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COMPARISON OF THE THROUGHPUT OF THE CARRIER SENSE MULTIPLE ACCESS PROTOCOL WITH CONFLICTS RESOLVING ON THE PHYSICAL LEVEL

At present, the global growth of communication needs makes us more efficient in using of the frequency spectrum. Assuming that at one frequency there is an opportunity to transmit several mutual interference signals at one time, the problem is the separation of these signals. But, complexity of demodulation procedures has significantly increased compared to the classical. Thus, we must determine whether a reasonable increase of complexity and how will increase the throughput of some communication system. In researching we will choose carrier sense multiple access protocol.

Keywords: *RMA – random multiple access, CSMA – carrier sense multiple access, CD – collision detection, CRPL – conflicts resolving on the physical layer, MDT – multiuser detection theory, QS – queuing system, SRC – source of recurring calls.*

В настоящее время глобальный рост потребностей в связи делает нас более эффективными в использовании частотного спектра. Предполагая, что на одной частоте имеется возможность передавать несколько сигналов взаимных помех одновременно, проблема заключается в разделении этих сигналов. Но сложность процедур демодуляции значительно возросла по сравнению с классической. Таким образом, мы должны определить, будет ли разумно увеличиваться сложность и как будет увеличиваться пропускная способность какой-либо системы связи. При исследовании мы выберем протокол множественного доступа с контролем несущей.

Ключевые слова: *случайный множественный доступ, протокол множественного доступа с контролем несущей, обнаружение конфликтов, разрешение конфликтов на физическом уровне, теория многопользовательского детектирования, системы массового обслуживания, источник повторных вызовов.*

Introduction. Mobile communication is one of the most important modern telecommunications trends that been undergoing intensive development over the last four decades, both general and special. The rapid development of mobile communication is, in essence, a new era in telecommunication, which has accrued to the present time for five generations and offers more and more unique services. At the same time, the growing information multimedia needs of humanity inevitably led to the rapid reloading of radio resources.

In radio systems with random access multiple access (RMA), radio resources are usually generalized, that is, they are provided to more than the maximum number of users, on condition that they are simultaneously successful. Objectively, this is justified by the fact that users of such systems needs radio channel not all the time, but some segments, randomly, depending on the circumstances, in the general case, nondeterministic, non-stationary and therefore difficulty predicted.

The problem of the shortage of radio resources, which thus arises, can be solved by applying simplex modes of operation. However, the decentralized management of radio because inevitably there are overlays (collision) of signals of different users with mutual independent behavior. According to the terminology defined in the seven-layer Open System Interconnection model [2], such overlays (leading to distortions) will be classified as conflicts at the physical layer.

The task of organizing access of the end users (subscribers) devices to the common resource rests on the additional sub-layer, which is called access syb-layer to the distribution medium [2].

Enormous intellectual resources was spend on the development of the RMA theory [3–6] over the half of the last century. The main purpose was the development of more advanced access protocols, characterized by more high parameters. At present, the theory of RMA has developed into a powerful independent discipline within the general theory of communication.

Together with the above, one must admit the obvious pattern that the algorithmic possibilities of the further significant development of the theory of the RMA are asymptotically exhausted.

The multiuser detection theory (MDT) arose and develops rapidly, with some delay and until recently, independently of the theory of RMA. One of its branches – the statistical theory of separation of digital signals [7].

One of the most common approaches to increasing the throughput of an RMA channel is the using of user signals with some power gradations transmitted in the common frequency-time resource [5–7]. The disadvantage of these protocols is obvious – only one of the most powerful signals from several conflicting can successfully be processed (and not in all cases).

At the present time, against the background of traditional independence of the development of the theories of RMA and MDT, takes a separate place so far insignificant series of works [1, 8, 9], in which the parameters of the RMA protocols are investigated with the additional assumption about the possibility of simultaneous transmission more than one signal (package) in one channel.

This assumption was caused by two factors – the implementation of broadband signals and the phenomenon of suppression in the demodulator (nonlinear for a powerful signal) of a weak signal by a strong.

Interpenetration and, even in some tasks, the merging of theories of RMA and MDT becomes a reality, because, obviously, the efficiency of access protocols can't not be improved by the implementation of conflicts resolving at the physical layer (CRPL). On the other hand, the Bayesian approach in the MDT theory to the synthesis of procedures for digital signals demodulation inevitably leads to the dependence of some parameters of the demodulators from the properties of the incoming traffic of RMA system.

Carrier Sense Multiple Access protocol with Conflicts Detection (CSMA- CD) have long been used only in cable (optic fiber) networks due to the fact that it was impossible to detect any foreign radiation in the radio networks on the background of relatively powerful signals from their transmitting devices. Now we can hope that the achievements in theory and practice of MDT and modern elemental base gradually eliminate this limitation. The results of the research indicate that it is possible not only to significantly increase the throughput of the RMA protocols with CRFL in the demodulators of radio receivers, as well as the complex of RMA procedures with CRPL. At the same time, the researching of RMA protocols of the CSMA family with an additional assumption of the possibility of CRPL to the present in full has not been completed yet.

To analyze the RMA protocols of his time, A. Nazarov [10] proposed an asymptotic method, which plays an important role in the researching of the appropriate mathematical models, including those that describe the operation on queuing systems (QS). However, accurate formulas for solutions can be obtained, as a rule, only in exceptional situations characterized by forced overlay of rigid simplifying limitations on the statistical nature of the investigated processes. At the same time, often applying asymptotic methods, one can obtain an approximate solution to a problem with fairly broad assumptions about input flow statistics and service even in the absence of an explicit form of the corresponding distributions [10].

Method of analysis. Consider the CSMA-CD protocol with assumptions about CRPL and analyze its throughput. Let's consider several cases when only single, pair and triple applications are served.

The traditional way of describing the QS is the graph of the probability of the transitions of states and differential systems of equations.

The graph vertex denotes the state of the system. The edges of the graph are oriented and show possible transitions from one state to another.

The convenience of such method for describing the QS is its clarity and the possibility of implementing a simple rule for the construction of a system of differential equations for the probabilities of states of QS.

The service of each requirement is two-stage exponential with parameter μ_1 on the first and μ_2 on the second stage. The requirement of service in the analyzed QS in the form of a two-stage procedure is due by the fact, that at a certain random interval of time the transmission of messages to all users should be allowed. At the end of this random interval of time, depending on the number of processed applications on the first stage, there is a its resetting in a source of repeated calls (SRC) (if there was an unresolved conflict), or a successful non-conflict service on the second stage. Thus, the task of the first stage is to "collect" a certain number of applications for further service, and the second task – a useful (successful) service. In real communication networks, this can be interpreted as the generation by terminals of some autonomous signal of a prohibition of transmission after the first stage to the end of the second stage – autonomously for each terminal, that is, as a detecting procedure by all terminals of the fact of the busy channel by the permissible number of signals (for example, that is considered – one, two or three) or as a procedure for detecting an unresolved conflict on the first stage, which, however, arose as a result of decentralized management.

We built mathematical model of such queuing system. Requirements for the simplest (Poisson) flow with the parameter λ enter the service system. If on the first stage three applications are detected, then they start to be immediately served. If at the end of the first stage comes more than three applications, then they and next reset to SRC, which may persist indefinitely. Graph of states this CSMA-CD protocol, when it have only three applications at the same length with prohibition of service of single and pair applications shown at Figure 1.

We write down the appropriate system of difference equations of the investigated process. Here and ahead we will set i number of applications in the SRC, ν – the state of the process, and make a replacement $P_\nu(i)\underline{\Delta}P(t,i,\nu)\underline{\Delta}P(i(t)=i,\ \nu(t)=\nu)$

$$\begin{cases} P(t+\Delta t,i,0)=\left[1-(\lambda+i\sigma)\Delta t\right]P(t,i,0)+\mu_2\Delta tP(t,i,7)+4\mu_1\Delta tP(t,\ i-4,\ 4); \\ P(t+\Delta t,i,1)=\left[1-(\lambda+i\sigma)\Delta t\right]P(t,i,1)+\lambda\Delta tP(t,i,0)+(i+1)\sigma\Delta tP(t,\ i+1,\ 0); \\ P(t+\Delta t,i,2)=\left[1-(\lambda+i\sigma)\Delta t\right]P(t,i,2)+\lambda\Delta tP(t,i,1)+(i+1)\sigma\Delta tP(t,\ i+1,\ 1); \\ P(t+\Delta t,i,3)=\left[1-(\lambda+3\mu_1+i\sigma)\Delta t\right]P(t,i,3)+\lambda\Delta tP(t,i,2)+(i+1)\sigma\Delta tP(t,\ i+1,\ 2); \\ P(t+\Delta t,i,4)=\left[1-(\lambda+4\mu_1)\Delta t\right]P(t,i,4)+\lambda\Delta tP(t,\ i,\ 3)+(i+1)\sigma\Delta tP(t,\ i+1,\ 3)+ \\ +\lambda\Delta tP(t,\ i-1,\ 4); \\ P(t+\Delta t,i,7)=\left[1-(\lambda+\mu_2)\Delta t\right]P(t,i,7)+3\mu_1\Delta tP(t,i,3)+\lambda\Delta tP(t,\ i-1,\ 7). \end{cases}$$

After limit transition $\Delta t\to 0$:

$$\begin{cases} P'(t,i,0)=-(\lambda+i\sigma)P(t,i,0)+\mu_2P(t,i,7)+4\mu_1P(t,\ i-4,\ 4); \\ P'(t,i,1)=-(\lambda+i\sigma)P(t,i,1)+\lambda P(t,i,0)+(i+1)\sigma P(t,\ i+1,\ 0); \\ P'(t,i,2)=-(\lambda+i\sigma)P(t,i,2)+\lambda P(t,i,1)+(i+1)\sigma P(t,\ i+1,\ 1); \\ P'(t,i,3)=-(\lambda+3\mu_1+i\sigma)P(t,i,3)+\lambda P(t,i,2)+(i+1)\sigma P(t,\ i+1,\ 2); \\ P'(t,i,4)=-(\lambda+4\mu_1)P(t,i,4)+\lambda P(t,i,3)+(i+1)\sigma P(t,\ i+1,\ 3)+\lambda P(t,i-1,4); \\ P'(t,i,7)=-(\lambda+\mu_2)P(t,i,7)+3\mu_1P(t,i,3)+\lambda P(t,\ i-1,\ 7). \end{cases}$$

In the stationary mode we have:

$$\begin{cases} (\lambda+i\sigma)P(i,0)=\mu_2P(i,7)+4\mu_1P(i-4,\ 4); \\ (\lambda+i\sigma)P(i,1)=\lambda P(i,0)+(i+1)\sigma P(i+1,\ 0); \\ (\lambda+i\sigma)P(i,2)=\lambda P(i,1)+(i+1)\sigma P(i+1,\ 1); \\ (\lambda+3\mu_1+i\sigma)P(i,3)=\lambda P(i,2)+(i+1)\sigma P(i+1,\ 2); \\ (\lambda+4\mu_1)P(i,4)=\lambda P(i,\ 3)+(i+1)\sigma P(i+1,3)+\lambda P(i-1,\ 4); \\ (\lambda+\mu_2)P(i,7)=3\mu_1P(i,3)+\lambda P(i-1,\ 7). \end{cases}$$

After replacing $i\sigma\underline{\Delta}x$, $\sigma=\varepsilon\to 0$ and designating $P(i,\nu)\underline{\Delta}\pi_\nu(x)$ we get:

$$\begin{cases}(\lambda+x)\pi_0(x)=\mu_2\pi_7(x)+4\mu_1\pi_4(x-4\varepsilon);\\(\lambda+x)\pi_1(x)=\lambda\pi_0(x)+(x+\varepsilon)\pi_0(x+\varepsilon);\\(\lambda+x)\pi_2(x)=\lambda\pi_1(x)+(x+\varepsilon)\pi_1(x+\varepsilon);\\(\lambda+3\mu_1+x)\pi_3(x)=\lambda\pi_2(x)+(x+\varepsilon)\pi_2(x+\varepsilon);\\(\lambda+4\mu_1)\pi_4(x)=\lambda\pi_3(x)+(x+\varepsilon)\pi_3(x+\varepsilon)+\lambda\pi_4(x-\varepsilon);\\(\lambda+\mu_2)\pi_7(x)=3\mu_1\pi_3(x)+\lambda\pi_7(x-\varepsilon).\end{cases}$$

Expanding in the Taylor series, bounded by the first terms and adding all the equations of the system (1), we obtain the condition of stationary:

$$\left\{x\left[\pi_0(x)+\pi_1(x)+\pi_2(x)+\pi_3(x)\right]-16\mu_1\pi_4(x)-\lambda\left[\pi_4(x)+\pi_7(x)\right]\right\}'=0$$

On the other hand, assuming in the system (1) that ε = 0, we can write the solution of this system through $\pi(x)\Delta\sum_{\nu=0}^{5}\pi_\nu(x)$ and through π_0:

$$\begin{cases}(\lambda+x)\pi_0=\mu_2\pi_7+4\mu_1\pi_4;\\(\lambda+x)\pi_1=\lambda\pi_0+x\pi_0;\\(\lambda+x)\pi_2=(\lambda+x)\pi_1;\\(\lambda+3\mu_1+x)\pi_3=(\lambda+x)\pi_2;\\(\lambda+4\mu_1)\pi_4=(\lambda+x)\pi_3+\lambda\pi_4;\\(\lambda+\mu_2)\pi_7=3\mu_1\pi_3+\lambda\pi_7;\end{cases}\quad(1)$$

Therefore:

$$\pi_1=\pi_0=\pi_2$$

$$\pi_3=\frac{\lambda+x}{\lambda+3\mu_1+x}\pi_2=\frac{\lambda+x}{\lambda+3\mu_1+}\pi_0$$

$$\pi_4=\frac{(\lambda+x)}{4\mu_1}\pi_3=\frac{(\lambda+x)^2}{4\mu_1(\lambda+3\mu_1+x)}\pi_0$$

$$\pi_7=\frac{3\mu_1}{\mu_2}\pi_3=\frac{3\mu_1(\lambda+x)}{\mu_2(\lambda+3\mu_1+x)}\pi_0$$

Write down the amount:

$$\pi(x)=\sum_{\nu=0}^{5}\pi_\nu(x)=\pi_0(x)\times$$
$$\times\frac{12\mu_1\mu_2(\lambda+3\mu_1+x)+4\mu_1(\lambda+x)(\mu_2+3\mu_1)+\mu_2(\lambda+x)^2}{4\mu_1\mu_2(\lambda+3\mu_1+x)}\quad(2)$$

Let's denote the numerator in (2) through $f(x)>0$. Then,

$$\pi_0(x)=\pi_1(x)=\pi_2(x)=\frac{4\mu_1\mu_2(\lambda+3\mu_1+x)}{f(x)}\pi(x);\quad \pi_3(x)=\frac{4\mu_1\mu_2(\lambda+x)}{f(x)}\pi(x);$$

$$\pi_4(x)=\frac{\mu_2(\lambda+x)^2}{f(x)}\pi(x);\quad \pi_7(x)=\frac{12\mu_1^2(\lambda+x)}{f(x)}\pi(x).$$

Now the equation that determines the conditions of stationary, we represent as follows (substituting the value of $\pi(x)$)

$$x\left[\pi_0(x)+\pi_1(x)+\pi_2(x)+\pi_3(x)\right]-16\mu_1\pi_4(x)-\lambda\left[\pi_4(x)+\pi_7(x)\right]=C$$

Or

$$\left[4x\mu_1\mu_2\left(3(\lambda+3\mu_1+x)+(\lambda+x)\right)-16\mu_1\mu_2(\lambda+x)^2-\lambda(\lambda+x)\left(\mu_2(\lambda+x)+12\mu^2{}_1\right)\right]\frac{\pi(x)}{f(x)}=C$$

Let's write a numerator in the form of a polynomial:

$$\left[-x^2\mu_2\lambda+x(-16\lambda\mu_1\mu_2+36\mu^2{}_1\mu_2-12\lambda\mu_1{}^2-2\mu_2\lambda^2)-\right.$$
$$\left.-\mu_2\lambda^3-16\mu_1\mu_2\lambda^2-12\mu_1{}^2\lambda^2\right]\frac{\pi(x)}{f(x)}=C \qquad (3)$$

Obviously, the equality of the constant C ≠ 0 will be observed with

$$\pi(x)=f(x)\left[-x^2\mu_2\lambda+x(-16\lambda\mu_1\mu_2+36\mu^2{}_1\mu_2-12\lambda\mu_1{}^2-2\mu_2\lambda^2)-\mu_2\lambda^3-16\mu_1\mu_2\lambda^2-12\mu_1{}^2\lambda^2\right]^{-1}$$

After changing the sign, because it doesn't matter:

$$\pi(x)=f(x)\left[x^2\mu_2\lambda+x(16\lambda\mu_1\mu_2-36\mu^2{}_1\mu_2+12\lambda\mu_1{}^2+2\mu_2\lambda^2)+\mu_2\lambda^3+16\mu_1\mu_2\lambda^2+12\mu_1{}^2\lambda^2\right]^{-1}$$

However, for such an expression for $\pi(x)$ we can show that $\pi(x\to\infty)=\frac{1}{\lambda^2}$. Then the integral of the last expression in the domain $x\geq 0$ will diverge. Accordingly, it remains in the expression (3) to make an assumption $C\equiv 0$.

Due to the fact that $f(x)>0$, we should make an assumption $\pi(x)=0$ at all points where the polynomial in the numerator (3) is not zero, i.e. where the condition is not fulfilled:

$$\left[x^2\mu_2\lambda+x(16\lambda\mu_1\mu_2-36\mu^2{}_1\mu_2+12\lambda\mu_1{}^2+2\mu_2\lambda^2)+\mu_2\lambda^3+16\mu_1\mu_2\lambda^2+12\mu_1{}^2\lambda^2\right]=0$$

This is the third-degree equation with real coefficients. This equation obviously solves analytically. Let us give equation to a form that is convenient for the interpretation of the results of analysis, for what divide each term of the equation on.

$$\xi z^2+(16\xi k-36k^2+12\xi k^2+2\xi^2)z+\xi^3+16\xi^2k+12\xi^2k^2=0 \qquad (4)$$

Where the denotation is used: $k\underline{\Delta}\frac{\mu_1}{\mu_2}$, $\xi\underline{\Delta}\frac{\mu_1}{\mu_2}$, $\underline{z\Delta}\frac{\mu_1}{\mu_2}$.

The results of the solution of this equation are based on the graphs given in the next section. Similar analysis has been carried out for other several CSMA-CD protocols. Their equations of stationary are obtained as follows:

$$\xi z^2 + (16\xi k - 36k^2 + 22\xi k^2 + 2\xi^2)z + \xi^3 + 16\xi^2 k + 22\xi^2 k^2 = 0 \quad (5)$$

hen solving triple conflicts of different duration;

$$\xi z^2 + (9\xi k - 12k^2 + 3\xi k^2 + 2\xi^2)z + \xi^3 + 9\xi^2 k + 3\xi^2 k^2 = 0 \quad (6)$$

when solving paired conflicts of the same duration;

$$\xi z^2 + (9k\xi - 12k^2 + 9k^2\xi + 2\xi^2)z + \xi^3 + 9k\xi^2 + 9k^2\xi^2 = 0 \quad (7)$$

when solving paired conflicts of different duration [11].

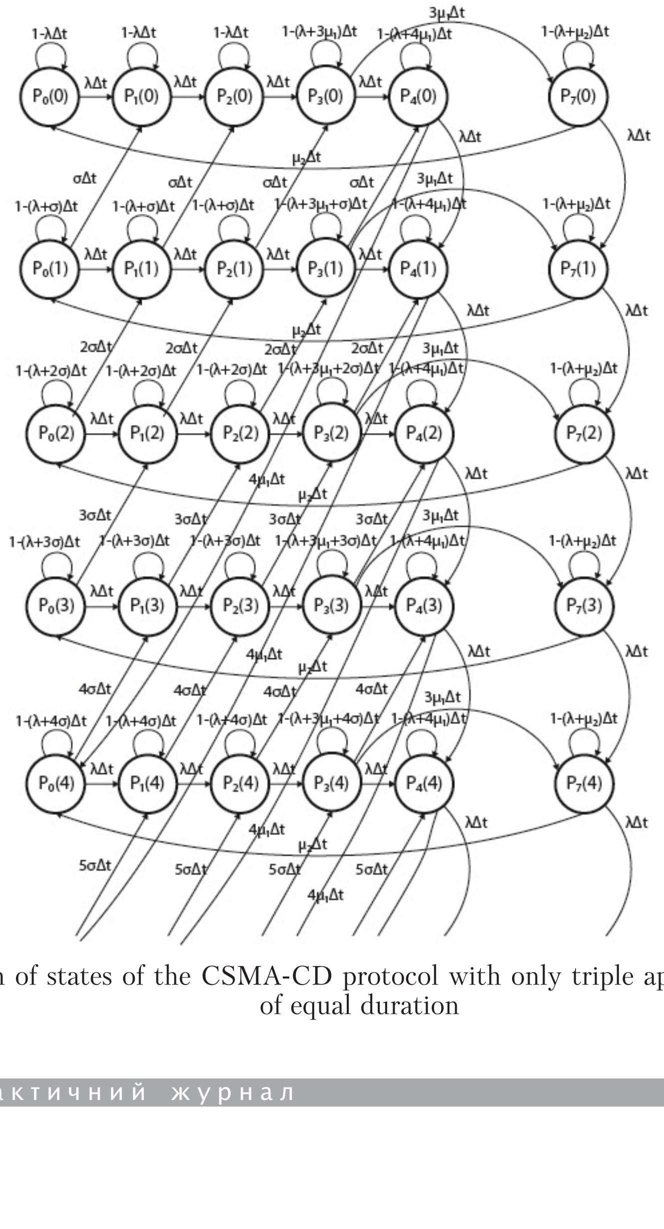

Fig. 1. Graph of states of the CSMA-CD protocol with only triple applications service of equal duration

Comparison of protocols. First Protocol CSMA-CD with only one application processing was analyzed in the 90s by A. Nazarov [10], where a full throughput reaches 1, on condition of increasing intensity of detection and service ratio.

In all varieties of the CSMA-CD protocol researched in the previous section, throughput is significantly increased in comparison with the classic protocol [10] when the CRPL was assumed impossible. For example, if the CRPL is implemented in the multiplicity 2, with their exponentially distributed mismatching durations of service requests on the second stage the throughput reaches 1.33, and with the same time randomly, but coinciding in duration – 2 (i.e., doubles).

Similarly with previous, the next case analyzed when success service of 3 applications is possible. It also gives a further increasing of throughput. When servicing on the second stage applications with random mismatched duration throughput reached 1.63, and while exponential law of service applications the same random length – 3 (increased threefold compared to [10]).

For clarity, the results of the analysis of equations (4–7) are shown in Fig. 2.

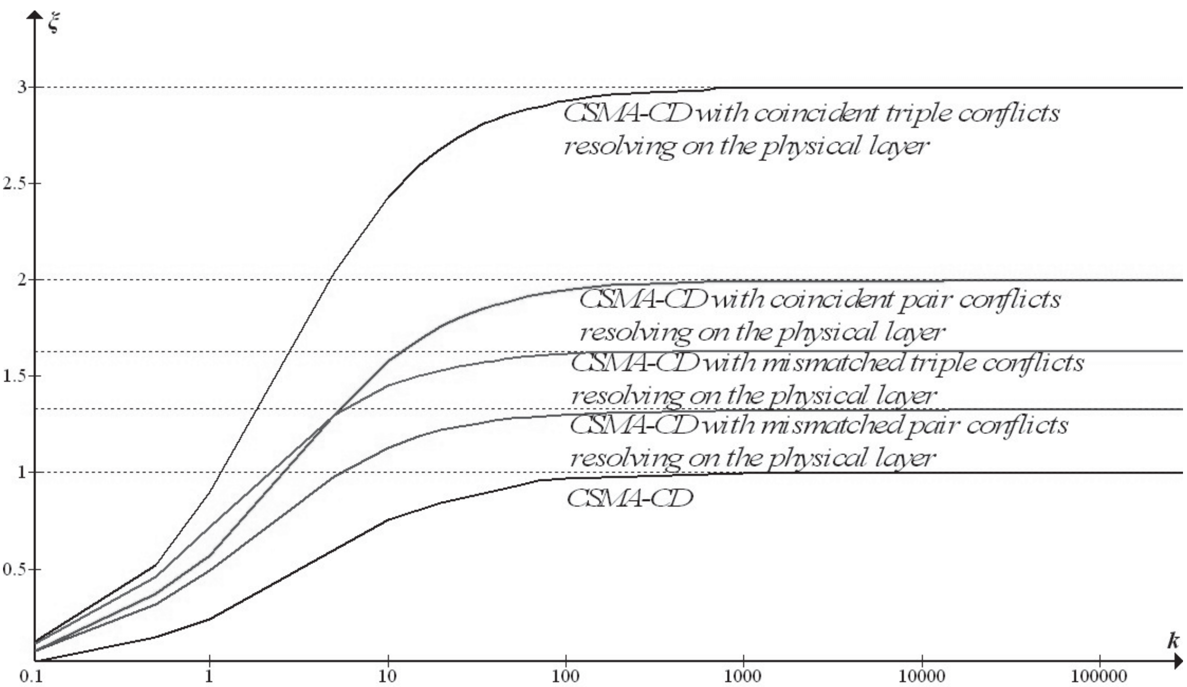

Fig. 2. Throughputs of the CSMA-CD protocols

The results of comparing the throughput of CSMA-CD protocols with the procedure of the CRPL with the protocol, which serves exclusively simple applications, are shown in Fig. 3.

Here $\xi(1)$ – results of the solution (search of the maximal real root) of the equation first obtained by A. Nazarov [10] , $\xi(2)$ – results of solutions of equations (4–7). In accordance, $\xi(2)/\xi(1)$ – relative throughput as a function of $k = \frac{\mu_1}{\mu_2}$.

Fig. 3. Dependence of relative changes in throughput of CSMA-CD protocols with CRPL with multiplicity 2 and 3 on the relative intensities of service on 1 and 2 stages

In Figure 4 shows the results of comparing protocols with the same multiplicity of the CRPL under different conditions of service on the second stage – service applications of mismatching and matching random durations. In this case, the win at full resolving of paired conflicts reaches 1.5, and for triple reaches 1.8.

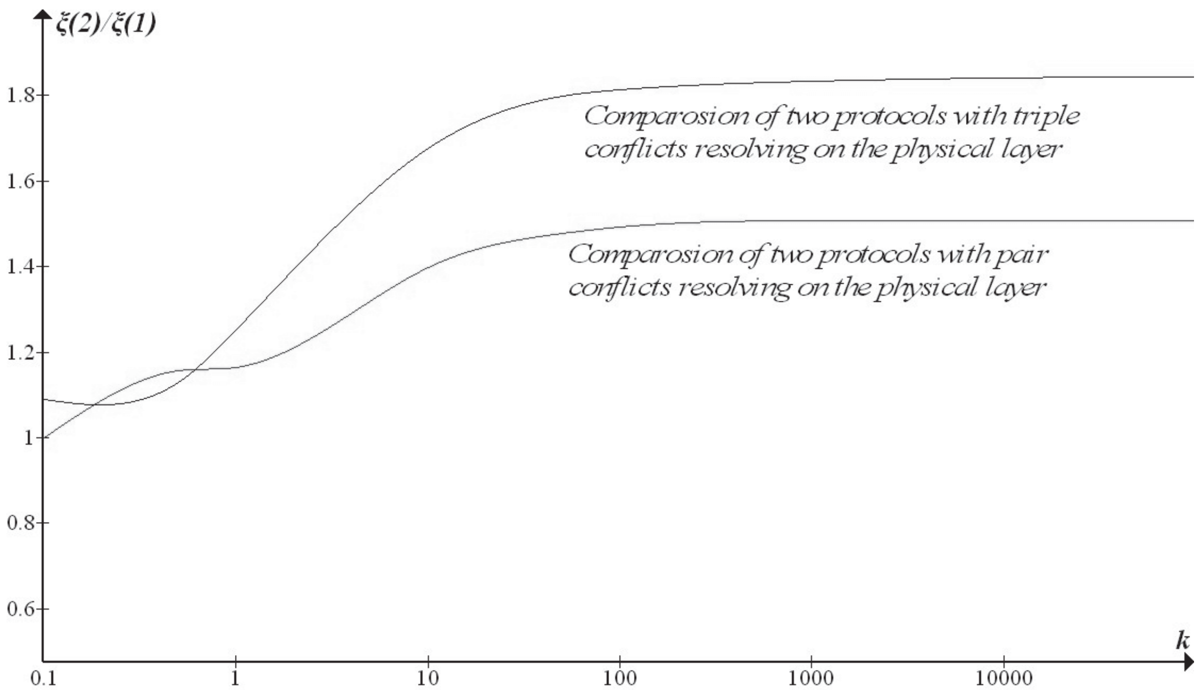

Fig. 4. Comparison of CSMA-CD protocols of the same multiplicity by throughput

At Figure 5 showed the results of comparing protocols with the same conditions of service on the second stage (coinciding and mismatching durations), which shows an increase in throughput depending on the multiplicity of the CRPL (comparing the triple full CRPL with a pair).

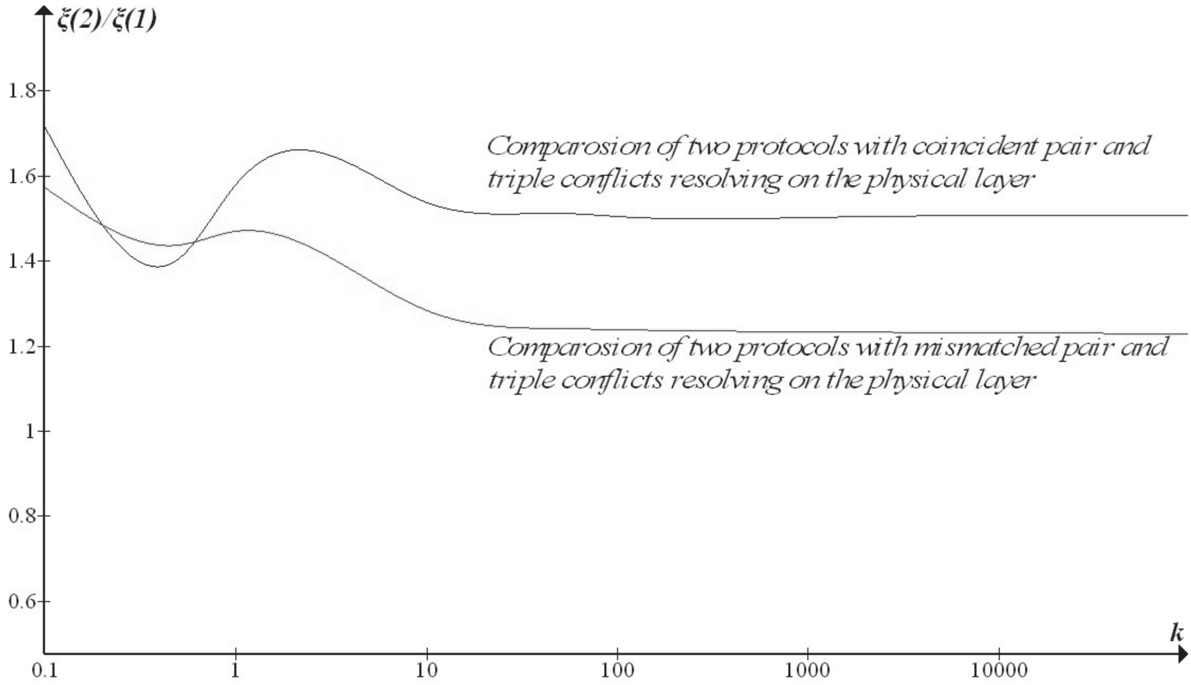

Fig. 5. Comparison of changes in throughput when solving conflicts of multiplicity 2 and 3 under the same conditions of the service

Comparison of the throughput of the CSMA protocols proves the expediency of the implementation of the CRPL even at a minimum multiplicity of 2–3. Problem of solving conflicts with multiplicity greater than 2–3 exponentially complicates demodulators, but subsequent additional increasing of throughput slows down, unless the duration of all serviced application matched.

Therefore, in practice, it should be limited of the CRPL by doubles (at most triple). This will significantly increase the throughput of telecommunication systems with RMA and, as can be proven, in the vast majority of modifications of the CSMA-CD protocols to reduce the average waiting time for the success service beginning.

It is also important to note (see Fig. 4 and Fig. 5) that on the interval $0{,}19 < k < 0{,}6$ the probability of detecting conflicts of multiplicity 2 is greater than the probability of detecting conflicts of multiplicity 3. Therefore, in this range of values k should be limited by the successful servicing of conflicts at least multiplicity 2, requiring the use of substantially simpler demodulation procedures than when solving conflicts of multiplicity 3.

Conclusions. The implementation of CRPL procedures even minimal multiplicities 2 and 3 in the communication system protocols such CSMA-CD was increase significantly throughput in the area of achievable k.

A protocol with CRPL opens qualitatively new opportunities for improving access protocols. For example, according to the results of the analysis on the stage of detection, one can recommend a waiver of service not only in case of unsolvable conflicts, but also in the case of receipt of single applications. At sufficiently high intensity detecting such tactics to improve the protocol will result in the common service resource will be used only sets of allowable multiplicity applications (i.e., two applications in the two most simple cases, when implemented CRPL multiplicity two, or three). Thus, the combination of two-stage CSMA-CD protocols and the procedures of the CRPL open up the possibility of realizing the parallel using of the common channel resource, when such resource for single and double applications (in solving conflicts of multiplicity 3) will not be provided. It should be added that the refusal to service single (or even double) applications with reasonable with significant intensity of input stream, corresponding throughput.

The actual fee for increasing the serviced load will be certain increase in the average time delay before the successful transmit beginning. Thus, it's already evident at the heuristic level that the two areas mentioned above for improving the communication systems with RMA – improving the access protocols at the sub-level of access to the transmission network and implementing procedures for CRPL not only do not oppose each other, but rather, are mutually complementary, interrelated and, at the same time, quite independent ways of modern development of communication systems with common resources and decentralized management. Also worth further researching and assess the real time delay before the successful transmit beginning.

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ПОРІВНЯННЯ ПРОПУСКНОЇ ЗДАТНОСТІ ПРОТОКОЛУ МНОЖИННОГО ДОСТУПУ КОНТРОЛЮ НЕСІВНОЇ З РОЗВ'ЯЗАННЯМ КОНФЛІКТІВ НА ФІЗИЧНОМУ РІВНІ

На сьогодні глобальне зростання потреб у зв'язку змушує більш ефективно використовувати частотний спектр. Розвиток систем зв'язку потребує збільшення пропускних спроможностей, при цьому частотний спектр обмежений, що не дозволить збільшувати ширину каналу чи їх кількість.

Якщо зробити припущення, що на одній частоті існує можливість передавати одразу декілька взаємозаважаючих сигналів, то виникає питання про розділення цих сигналів. Очевидно, що складність процедур демодуляції суттєво зросте в порівнянні з класичними. Тому треба з'ясувати, чи буде виправданим таке зростання складності. Щоб відповісти на це питання, необхідно визначити – як збільшиться пропускна спроможність деякої системи зв'язку з випадкового множинним доступом, де можливе кратне повторне використання частотного ресурсу.

Для дослідження оберемо протоколи множинного доступу з контролем несівної, що набули широкого поширення в пакетних мережах за їх вдале поєднання відносної простоти алгоритмів доступу та досить високої ефективності.

Метою дослідження є визначення основних характеристик різновидів протоколів множинного доступу з контролем несівної та виявленням конфліктів за додаткових припущень про розв'язання конфліктів на фізичному рівні.

Об'єкт дослідження – система зв'язку з випадковим множинним доступом.

Предметом досліджень є асимптотичні методи аналізу протоколів множинного доступу з контролем несівної та виявленням конфліктів за припущення про розв'язання конфліктів на фізичному рівні.

Відповідно до мети дослідження вирішені такі завдання:

1. Огляд базових протоколів випадкового множинного доступу з контролем несівної.

2. Вибір методу дослідження алгоритмів випадкового множинного доступу за додаткового припущення при можливості розв'язання парних конфліктів на фізичному рівні кратності 2 та 3.

3. Побудова математичної моделі функціонування протоколу МДКН-ВК за додаткового припущення про РКФР кратності до 3 та оцінка на її основі пропускної здатності телекомунікаційної системи із зазначеним протоколом доступу.

4. Чисельний порівняльний аналіз низки протоколів МДКН-ВК за додаткового припущення про заборону обслуговування поодиноких заявок.

Ключові слова: випадковий множинний доступ, протокол множинного доступу з контролем несівної, виявлення конфліктів, розв'язання конфліктів на фізичному рівні, теорія багатокористувацького детектування, системи масового обслуговування, джерело повторних викликів.

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