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OPTIMIZING THE ACTION OF IEEE 802.11 COMPUTER NETWORKS AT SIGNIFICANT LEVELS OF BIT ERROR RATE

Abstract. For a given level of noise, fragmentation of the frame's data field increases the probability of transmitting each individual fragment. But this is accompanied by an increase in the relative weight of overhead costs, i.e. the amount of service information that is necessary to support the frame transfer process. We propose to determine the fragmentation optimum under condition of increased noise intensity by the maximum value of the product of fragmented frame successful transmission probability by the relative weight of overhead costs. The article presents detailed results of calculations of the optimality criterion dependence on the fragmentation coefficient at different levels of noise, which allow optimizing the process of fragmentation of the transmitted frames.
Key words: computer networks IEEE 802.11, transmission, frame fragmentation, noise, bit error rate BER.

Introduction. At present time the use of wireless computer networks of the IEEE 802.11 standard is intensively expanding, including in industrial production automation systems, where they are located directly in the workshops of enterprises.

The wireless communication capability allows the devices stay connected even they are mobile. The list of these devices includes notebook and palmtop computers, personal digital assistants, digital cameras, smartphones from different manufactures. We will unite all these devices under one name – station operating in a network with infrastructure topology.

At the same time, network developers are faced with the need to ensure their operability, sufficient throughput in conditions of high intensity of industrial noise and, as a result, a high bit error rate (BER) in transmission channels from stations to the access point of the network. The problem in general is the inability of wireless network to cope with the complexities of the wireless channel due to noise, fading, mutual channels interference, and collisions. Nodes cannot separate distorted interference or noise frames from collisions because the symptoms are the same, namely a frame loss.

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Problem statement. It is necessary to determine the criterion and conditions for optimizing the volume of transmitted data in computer networks IEEE 802.11 at high noise levels.

Main part. In most cases, noise influence can be described with sufficient reliability for practical applications by using a time-discrete Gaussian channel without memory. In such a channel, the bit errors are independent and equally distributed over the bits of the frame's data field [1]. Under conditions of high intensity of external noise, the probability of successfully transmitting a frame from station to access point P_S can be expressed as follows:

$$P_S = P_C(1 - p_b)^L, \quad (1)$$

where P_C is the probability of successful frame transmission, which is determined by the intensity of collisions due to the use of competitive access from stations to the channel during transmission, which is based on the application of a distributed coordinate function DCF and algorithm CSMA/CA [2]; p_b is the probability of an error in the data bit; L is the length of the frame's data field in bits.

In its most basic form, the DCF consists of a carrier sensing function and a random backoff protocol. Carrier sensing allows stations to understand when the channel is busy, and to postpone transmission attempts until the channel will be free. Once the channel becomes free, if two or more stations have a frame to send, the probability exists that their transmissions will collide. To avoid collisions, station will backoff their attempts for a random number of slot times selected from a contention window. If competing stations select different random numbers, one station will access the channel first and will begin transmission, and the other stations will wait. If two or more competing stations select the same transmission time, their transmissions will collide. They will temporarily increase their contention window size and try again and reset their contention window upon eventual successful transmission.

An influence analysis of the number of simultaneously operating stations on the intensity of collisions and, accordingly, on the value of P_C was carried out by us earlier [3], and we will not dwell on this here. Without losing the generality of the subsequent analysis, we take P_C=1. Then $P_S = (1 - p_b)^L$.

As can be seen from this expression, reducing the length of the frame's data field L increases the probability P_S of successful transmission (Table 1).

At the same time, due to the independence of the transmitted frame's fragments

$$\prod_{i=1}^{k}(1-p_b)^{\frac{L}{k_i}}=(1-p_b)^L\ ,\qquad(2)$$

at $k_1= k_2=...= k_k= k$, that is, fragmentation does not change the probability of transmitting the entire initial date array of the frame with length L.

But the advantage here is in following.

For example, in accordance with Table 1 a frame with k=1 and, accordingly L=12000 bits, when BER=10^{-4} has a probability of successful transmission P_S=0,3. The transmission of such frame will be accompanied by a considerable quantity of retransmissions, which will lead to a significant reduction in the transmission throughput and network congestion with service traffic. As can be seen from the table, fragmentation significantly increases P_S, and, accordingly, reduces the probability of fragments retransmission.

Table 1 details the results for high noise levels (BER=$5\cdot10^{-5}$-$5\cdot10^{-4}$). It can be seen that almost zero probabilities of successful frame transmission P_S for k=1 in the range BER= $2\cdot10^{-4}$-$5\cdot10^{-4}$ for k=10 and k=12 already correspond to the practical possibility of transmission.

Along with this positive phenomenon, an increase in the value of k is accomplished by an increase in the relative weight of overhead costs, i.e. the amount of service information that is necessary to support the data transfer process. In accordance with [3] the ratio of the time intervals required for the transmission of frame's data and for the transmission of the corresponding service information can be expressed as

$$\eta=\frac{T_{data}}{T_{serv}}=\frac{T_{data}}{T_{in}+k(T_{SIFS}+T_{ACK}+T_{MAChdr}+2\delta)}\ ,\qquad(3)$$

where $T_{data}=L/R$, R is the physical data transmission (PHY) rate; $T_{in}=T_{DIFS}+T_{CW}+T_{PHYhdr}$, T_{PHYhdr} and T_{MAChdr} are the transmission durations of the physical (PHY) and data link MAC layer headers, respectively; $T_{CW}=\sigma\cdot(CW_{min}-1)/2$, where σ stands for the idle slot duration; CW_{min} is the minimum (initial value) of the contention window; SIFS and DIFS are the interframe spacing; ACK is the acknowledgment's frame duration; δ is the propagation delay.

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Table 1

Dependence of the probability P_S on the fragmentation factor k at different noise level

BER	P_S							
	k=1	k=2	k=3	k=4	k=6	k=8	k=10	k=12
10^{-6}	0,988	0,994	0,996	0,997	0,998	0,9985	0,999	0,999
10^{-5}	0,887	0,942	0,961	0,970	0,980	0,985	0,988	0,99
$5\cdot10^{-5}$	0,549	0,741	0,819	0,861	0,905	0,928	0,942	0,951
$7\cdot10^{-5}$	0,432	0,657	0,756	0,811	0,869	0,900	0,919	0,932
$8\cdot10^{-5}$	0,383	0,619	0,726	0,787	0,852	0,887	0,908	0,923
$9\cdot10^{-5}$	0,340	0,583	0,698	0,763	0,835	0,874	0,898	0,914
10^{-4}	0,301	0,549	0,670	0,741	0,819	0,861	0,887	0,905
$1{,}3\cdot10^{-4}$	0,210	0,458	0,595	0,677	0,771	0,823	0,856	0,878
$1{,}5\cdot10^{-4}$	0,165	0,407	0,549	0,638	0,741	0,799	0,835	0,861
$2\cdot10^{-4}$	0,0907	0,301	0,449	0,549	0,670	0,741	0,787	0,819
$3\cdot10^{-4}$	0,0273	0,165	0,301	0,407	0,549	0,638	0,698	0,741
$4\cdot10^{-4}$	0,0082	0,091	0,202	0,301	0,449	0,549	0,619	0,67
$5\cdot10^{-4}$	0,0025	0,050	0,135	0,223	0,368	0,472	0,549	0,606

In the calculations according to the formula (3), the following values of the parameters were taken [4]: T_{DIFS}=34 µs, T_{SIFS}=16 µs, CW_{min}=15, σ=9 µs, T_{PHYhdr}=68,8 µs; L_{MAChdr}=272 bits, T_{MAChdr}= L_{MAChdr}/R, R=54 Mbps; T_{ACK}= T_{PHYhdr}+L_{ACK}/6Mbps = 87,5 µs (for RTS, CTS and ACK the rate is 6 Mbps according to IEEE 802.11ac); δ=0,33 µs (the distance between the sender station and the access point is assumed to be 100 m); T_{data}=L_{data}/R, L_{data}=12000 bits; k is the fragmentation factor.

The performed calculations show that for k=1 η=0,808, k=2 η=0,578, k=3 η=0,450, k=6 η=0,271, k=8 η=0,214, k=10 η=0,177, k=12 η=0,151.

Thus, it can be seen that with an increase in the fragmentation factor k, the relative part of the time for transmission of service information T_{serv} increases significantlye propose to determine the fragmentation optimum under condition of increased noise intensity by the maximum value of the $\lambda=P_S\cdot\eta$ criterion.

The results of calculations of this criterion for same BER values as in Table 1 are shown in Table 2.

Table 2

Values of the optimality criterion λ

BER	$\lambda = P_S \cdot \eta$							
	k=1	k=2	k=3	k=4	k=6	k=8	k=10	k=12
10^{-6}	0,798	0,575	0,448	0,368	0,270	0,214	0,177	0,151
10^{-5}	0,717	0,544	0,432	0,358	0,266	0,211	0,175	0,149
$5 \cdot 10^{-5}$	0,444	0,428	0,369	0,318	0,245	0,199	0,167	0,144
$7 \cdot 10^{-5}$	0,349	0,380	0,340	0,299	0,235	0,193	0,163	0,141
$8 \cdot 10^{-5}$	0,309	0,358	0,327	0,290	0,231	0,190	0,161	0,139
$9 \cdot 10^{-5}$	0,275	0,337	0,314	0,282	0,226	0,187	0,159	0,138
10^{-4}	0,243	0,317	0,302	0,273	0,222	0,184	0,157	0,137
$1{,}3 \cdot 10^{-4}$	0,170	0,265	0,268	0,250	0,209	0,176	0,152	0,133
$1{,}5 \cdot 10^{-4}$	0,133	0,235	0,247	0,235	0,200	0,171	0,148	0,130
$2 \cdot 10^{-4}$	0,073	0,174	0,202	0,203	0,182	0,159	0,139	0,124
$3 \cdot 10^{-4}$	0,0221	0,0954	0,135	0,150	0,149	0,137	0,124	0,112
$4 \cdot 10^{-4}$	0,0066	0,0526	0,091	0,111	0,122	0,117	0,110	0,101
$5 \cdot 10^{-4}$	0,0020	0,0289	0,061	0,082	0,0997	0,101	0,097	0,092

Here you should pay attention to the following. Dependencies $\lambda(k)$ at a relatively low noise level (BER=10^{-6}-$5 \cdot 10^{-5}$) are monotonic, the value of λ smoothly decreases with increasing k. However, with increasing noise level (BER=$7 \cdot 10^{-5}$-$5 \cdot 10^{-4}$) they become extreme with pronounced maximum. Moreover, with an increase in BER, the abscissa of the maximum shifts towards higher values of k.

Figures 1 and 2 show plots of $P_S(k)$ for several values of noise intensity and plots of $\lambda(k)$ for the same values of BER.

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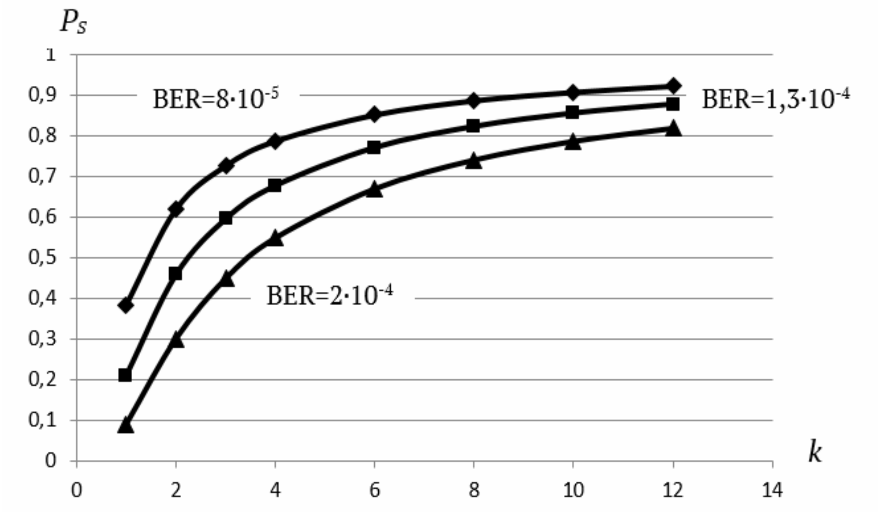

Figure 1 – Dependences of the probability of successful frame transmission P_S on the data field fragmentation coefficient *k* at various values of the noise intensity (BER)

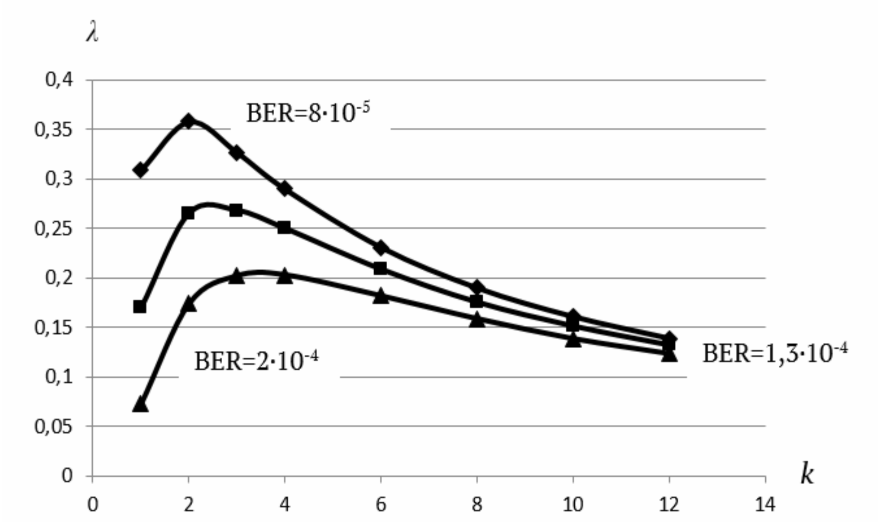

Figure 2 – Dependences of the optimality criterion *λ* on the data field fragmentation coefficient *k* at various values of the noise intensity (BER)

From the graphs, presented in Fig.2 it can be seen that with an increase in *k* the maxima of the *λ*(*k*) dependences expand and shift to the region of higher values of *k*. To the point, it should be noted that, as a matter of fact, the sign of extremity of the dependences *λ*(*k*) begins to appear at an increased noise level, in accordance with Table 2 after the values of BER=$5{\cdot}10^{-5}$.

Conclusions

1. The integral probability of successful frame transmission from a workstation to an access point in a network with infrastructure topology under conditions of increased interference intensity is propose to be determined by the product of two com-

ponents. The first component is determined by the intensity of collisions due to the use of competitive access from stations to the channel during transmission. The second component is determined by the probability of distortion of each data bit of transmitted frame by external noise (BER). The first component was studied by us earlier, therefore, in this paper attention is paid to the second component of integral probability.

2. For a given level of interference, fragmentation of the frame's data field increases the probability of transmitting each individual fragment. Along with this positive phenomenon, fragmentation is accompanied by an increase in the relative weight of overhead costs, i.e. the amount of service information that is necessary to support the data transfer process.

3. We propose to determine the fragmentation optimum under condition of increased noise intensity by the maximum value of the product of fragmented frame transmission probability by the relative weight of overhead costs.

4. The article presents detailed results of calculations of the optimality criterion dependence on the fragmentation coefficient at different levels of BER, which allow optimizing the process of fragmentation of the transmitted frames data field.

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Оптимізація роботи комп'ютерних мереж IEEE 802.11 при значних рівнях бітових помилок

Інтегральну імовірність успішної передачі фрейму від робочої станції до точки доступу в мережах з інфраструктурною топологією в умовах підвищеної інтенсивності завад запропоновано визначати у вигляді добутку двох компонент. Перша компонента виначається інтенсивністю колізій, що виникають внаслідок конкурентного доступу станцій до каналу при передачі. Друга компонента визначається імовірністю викривлення кожного біту даних фрейму зовнішніми завадами. Перша компонента була досліджена нами раніше, тому в цій статті увага приділена другій компоненті інтегральної імовірності.

Для заданого рівня шуму фрагментація поля даних фрейму збільшує імовірність передачі кожного окремого фрагменту. Але це супроводжується збільшенням відносної ваги накладних втрат, тобто кількості службової інформації, необхідної для підтримки процесу передачі фрейму. Ми пропонуємо визначати оптимум фрагментації в умовах підвищеної інтенсивності шуму по максимуму добутку імовірності успішної передачі фрагментованого фрейму на відносну вагу накладних втрат. В статті представлені деталізовані результати розрахунків залежності критерія оптимальності від коефіцієнту фрагментації при різних рівнях шуму, які дозволяють оптимізувати процес фрагментації поля даних передаваємих фреймів.

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