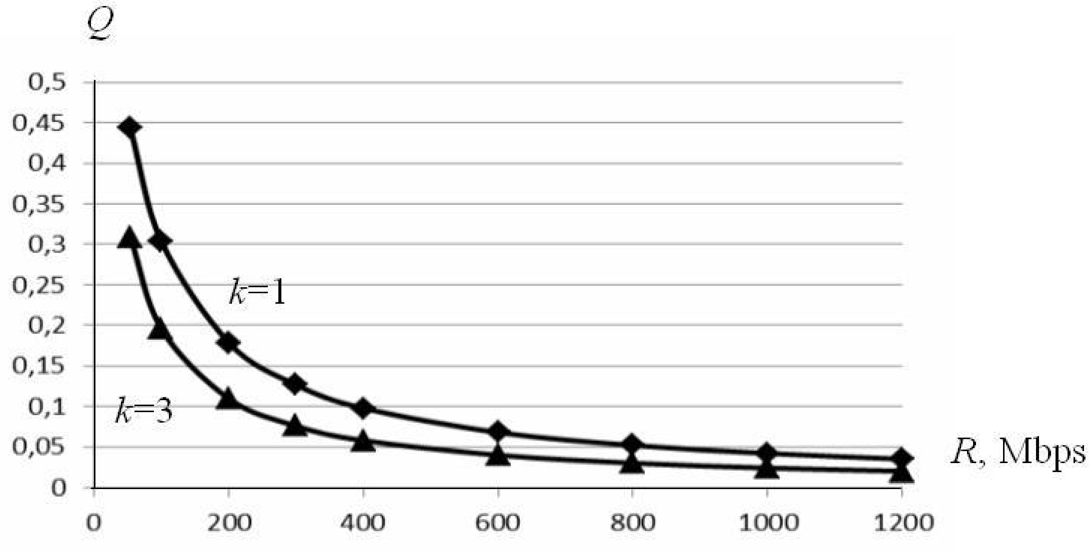

Figure 1 – Dependencies of MAC efficiency *Q* on the physical data rate *R* for different values of the fragmentation coefficient *k*

However, you should pay attention to Tabl.1. At p_b (BER) = 10^{-4}, dividing the original frame with L_{data} = 12000 bit into three fragments reduces the probability of the frame distortion from p_e = 0,7 to p_e = 0,33.

It is very likely that when p_e = 0,7 the original frame will be damaged and it will need to be retransmitted after the ACK timeout. We took this timeout to be 120 μs. The corresponding plot for *k* = 1 is shown in Fig.2. Here, for comparison, we left the plot for *k* = 3.

The curves in Fig.2 show that the efficiency *Q* in the range of low rates *R* for the corrupted and retransmitted frame with *k* = 1 becomes lower than for the same frame with *k* = 3. Table 3 shows the values of deviation Δ*Q* for various data rates *R*:

$\Delta Q_{12} = Q(k = 1) - Q(k = 2), \Delta Q_{13} = Q(k = 1) - Q(k = 3), \Delta Q_{14} = Q(k = 1) - Q(k = 4)$

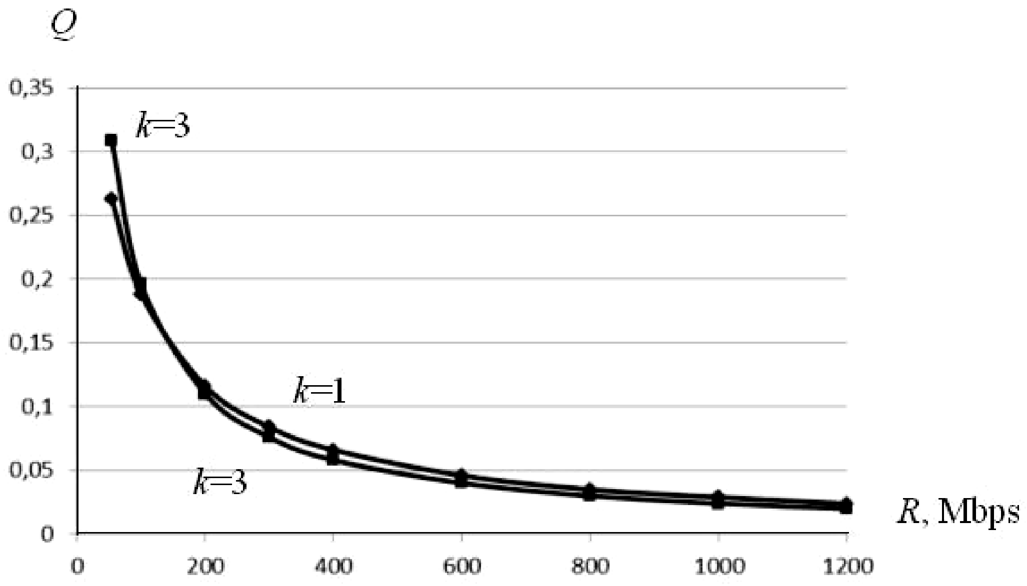

Figure 2 – Effect of retransmission of the corrupted frame with k = 1

Table 3

Deviations ΔQ for different values of the fragmentation coefficient k

ΔQ	R, Mbps								
	54	100	200	300	400	600	800	1000	1200
ΔQ_{12}	-0,101	-0,05	-0,02	-0,011	-0,007	-0,004	-0,003	-0,002	-0,002
ΔQ_{13}	-0,046	-0,008	0,006	0,008	0,008	0,006	0,005	0,005	0,004
ΔQ_{14}	-0,005	0,021	0,024	0,021	0,018	0,013	0,010	0,009	0,007

As follows from the above data, the retransmission of the original frame leads to a significant decrease in the efficiency Q. For the fragmentation variant with k = 3, the efficiencies become comparable. At the same time, it should be noted that retransmission original frame will reduce the probability of damage to a pair of frames for p_b(BER) = 10^{-4} to 0,49, while its fragmentation with k = 2 will reduce the probability of separate frame damage to 0,45, and with k = 3 – to 0,33.

Conclusions

1. Analysis of new technologies IEEE 802.11ac/ax of wireless networks showed that the measures taken to increase the speed of the networks do not contribute to increasing their noise immunity. Reducing the effect of noise on operation of Wi-Fi 5th and 6th generations networks remains an actual task.

2. Fragmentation of the original frame increases the probability of data transfer, but at the same time reduces the efficiency of the network due to increased overhead. The article studies the efficiency of transmission of fragmented data

frames. Comparison of the efficiencies in the case of retransmission of the corrupted original frame and its fragmentation in a wide range of physical data rates is carried out. It is shown that if the probability of corruption is more than 0.5, it is expedient to divide the frame into 2-4 paths in the case of using ACK for each fragment.

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Швидкість передачі даних в зашумлених каналах бездротових мереж

Аналіз нових технологій IEEE 802.11ac/ax бездротових мереж показав, що засоби, які застосовуються для підвищення швидкості передачі даних в мережах, не сприяють підвищенню їх завадостійкості. Зменшення впливу шуму на роботу Wi-Fi мереж п'ятого і шостого поколінь залишається актуальною задачею.

В статті досліджується ефективність передачі фрагментованих фреймів даних в зашумлених каналах. Фрагментація фрейму підвищує імовірність передачі даних, проте знижує ефективність роботи бездротової мережі внаслідок збільшення накладних расхо-

дів на передачу заданого об'єму даних. Проведене порівняння ефективностей у випадку повторної передачі первинного викривленого фрейму і у випадку його фрагментації з різними коефіцієнтами в широкому діапазоні фізичних швидкостей передачі 54 – 1200 Мбіт/с. Показано, що при рівні шуму, який відповідає BER = 10^{-4}, доцільно розділяти фрейм з довжиною поля даних (12-16)·10^3 біт на 2 – 4 частини у випадку використання підтвердження АСК після кожного фрагменту.

Data transfer rate in noisy channels of wireless networks

Analysis of new technologies IEEE 802.11ac/ax wireless networks showed that increasing their noise immunity is an actual task. The paper discusses the transmission efficiency of fragmented data frames. The transmission efficiency of a damaged frame is compared in the case of its retransmission and in the case of its fragmentation in a wide range of physical data transmission rates.

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