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# Parameters of the Carrier Sense Multiple Access Protocol with Conflicts Resolving at the Physical Layer

*Yerokhin V. F., Poliakova A. S., Sboiev R. Yu., Hol V. D.*

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

E-mail: *Roman.sboyev@gmail.com*

At present, the global growth of communication needs makes us more efficient in using of the frequency spectrum. The development of communication systems requires an increase of throughputs, but the frequency spectrum is limited, which will not allow to increase the channel width or the number of channels. Assuming that at one frequency there is an opportunity to transmit several mutual interference signals at one time, the problem of the separation of these signals arises. But, complexity of demodulation procedures has significantly increased compared to the classical. It is necessary, therefore, to determine whether this complexity increasing will be justified. To answer this question, it is necessary to find out how the throughput of the random multiple access system increases, where the frequency resource multiple reusing is possible. For research was chosen the carrier sense multiple access protocol, which have become widespread in packet networks for their successful combination of relative simplicity of access algorithms and fairly high efficiency. The purpose of the research is to determine the main characteristics of the various carrier sense multiple access protocols with collision detection and with additional assumption about conflicts resolving at the physical layer. The parameters of the carrier sense multiple access protocols with collision detection and with additional assumption about conflicts resolving at the physical layer are obtained. It is shown that in comparison with the classical protocol, the assumption about paired conflicts resolving at the physical layer gives the significant increasing of the throughput in the communication systems with such access protocols. The comparison results are given. The obtained results allow to confirm the expediency of implementation in demodulators of the perspective receiving devices algorithms of conflicts resolving at the physical layer as being characterized by relatively small complexity.

*Key words:* CSMA – CD; conflicts resolvconflicts resolving on the physical layer; multiuser detection theory; queuing system; source of recurring calls

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## Introduction

With the rapid development of telecommunication networks and the continuous increase of their traffic. There is an urgent need to consider about reusing of a frequency resource by complicating demodulators that will be able to receive two or even more interfering signals [1].

For specialized radio networks in Ukraine fixed bands are allocated [2], which are identified and controlled by radio frequency distribution services. At the same time, the number of subscribers of such networks and the intensity of information exchange in them gradually increase. The solution of the problem of frequency resource deficit can be based on its reusing – for example, by the methods of the multiuser detection theory [1–7]. However, algorithms for optimal demodulation of mutually interferingsignals are characterized by rapid increasing of complexity — its exponential dependence on the number of mutually interferingsignals thatmust be separated. Even when mutually non-orthogonal signals are 2-3, the appropriate algorithms are nontrivial (see, for example, [3–10]). Therefore, apractical interest is the question of how much the parameters of a random multiple access protocol will improve with conflictsresolving between radio signals in receiver demodulators, that is, at the physical layer. Such parameters firstlyare their throughput and the average time before the successful transmitting [7, 12].

The purpose of the article is to summarize the obtained results about the throughput of the widely used CSMA-CD protocol [7,11,12], and to calculate the average time before the successful transmittingwith an

[1] https://news.finance.ua/ua/news/-/431277/
[2] https://www.kmu.gov.ua/ua/npas/39517235 https://zakon.rada.gov.ua/laws/show/1208-2005-%D0%BF

additional assumption about conflicts resolving at the physical layer (CRPL). Were selected examples that expected for the possibility of technical implementation in the near future – the CRFL multiplicity 2 and 3.

## 1 Throughput of the CSMA-CD protocol with CRPL

The CSMA-CD protocol functions as follows. Requirements for the simplest flow with the parameter $\lambda$ enter the service system. The servicing of each requirement is a two-stage exponentially distributed with a parameter $\mu_1$ on the first and $\mu_2$ at the second stage. The description of the service in the analyzed queuing system (QS) in the form of a two-stage procedure is due to the fact that at a certain random interval of time, initially, the transmission of messages to all users should be allowed. At the end of this random time interval, depending on the number of processed (identified) applications at the first stage, there arises either their reset to the source of recurring calls (SRC) with intensity $x$ (if there was an unresolved conflict) or successful non-conflict service in the second stage. Thus, the task of the first stage is to “collect” a certain number of applications for further servicing, and the task of the second – useful service. In real communications networks, this can be interpreted as the generation by terminals of some autonomous signal of a prohibition of transmission after the first phase to the end of the second (non-conflict) phase – autonomously for each terminal, that is, as a procedure for detecting all terminals by the fact that the channel is occupied with the allowable number of signals (in the examples, considered one, two or three) or as a procedure for detecting an unresolved conflict at the first stage, but which arose as a result of decentralized management. The simplest (Poisson) flow is considered as it has stationary properties and no aftereffect.

The stationary equations obtained in previous papers have the form:

— when serving only single applications of exponentially distributed duration [12]:

$$\xi z^2 + z\left(4\xi k + 2\xi^2 + 2\xi k^2 - 2k\right) + 4\xi^2 k + \xi^3 + 2\xi^2 k^2 = 0. \quad (1)$$

Here and then

$$\xi = \frac{\lambda}{\mu_2}, \quad k = \frac{\mu_1}{\mu_2}, \quad z = \frac{x}{\mu_2}.$$

Nazarov’s proposed asymptotic method of QS analysis is determined not by the system load, but by the intensity of the repetition of a single call when this intensity approaches zero. The network performance thus reaches the maximum value, that is, asymptotic analysis in this case allows to determine the limiting (by productivity) capabilities of access protocols and to obtain analytical expressions that determine the dependencies for their basic numerical characteristics.

Also, using previously obtained results in this area of research and for a description of obtaining stationary equations, see [11]:

— when it is solving paired conflicts between applications of non-coincident random duration [11]:

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

— when it is solving pairs of conflicts between applications of coincident random duration [11]:

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

— when it is solving triple conflicts between applications of non-coincidentrandom duration:

$$\xi z^2 + (16\xi k - 36k^2 + 22\xi k^2 + 2\xi^2)z + \xi^3 + 16\xi^2 k + 22\xi^2 k^2 = 0; \quad (4)$$

— when it is solving triple conflicts between applications of coincident random duration:

$$\xi z^2 + (16\xi k - 36k^2 + 12\xi k^2 + 2\xi^2)z + \xi^3 + 16\xi^2 k + 12\xi^2 k^2 = 0. \quad (5)$$

For clarity, the results of the throughput analysis using the equations (1)-(5) are shown in Fig. 1.

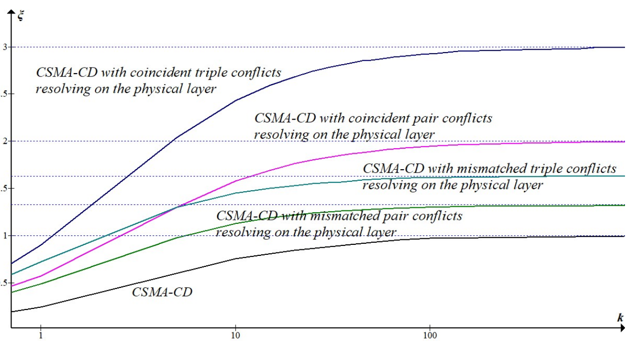


Fig. 1. Throughputs of CSMA-CD protocols

The obtained dependencies testify to the following. If the CRPL is multiplied by 2, then on the condition that their exponentially distributed non-coincident times of service requests in the second stage, the throughput is asymptotically reaching 1.33, and if, at the same time, they are random but coincide with the duration it is reaching 2 (it doubles).

When successful simultaneous servicing of three applications is possible, this also gives a further noticeable increase in throughput. When serving at the second stage of applications with non-coincident random duration, the throughput reaches 1.63, while when processing applications of coincident random duration it is reaching 3 (increases asymptotically three times as compared with [10]).

## 2 The average time before the start of successful servicing

The average time before the start of successful servicing can be determined by the number of repeated unsuccessful attempts. Attempting to get to the second stage of service will be successful only if the first stage reveals the number of applications (which then enters the second, stage of service without conflicts), which does not exceed the possibilities of resolving conflicts at the physical layer. Otherwise, after the first stage, all applications are sent to the source of repeated calls.

The appropriate expressions have the form:

— when it is serving only individual applications:

$$\overline{T} = \left(\frac{1}{\mu_1} + \frac{1}{\mu_2}\right) x; \tag{6}$$

— when it is solving pairs of conflicts between applications of non-coincidence durations:

$$\overline{T} = \left(\frac{1}{2\mu_1} + \frac{1}{2\mu_2} + \frac{1}{\mu_2}\right) x; \tag{7}$$

— when it is solving pairs of conflicts between applications of the coincidence duration:

$$\overline{T} = \left(\frac{1}{2\mu_1} + \frac{1}{\mu_2}\right) x; \tag{8}$$

— when it is solving triple conflicts between applications of non-coincidence durations:

$$\overline{T} = \left(\frac{1}{3\mu_1} + \frac{1}{3\mu_2} + \frac{1}{2\mu_2} + \frac{1}{\mu_2}\right) x; \tag{9}$$

— when it is solving triple conflicts between applications of the coincidence duration:

$$\overline{T} = \left(\frac{1}{3\mu_1} + \frac{1}{\mu_2}\right) x. \tag{10}$$

The results of calculations by the formulas (6)-(10) at the edge of existence of stationary equations (1)-(5) are presented at the graphic of Fig. 2.

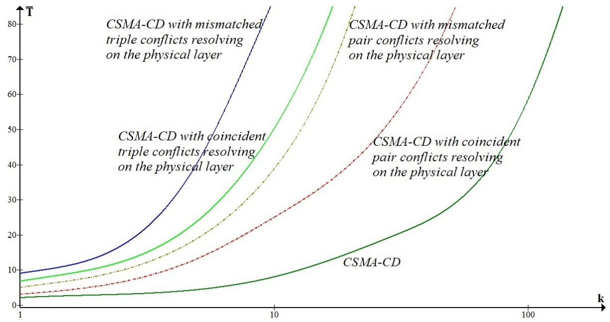


Fig. 2. Dependence of the average time before the successful transmitting from the intensities of applications servicing

The payment for an increasing the throughput at the CRPL is a significant growth of the average time before the successful transmitting in the analysed protocols when reached their throughputs. For example, even with $k = 5$ and solving conflicts of multiplicity 2, the average time before the successful transmitting is increased by 2.79 times, if the duration of the servicing of both applications coincide, and by 4 times, if not coincide.

Depending on the average time before the successful servicing from the intensity of the incoming stream (at $k = 10$) shown at graphic Fig. 3. The comparison of these graphics shows that when applying the protocols with the implementation of the CRPL procedures it is necessary to significantly shorter time before the successful transmitting with the served load equal to the protocol throughput without the CRPL. For example, with the CRPL the servicing of paired applications of non-coincidence durations is less than 2.9 times and 9.8 times – at their coinciding durations, and at CRPL multiplicity of 3 – in 7.6 and 18.7 times in accordance (see vertical dotted line at the Fig. 3). If, however, compare the average time before the start of the successful servicing of the CSMA-CD with the same condition, but without the CRPL, with this parameter in other protocols, we obtain an increasing of the throughput with the CRPL multiplicity of 2 in 1.3 and 1.8 times, and at multiplicity of 3 in 1.65 and 2.58 times - (see the horizontal dotted line in Fig. 4).

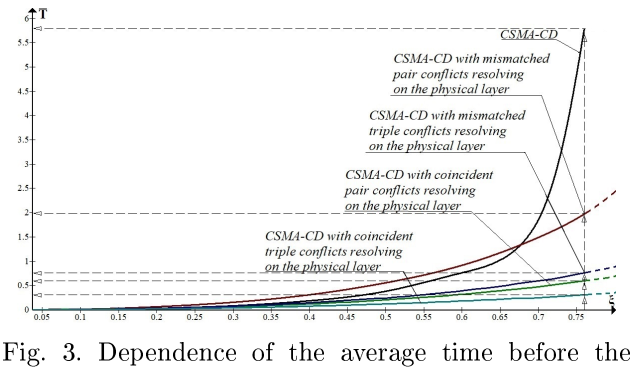


Fig. 3. Dependence of the average time before the successful transmitting from the intensity of the incoming stream of applications

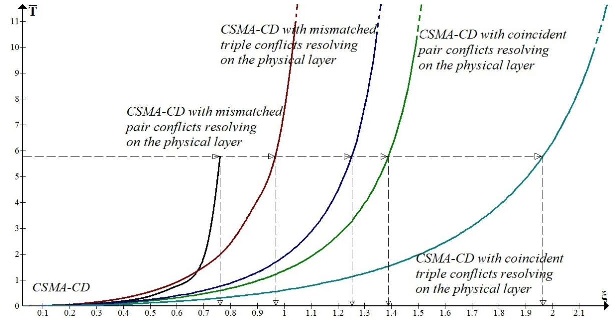


Fig. 4. Comparison of the served load of the CSMA-CD protocols with the CRPL with the classical CSMA-CD protocol

## Conclusions

1. Resolving conflicts at the physical layer significantly improves the throughput of the CSMA-CD protocol: in 1.33 ÷ 2 times, with the successful resolving conflicts of multiplicity 2 and 1.63 ÷ 3 times when solving conflicts of multiplicity 3. When really achievable values $k \in (5 \div 50)$ such an increase ranges from 1.38 to 2.2 when it is solving conflicts of multiplicity 2 and in the range from 1.72 to 3.46 when it is solving conflicts of multiplicity 3 in accordance, depending on the coincidence or non-coincidence of the servicing time of applications at the second stage.

2. The average time before the successful transmitting, assuming the CRPL and the incoming stream intensities equal to the throughput of the analyzed protocols, increases significantly – in 1.8 ÷ 5.67 times, depending on the multiplicity of resolving conflicts and the coincidence or non-coincidence of the servicing durations. At the same time, when the average time before the successful servicing is limited by the throughputs of the CSMA-CD protocols without the RCFR, the served load of the protocols with the CRPS increases in 1.3 ÷ 2.58 times, depending on the abovementioned factors.

3. Comparison of the throughputs and the average time before the successful servicing of CSMA-CD protocols proves the expediency of implementing CRPL even with minimal multiplicities of 2–3. The task of resolving conflicts with multiplicity greater than 2-3 exponentially complicates the demodulator circuits, and further increases the throughput (except when the duration of all the second phase applications is coincident).

## References


[1] Verdu S. (1998) *Multiuser Detection*, Cambridge University Press, 474 p.

[2] Lupas R. and Verdu S. (1989) Linear multiuser detectors for synchronous code-division multiple-access channels. *IEEE Transactions on Information Theory*, Vol. 35, Iss. 1, pp. 123-136. DOI: 10.1109/18.42183

[3] Ageev D.V. (1935) Osnovyi teorii lineynoy selektsii, *Nauchno-tehnicheskiy sbornik*, Iss. 10, pp. 8-28.

[4] Borisov Yu. and Penin P. (1967) *Osnovyi mnogokanalnoy peredachi informatsii*, Moskva, Svyaz, 435 s.

[5] Burachenko D. (1990) *Optimalnoe razdelenie tsifrovyih signalov mnogihpolzovateley v liniyah i setyah svyazi v usloviyah pomeh.* Leningrad: VAS, 302 p.

[6] Bobrovskiy V. (2007) *Mnogopolzovatelskoe detektirovanie.* Ulyanovsk: Vektor-S, 348 s.

[7] Yerokhin V. F. and Peleshok Y. V. (2016) Mathematical model coherent demodulation of synchronous mutually nonorthogonal digital signals with minimum frequency-shift keying, *Visnyk NTUU KPI Seriia - Radiotekhnika Radioaparatobuduvannia*, Iss. 64, pp. 41-50. doi: 10.20535/RADAP.2016.64.41-50.

[8] Klyuev V.F. (2015) *Issledovanie optimal'nykh kogerentnykh demodulyatorov AM i ChM signalov* [The study of optimal coherent demodulators AM and FM signals], Nizhniy Novgorod, 20 p.

[9] Gerasimenko E. S. (2017) Algorithm for digital coherent demodulation of phase-shift keyed signals and its characteristics, *Vestnik of Voronezh Institute of the Ministry of Internal Affairs of the Russian Federation*, no. 1, pp. 137-143.

[10] Glushkov A.N. and Gerasimenko E.S. (2017) Algorithm of digital coherent demodulation of binary signals with differential phase keying and its interference immunity *Vestnik Voronezhskogo gosudarstvennogo tekhnicheskogo universiteta*, No. 5, pp. 70-74.

[11] Sboyev R.Yu., Polyakova A.S. and Yerokhin V.F. (2018) Asymptotic analysis of the random multiple access protocol "Nonpersistent CSMA-CD" with pairwise conflicts resolving at the physical layer, *Problemy teplekomunikatsii*, 3p.

[12] Nazarov A.A. (1991) *Asimptoticheskiy analiz markoviziruemyih sistem*, Tomsk, TGU, 158 p.


## Параметри протоколів МДКН-ВК при розв'язанні конфліктів на фізичному рівні

*Єрохін В. Ф., Полякова А. С., Сбоєв Р. Ю., Голь В. Д.*

На теперішній час глобальне зростання потреб у зв'язку змушує нас 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 задача розділення цих сигналів. Очевидно, що складність процедур демодуляції суттєво зросте в порівнянні з класичними. Тому необхідно з'ясувати, чи буде виправданим таке зростання складності. Щоб відповісти на це питання, необхідно визначити – як збільшиться пропускна спроможність деякої системи зв'язку з випадковим 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. Були одержані параметри протоколів множинного доступу з контролем несівної та виявленням конфліктів за додаткових припущень про їх розв'язання на фізичному рівні. Показано, що в порівнянні з класичним протоколом за припущення про розв'язання парних конфліктів на фізичному рівні суттєво підвищується пропускна спроможність системи зв'язку з таким протоколом доступу. Наведені результати порівняння. Одержані результати дозволяють стверджувати про доцільність впровадження в демодулятори перспективних приймальних пристроїв алгоритмів розв'язання конфліктів на фізичному рівні як таких, що характеризуються відносно невеликою складністю.

*Ключові слова:* випадковий множинний доступ; МДКН-ВК; розв'язання конфліктів на фізичному рівні; теорія багатокористувацького детектування; системи масового обслуговування

## Параметры протоколов МДКН-ВК при разрешении конфликтов на физическом уровне

*Ерохин В. Ф., Полякова А. С., Сбоев Р. Ю., Голь В. Д.*

В статье представлены уравнения стационарности протоколов множественного доступа с контролем несущей и обнаружением конфликтов при дополнительном предположении о разрешении конфликтов на физическом уровне. Наведены результаты сравнения нескольких протоколов по пропускной способности и среднего времени до начала успешной передачи. Полученные результаты позволяют утверждать о целесообразности внедрения в демодуляторы перспективных приемных устройств алгоритмов решения конфликтов на физическом уровне с относительно небольшой сложностью.

*Ключевые слова:* случайный множественный доступ; МДКН-ВК; разрешение конфликтов на физическом уровне; теория многопользовательского детектирования; системы массового обслуживания