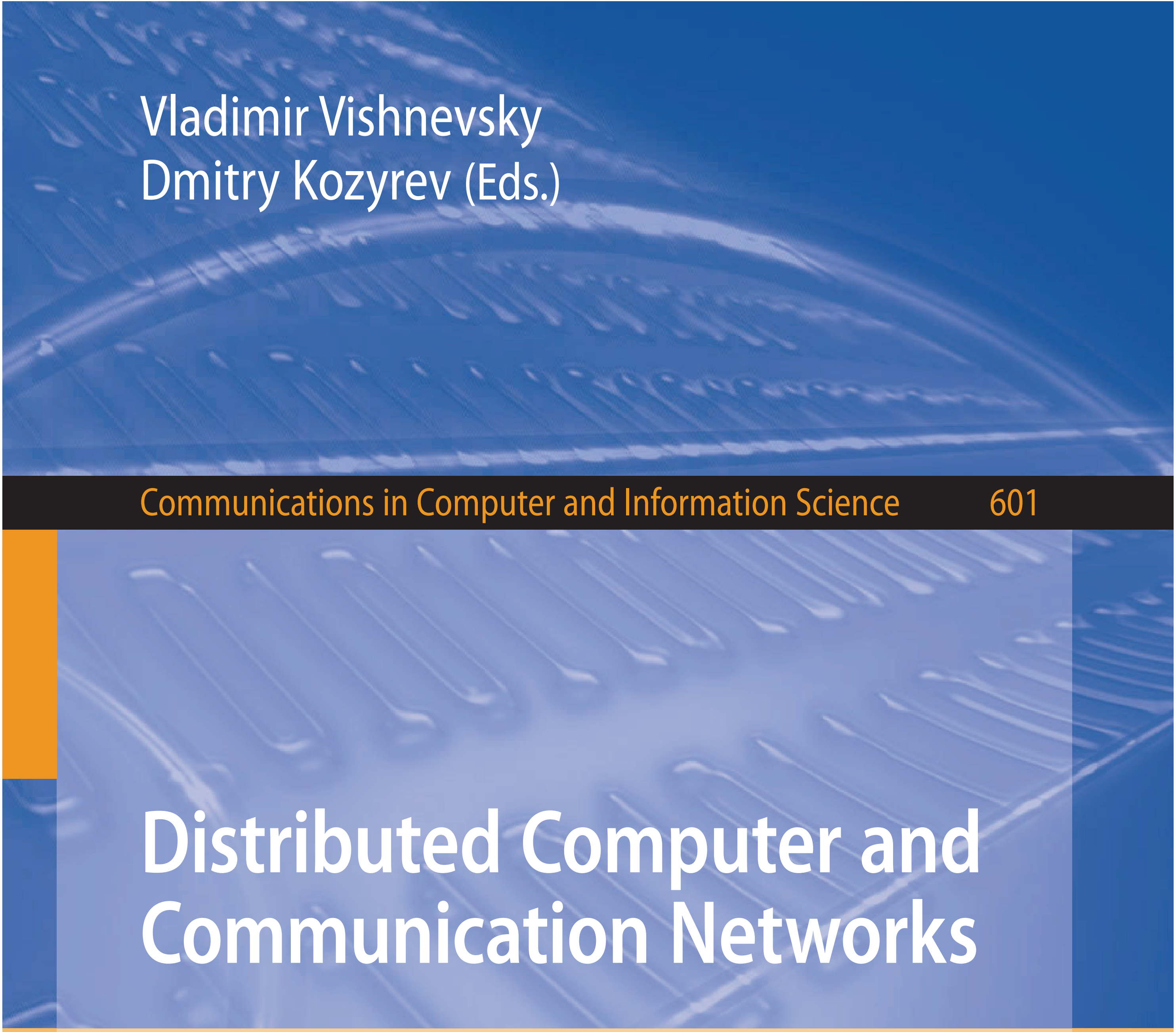

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Communications in Computer and Information Science 601

Distributed Computer and Communication Networks

18th International Conference, DCCN 2015
Moscow, Russia, October 19–22, 2015
Revised Selected Papers

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Preface

This volume contains a collection of revised selected full-text papers presented at the 18th International Conference on Distributed Computer and Communication Networks (DCCN-2015), held in Moscow, Russia, October 19–22, 2015.

The conference is a continuation of traditional international conferences of the DCCN series, which took place in Bulgaria (Sofia, 1995, 2005, 2006, 2008, 2009, 2014), Israel (Tel Aviv, 1996, 1997, 1999, 2001), and Russia (Moscow, 1998, 2000, 2003, 2007, 2010, 2011, 2013) in the last 18 years. The main idea of the conference is to provide a platform and forum for researchers and developers from academia and industry from various countries working in the area of theory and applications of distributed computer and communication networks, to exchange their expertise, and to discuss the perspectives of development and collaboration in this area. The content of this volume is related to the following subjects:

1. Computer and communication networks architecture optimization
2. Control in computer and communication networks
3. Performance and QoS evaluation in wireless networks
4. Modeling and simulation of network protocols
5. Queueing and reliability theory
6. Wireless IEEE 802.11, IEEE 802.15, IEEE 802.16, and UMTS (LTE) networks
7. FRID technology and its application in intellectual transportation networks
8. Protocols design (MAC, Routing) for centimeter and millimeter wave mesh networks
9. Internet and Web applications and services
10. Application integration in distributed information systems
11. Big data in communication networks

The DCCN 2015 conference received 126 submissions from 164 authors in 16 different countries. From these, 94 submissions were accepted and presented at the conference, 38 of which were recommended by session chairs and selected by the Program Committee for the proceedings, yielding an overall acceptance rate of 40 %.

All the papers selected for the proceedings are given in the form presented by the authors. These papers are of interest to everyone working in the field of computer and communication networks.

We thank all the authors for their interest in DCCN, the members of the Program Committee for their contributions, and the reviewers for their peer-reviewing efforts.

February 2016 Vladimir Vishnevsky

Organization

DCCN 2015 was organized by the Russian Academy of Sciences (RAS), V.A. Trapeznikov Institute of Control Sciences of RAS, the Research and Development Company Information and Networking Technologies, and the Institute of Information and Communication Technologies (Bulgarian Academy of Sciences).

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On Initial Width of Contention Window Influence on Wireless Network Station IEEE 802.11 Characteristics

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Abstract. A mathematical model of access method "carrier sense multiple access with collision avoidance" for two active stations was proposed. The effect of carrier capture and unimodal dependence of the operating characteristics from the initial width of the contention window was detected. Measures of preventing the effect of carrier capture, based on the modifications of the standard protocol were proposed.

1 Random Multiple Access Method in 802.11 Wireless Networks

Let us analyze the wireless local area network (LAN) based on the IEEE 802.11 standard. The fundamental access method of such LANs is called DCF (Distributed Coordination Function) [1,2] known as *carrier sense multiple access with collision avoidance* (CSMA/CA) [2–4].

This mechanism is based upon the fact that the transmitting station checks whether the carrier signal is present in the medium, and, before starting transmission of a data frame, expects release of the communication medium. IEEE 802.11 stations, in contrast to wired Ethernet, are not capable of detecting collisions in a communication medium [1,5]. Due to this fact, detection of collisions and non-conflict transmissions of protocol-based data units is based on the time-outs mechanism and on the algorithm of positive decision feedback.

Let us analyze the cycle of a data frame transmission from the sending station to the recipient station. First and foremost, the sending station senses the medium to determine if another station is transmitting. Thereafter, at the end of the inter-frame interval, the random delaying algorithm is initiated to select a random backoff interval (the number of a slot in which the data transmission may be started). The slot number is selected with equal probability from the interval $[0, S_n - 1]$, where S_n is the size of the contention window measured in slot intervals t_c and determined by the relation $S_n = 2^{N_0+m}$, $m = n$ if $n \leq 10 - N_0$ and $m = 10 - N_0$ if $n \geq 10 - N_0$. Here $N_0 = \overline{1, 10}$ is the initial value predetermining the width of the contention window during the first attempt of a sender to transfer data, and $n \geq 0$ is the number of retransmission. The width

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of the contention window may not exceed the maximum value established by the standard. For all physical layers and methods of modulation, the IEEE 802.11 standard has established the maximum width of the contention window equal to $S_{max} = 1024$ [2] The number of a selected slot shall be assigned to the backoff interval counter t_o, after which the countdown of slot intervals begins. At the end of each slot interval, the backoff interval counter shall decrement as long as medium is idle. If the medium is determined to be busy at any time during a backoff slot, then the backoff procedure is suspended. Decrementing is resumed when the medium is idle again. Transmission shall commence when the backoff interval counter reaches zero ($t_o = 0$). When the transmission is completed, the sender waits for a acknowledgement during the time t_{out}, after which it is considered that a conflict has occurred, and stations having got into such conflict increase the n value by one, and the actions targeted at data transmission are repeated. The width of the contention window is doubled with each attempt of data frame transmission, until the maximum value is achieved; and the width of the contention window remains equal to S_{max} with each subsequent attempt of data frame transmission. After successful transmission, the window width obtains the initial value S_0.

Thus, the wireless access technology, due to lack of possibility to detect collisions in a communication medium, has three significant differences from the random access method implemented in the wired medium. Firstly, the wireless transmission method employs the mechanism of positive feedback (positive acknowledgements). Secondly, in contrast to the random access method, in wired networks the WiFi technology employs the random delay mechanism as early as during the first transmission. And at last, the wireless access protocol employs the mechanism of “suspension” of the delaying timer from the time of detection of the medium occupation until expiration of the random delay timer.

2 Mathematic Modelling of 802.11 Wireless LAN

Let us analyze the operation of a wireless local area network until the first error-free data frame transmission with obtained acknowledgement on successful delivery of data. Let us suppose that the wireless LAN contains K stations which are data sources. Consider that all the sources are independent and equal, and always have data frames for sending, and all interval spaces are expressed in slot intervals t_c. Let all the stations exchange frames of equal sizes. Then, according to the sequence of protocol actions, the elementary cycle of data frame transfer to the recipient will be determined by the size of the interframe space t_m, random delay period t_o, duration of “suspension” of the random delay timer t_z, time of data frame transmission t_k, and the value of time-out for expecting a positive acknowledgement t_{out}, which consists of a short interframe space plus the time of transmission of a positive acknowledgement [2,4]. The average time of data frame transmission $T(K, N_0)$ consists of the weighted sum of average periods of waiting for failed transmissions and the time of successful transmission [6]:

$$T(K,N_0)=d+\sum_{N=0}^{\infty}\left[Nd+\sum_{n=0}^{N-1}t(n,K,N_0)+\tau(N,K,N_0)\right]f(N,K,N_0). \qquad (1)$$

Here $d=t_m+t_k+t_{out}$, $t(n,K,N_0)$ and $\tau(N,K,N_0)$ are the average conditional times until failed and successful N-th repeated attempts to send a data frame by a subscriber, and $f(N,K,N_0)$ is the function of probability [7] of the duration of competition between subscribers for the medium, which is determined by the probability of successful data frame transmission on the N-th repeated step after $N-1$ failures [6]:

$$f(N,K,N_0)=P(N,K,N_0)\prod_{n=0}^{N-1}\pi(n,K,N_0).$$

Along with the average time of data frame transmission, one of the main indicators showing the efficiency of functioning the data transfer network is the throughput performance. In the case under analysis, we will look for an individual throughput performance, the standardized value of which shall be determined as a ratio between the time necessary for data frame transmission t_k and the average time of data frame transmission $T(K,N_0)$:

$$C(K,N_0)=\frac{t_k}{T(K,N_0)}. \qquad (2)$$

3 The Competition of Two Wireless Stations

Let us analyze the competition of two wireless stations ($K=2$) of a local area network. We denote the competing (conflicting) stations through A and B. Let us find the probability timing characteristics of the data transmission process executed by the A station. Let us denote via $p_n(i)$ the probability of selection of random backoff interval with a duration equal to i slot intervals on the n-th repeated transmission by the A station, and via $f_n(j)$ the probability of selection of random backoff interval with a duration equal to j slot intervals on the n-th repeated transmission by the B station. Then the conditional probability of a conflict on the n-th repeated transmission for the A station is determined by the relation

$$\pi(n,2,N_0)$$
$$=\begin{cases}\sum\limits_{i=0}^{S_0-1}p_0(i)\sum\limits_{j=0}^{i}f_0(j)L_{i-j}, & n=0;\\ \sum\limits_{k=1}^{n}E_k(n)\left[\sum\limits_{i=0}^{S_k-1}p_n(i)\sum\limits_{j=0}^{i}f_k(j)L_{i-j}+\sum\limits_{i=S_k}^{S_n-1}p_n(i)\sum\limits_{j=0}^{S_k-1}f_k(j)L_{i-j}\right], & n\geq 1.\end{cases} \qquad (3)$$

Here L_k represents recurrent probabilities of movement of the B station "bottom-up" from originally selected slot interval j to a conflict slot interval i selected by the A station (k is a difference between j-th and i-th slots), for many steps with successful transmissions:

$$L_k = \begin{cases} \sum\limits_{i=0}^{\infty} f_0^i(0) \sum\limits_{i=1}^{k} f_0(i) L_{k-i}, & k = \overline{1, S_0 - 1},\ L_0 = 1; \\ \sum\limits_{i=0}^{\infty} f_0^i(0) \sum\limits_{i=1}^{S_0-1} f_0(i) L_{k-i}, & k = \overline{S_0, S_n - 1}. \end{cases}$$

In other words elements L_k include probabilities of all possible actions of the B station before collision with the A station, if the B station originally selected slot interval j and the A station selected slot interval i. From this point, it is not difficult to see that, before the conflict with the A rival, the competing B station may carry out an unlimited number of successful transmissions in case of "fallout" of random delay having zero duration. Using the relations for the arithmetic-geometrical progression [8] for L_k with $k = \overline{1, S_0 - 1}$, we obtain the final relation:

$$L_k = \frac{S_0^{k-1}}{(S_0 - 1)^k}, \quad k = \overline{1, S_0 - 1}. \tag{4}$$

Inserting (4) into (3), we find the probability of a conflict on the first attempt of data frame transmission:

$$\pi(0, 2, N_0) = \frac{S_0 - 1}{S_0^2} \left[\left(\frac{S_0}{S_0 - 1} \right)^{S_0} - 1 \right].$$

The coefficients $E_k(n)$ in the relation (3) are the probabilities that on the n-th repeated transmission by the A station, the B station will be in the condition of the k-th repeated transmission:

$$E_1(1) = 1; \quad E_1(n) = \sum_{k=1}^{n-1} \frac{E_k(n-1)}{\pi(n-1, 2, N_0)} \left[\sum_{i=1}^{S_k - 1} p_{n-1}(i) \sum_{j=0}^{i-1} f_k(j) L_{i-j} \right.$$
$$\left. + \sum_{i=S_k}^{S_{n-1}-1} p_{n-1}(i) \sum_{j=0}^{S_k - 1} f_k(j) L_{i-j} \right], \quad n \geq 2;$$
$$E_k(n) = \frac{E_{k-1}(n-1) \sum\limits_{i=0}^{S_{k-1}-1} p_{n-1}(i) f_{k-1}(i)}{\pi(n-1, 2, N_0)}, \quad n \geq 2,\ k = \overline{2, n}.$$

The average conditional times until failed and successful n-th attempt of data transmission $t(N, K, N_0)$ and $\tau(N, K, N_0)$ consist of the average duration of random delay $N_s(n)$ (average number of slots until the start of transmission) and the average number of suspensions caused by medium capture by the B station, $Z_t(n, N_0)$ in case of failure and $Z_\tau(n, N_0)$ in case of success, respectively:

$$t(n, 2, N_0) = N_s(n) + Z_t(n, N_0) d, \quad \tau(n, 2, N_0) = N_s(n) + Z_\tau(n, N_0) d.$$

Here $N_s(n) = \sum_{i=0}^{S_n-1} ip_n(i) = (S_n - 1)/2$, and the average numbers of suspensions $Z_t(n, N_0)$ and $Z_\tau(n, N_0)$ look similar:

$$Z_t(n, N_0) = \begin{cases} \sum\limits_{i=1}^{S_0-1} p_0(i) \sum\limits_{j=0}^{i-1} f_0(j) M_{i-j}, & n = 0; \\ \sum\limits_{k=1}^{n} E_k(n) \left[\sum\limits_{i=1}^{S_k-1} p_n(i) \sum\limits_{j=0}^{i-1} f_k(j) M_{i-j} + \sum\limits_{i=S_k}^{S_n-1} p_n(i) \sum\limits_{j=0}^{S_k-1} f_k(j) M_{i-j} \right], & n \geq 1; \end{cases} \tag{5}$$

$$Z_\tau(n, N_0) = \begin{cases} \sum\limits_{i=1}^{S_0-1} p_0(i) \sum\limits_{j=0}^{i-1} f_0(j) V_{i-j}, & n = 0; \\ \sum\limits_{k=1}^{n} E_k(n) \left[\sum\limits_{i=1}^{S_k-1} p_n(i) \sum\limits_{j=0}^{i-1} f_k(j) V_{i-j} + \sum\limits_{i=S_k}^{S_n-1} p_n(i) \sum\limits_{j=0}^{S_k-1} f_k(j) V_{i-j} \right], & n \geq 1. \end{cases} \tag{6}$$

The elements M_k and V_k are indicators of the average number of suspensions of the delaying timer for the A station after selection of random delay with the duration i on the n-th repeated transmission upon selection of the j-th slot preceding to the i-th one by the competing B station (k is a difference between j-th and i-th slots):

$$M_k = \begin{cases} \sum\limits_{m=1}^{k} f_0(m) \sum\limits_{i=0}^{\infty} (i + 1 + M_{k-m}) f_0^i(0), & k = \overline{1, S_0 - 1},\ M_0 = 0; \\ \sum\limits_{m=1}^{S_0-1} f_0(m) \sum\limits_{i=0}^{\infty} (i + 1 + M_{k-m}) f_0^i(0), & k = \overline{S_0, S_n - 1}; \end{cases}$$

$$V_k = \begin{cases} \sum\limits_{i=0}^{\infty} (i+1) f_0^i(0) \sum\limits_{m=k+1}^{S_0-1} f_0(m) + \sum\limits_{m=1}^{k-1} f_0(m) \sum\limits_{i=0}^{\infty} (i + 1 + V_{k-m}) f_0^i(0), k = \overline{1, S_0 - 1}; \\ \sum\limits_{m=1}^{S_0-1} f_0(m) \sum\limits_{i=0}^{\infty} (i + 1 + V_{k-m}) f_0^i(0), \quad k = \overline{S_0, S_n - 1}. \end{cases}$$

After inserting here the probabilities of fallout of delay duration $f_0(m)$, we obtain the following relations:

$$M_k = \begin{cases} \dfrac{S_0}{S_0 - 1} \left[\left(\dfrac{S_0}{S_0 - 1} \right)^k - 1 \right], & k = \overline{1, S_0 - 1}; \\ \dfrac{S_0}{S_0 - 1} + \dfrac{\sum_{m=1}^{S_0-1} M_{k-m}}{S_0 - 1}, & k = \overline{S_0, S_n - 1}. \end{cases}$$

$$V_k = \begin{cases} \dfrac{S_0 - 2}{S_0 - 1} \left(\dfrac{S_0}{S_0 - 1} \right)^k, & k = \overline{1, S_0 - 1}; \\ \dfrac{S_0}{S_0 - 1} + \dfrac{\sum_{m=1}^{S_0-1} V_{k-m}}{S_0 - 1}, & k = \overline{S_0, S_n - 1}. \end{cases}$$

The indicator of the general throughput performance can be found by analogy with individual operational speed (2), therewith the numerator of such relation should be adjusted not only for the package successfully transferred by the A station, but also for the average number of packages transferred by the B station for the concerned period:

$$C_{\mathrm{g}}(2, N_0) = \frac{(G(N_0)+1)t_k}{T(2, N_0)},$$

where $G(N_0)$ will be determined by the weighted amount of the average number of suspensions of the delaying timer of the A station in expectation of failed and successful transmissions, which are determined by the relations (5) and (6):

$$G(N_0) = \sum_{N=0}^{\infty}\left[\sum_{n=0}^{N-1} Z_t(n, N_0) + Z_\tau(N, N_0)\right] f(N, 2, N_0).$$

4 Numerical Results

The numeric research into the average time of data frame transmission by the A station shows that the function (1) has a strongly manifested minimum at the coordinate N_0 (see Fig. 1) determining the initial size of the competition window and, subsequently, the degree of scattering of stations by durations of delays before the start of the competition procedure. For two competing stations, the minimum is reached at $N_0 = 4$. It is obvious that the value N_0 minimizing the average time of data frame transmission maximizes the individual throughput (see Fig. 1). Moreover, as early as at the stage of formalization of the task, the probability of capture of the communication medium by one of the subscribers mentioned in [9,10] has become obvious. This effect manifests itself especially strongly with small values N_0. The effect of capturing the communication medium causes discrimination-related individual indicators against a good level of the general throughput performance of the network (see Fig. 1).

As early as at the first attempt of competition between two stations, capture of the communication medium becomes possible (e.g. by the B station), and its probability will be determined by the probabilities that for one of the stations (B) the delay duration will turn out to be shorter than the duration of delay of the other station (A); then the "succeeded" station (B) will have fallout of zero duration, which will alternate with shorter delays than the residual value of the station's A delaying timer:

$$P_z(0, 2, N_0) = \sum_{i=1}^{S_0-1} p_0(i) L_{i-1} \sum_{k=1}^{\infty} f_0^k(0) = \frac{1}{S_0^2}\left(\frac{S_0}{S_0-1}\right)^{S_0-1}.$$

From this point, it is not difficult to see that the probability of capture is considerably determined by the initial width of the contention window S_0 (see Fig. 2). After several conflicts, the possibility of capture for the "succeeded" station becomes yet more probable.

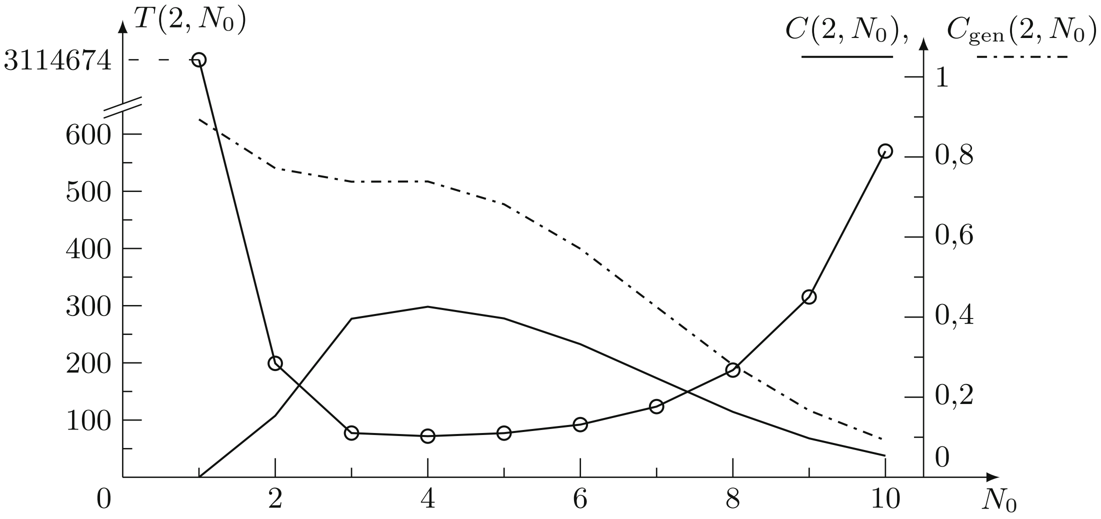

Fig. 1. Average time of data frame transmission, and individual and general throughput performances

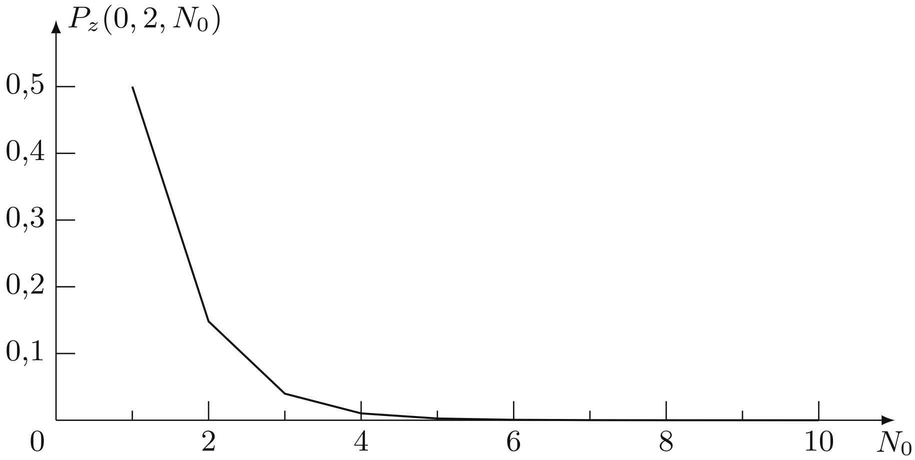

Fig. 2. Probability of the medium capture by one of the stations

The main reason for the effect of capturing the communication medium is the protocol action — “suspension of delay”, because this results in a fact that after a non-conflict transmission the station may capture the communication medium for an infinitely long time, getting into the delay interval from 0 to the residual value of the delay of other stations.

Another reason for an increase in the probability of capturing the communication medium by one of the subscribers after several conflicts, consists in various sizes of the contention window for stations withdrawn from the conflict and stations continuing resolution of the conflict in the condition of waiting for expiration of delay time and suspension periods. After a positive resolution of the conflict by one of the stations (or by several stations), the size of its contention window is reduced in multiples down to the initial value $S_0 < S_n$, which gives this station a priority right in subsequent competition for the medium with "conflicting" stations, because the shorter duration of an occasional delay for such station has a significantly higher probability as compared with the similar operational indicator of the "conflicting" station.

It is obvious that to reduce the probability of the effect of medium capturing for an infinitely long time, it is possible to offer, on one hand, to fix the size of the contention window for the first and all subsequent transmissions, and on the other hand – the duration of random delay t_o should be selected within the interval from 1 to $2^{N_0} - 1$ of slot periods t_c, thus excluding the delay of the zero size. Therewith, medium capturing by one station will never exceed $2^{N_0} - 2$ successful transmissions until the subsequent conflict or its resolution.

5 Conclusion

The performed analysis is targeted at studying the method of carrier sense multiple access with collision avoidance. Analytic correlations have been obtained for probability timing characteristics of the competition process between two stations. The "medium capture effect" and the extreme dependence of operational parameters on the initial contention window size have been revealed.

It has been suggested to change the parameters of the protocol procedure of competition, ensuring prevention of the capture effect by saving high values of individual and integral indices of operational speed.

It has been shown that the optimal initial width of the contention window (S_0) is determined by the active size of the network (the number of competing stations), and it ensures almost uniform distribution of a jointly used time resource of the medium between competing subscribers.

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