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METHODS OF ACCESSING LOCAL NETWORKS ENVIRONMENT

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Abstract: *In modern society, computers can be used in any field of human activity. The level of use of computing depends on how developed a particular country is. The richest countries are the most developed in the IT (information technology) field. The countries with the greatest natural resources: gas, oil, metals, etc., are not always the richest. Likewise, among the richest companies are also those in the IT field. Of the top 10 companies in the world, more than half are from the IT domain, which means that mean that billions of dollars are spent annually on the IT field. This results in the efficient utilization of allocated resources, so that the use of IT tools allows accessing and transferring information as quickly and comfortably as possible. Information can be managed from home, work, on the go. When we use IT tools at home, at work, we are talking about data transfer in local networks. The larger the network is (number of users, number of computers), the more stringent the requirements are. An important factor in meeting these requirements is how efficiently the data transfer medium is used.*

Keywords: xEthernet, network performance, methods of accessing the environment, CSMA/CD, persistent and nonpersistent CSMA.

JEL Classification: D85

1. Introduction

In modern society, computers can be used in any field of human activity. The level of use of the computing technique depends on how developed a particular country is, see Table 1, which lists the richest countries in the world by GDP. As you can see, the countries with the greatest natural resources: gas, oil, metals, etc., are not always the richest. For example, Russia, Iran, Iraq, Venezuela are the countries with the most natural resources but are not in the list of the richest countries (Please take a look at the following link for more details on https://www.investopedia.com/articles/markets-economy/090516/10-countries-most-natural-resources.asp accessed 08.08.2022).

Similarly, among the richest companies a lot of them are from the IT sector (Information Technology), see figure 1. As can be seen from this figure, the are 6 IT companies in the top 10 richest companies in the world: Apple, Microsoft, Alphabet, Amazon, Meta Platforms Inc (Facebook), Taiwan Semiconductor. The ones that mean that billions of dollars are spent annually on the IT field. This results in the efficient utilization of allocated resources, so that the use of IT tools allows accessing and transferring information as quickly and comfortably as possible. Information can be managed from home, work, transport, etc. When we use IT tools at home, at work, we are talking about data transfer in local networks. The larger the network is (number of users, number of computers), the more stringent the requirements are. An important factor in

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meeting these requirements is the method of connecting to the network. The connection method is chosen depending on how efficiently the data transfer medium is used.

In the 80s, when local area networks appeared, among the most popular we can mention Ethernet, Token Ring, Token Bus. Over time, other types of local networks appeared, but currently the most popular is Ethernet (Tanenbaum, et al., 2021). Token Ring, Token Bus are basically only used by the companies that developed them - IBM and General Motors respectively. As can be seen from table 2, current technologies are marked with an asterisk, those in decline - with a down arrow, those not used - with a cross. The standards that thrive are Ethernet, Wireless LANs, Personal Area Networks.

Table 1. List of the richest countries in the world 2022

	Country	Economy
1	United States	$25.347 trillion
2	China	$19.91 trillion
3	Japan	$5.396 trillion
4	Germany	$4.55 trillion
5	United Kingdom	$3.19 trillion
6	India	$3.18 trillion
7	France	$ 3.06 trillion
8	Italy	$3.18 trillion
9	Canada	$1.99 trillion
10	South Korea	$1.8 trillion

Source: https://www.jagranjosh.com/general-knowledge/ list-of-richest-countries-in-the-world-1637214709-1 (accessed 08.08.2022)

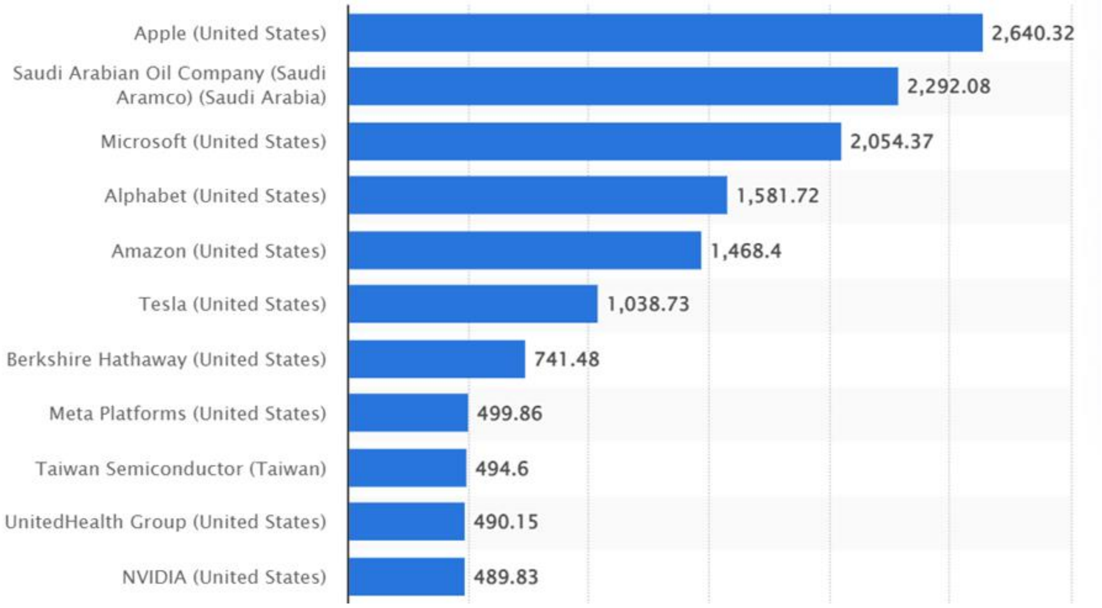

Figure 1. The largest companies in the world by market capitalization in 2022(in billion U.S. dollars).

Source: https://www.statista.com/statistics/263264/top-companies-in-the-world-by-market-capitalization/ (accessed 08.08.2022)

The popularity of xEthernet networks is due to the following factors:

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- It is backwards compatible. This means that we don't have to throw away older network cards, network equipment, etc. In this case the network can be renewed step by step depending on the available resources. For large organizations with many computers these expenses are significant.
- It is cheap compared to other types.
- There is no need for new specialists, existing ones can be retrained.
- Easily adapts to new requirements, where the main factor is the increase in data transfer speed. Since 2018, work is being done on standards capable of operating at speeds of 100 Gbps and 200 Gbps. The most numerous are small and medium local networks, and here in most cases 1 Gbps and 10 Gbps networks are used.

Table 2. The 802 working groups. The important ones are marked with *. The ones marked with ┼ gave up and stopped.

Number	**Topic**
802.1	Overview and architecture of LANs
802.2	Logical link control
802.3 *	Ethernet
802.4 ┼	Token bus (was briefly used in manufacturing plants)
802.5 ┼	Token ring (IBM's entry into the LAN world)
802.6 ┼	DQDB (Distributed Queue Dual Bus), early metropolitan area network
802.7 ┼	Technical advisory group on broadband technologies
802.8 ┼	Technical advisory group on fiber-optic technologies
802.9 ┼	Isochronous LANs (for real-time applications)
802.10 ↓	Virtual LANs and security
802.11 *	Wireless LANs (WiFi)
802.12 ┼	Demand priority (Hewlett-Packard's AnyLAN)
802.13	Unlucky number, nobody wanted it
802.14 ┼	Cable modems (defunct: an industry consortium got there first)
802.15 *	Personal area networks (Bluetooth, Zigbee)
802.16 ┼	Broadband wireless (WiMAX)
802.17 ┼	Resilient packet ring
802.18	Technical advisory group on radio regulatory issues
802.19	Technical advisory group on coexistence of all these standards
802.20	Mobile broadband wireless (similar to 802.16e)
802.21	Media independent handoff (for roaming over technologies)
802.22	Wireless regional area network

Source: Tanenbaum A.S., Wetherall D.J., Feamster N. Computer networks. 6th ed., p.73./
https://ro.wikipedia.org/wiki/IEEE_802 (accessed 12.08.2022)

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Although Token Ring and Token Bus networks are practically not used, in the beginning there was fierce competition between them and Ethernet networks. In Ethernet networks, the medium access method can be a variation of the CSMA/CD (Carrier Sense Multiple Access with Collision Detection) algorithm, where the station transmits at any time if the medium is free. Only, in this case, collisions may occur, at many stations this decreases the performance of the network. In Token Ring and Token Bus networks the station transmits when it is its turn, the station holding the token. On many computers, it ensures stable performance, according to the standard. But at low network load the performance (utilization) is low because the station must wait for its turn. So, in this case Ethernet networks are preferable. The medium access algorithms of next-generation Token Ring and Token Bus networks have been improved. But since they are too complex and considering the advantages of xEthernet networks, the latter have become the most popular (Hammond J., et al., 1986). Wireless LAN is another popular technology nowadays. This kind of networks use wireless access points (WAP or AP), where the WAP connects to the network, usually by cable, but the clients are connected wirelessly. Because wireless LANs connect to xEthernet LANs, they use an algorithm similar CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance).

2. Medium access methods in xEthernet networks

2.1. General characterization of CSMA/CD

All types of xEthernet networks (including Fast Ethernet, Gigabit Ethernet, etc.) use one and the same medium access method for CSMA/CD data transfer. The computers of such a network have common access to the transmission medium and at each moment of time it can be used for data transfer only between two stations. The data transmitted by a station are received by all stations of the network (Nanda K., 1989).

The data required for the transfer are put in data packets of a certain format in which is also the address of the destination computer. To start transmitting data, the station must check if the medium is free. This is done by carrier sense (CS), which for Manchester coding is 5-10 MHz, depending on the string of 0 or 1 bits transmitted at the given time.

If the transfer medium is free, the station can start transmitting data. Suppose that node 1 (see figure 2) found that the medium is free and started transmitting data. Destination station 3, recognizing its address from the packet, copies the packet into its own memory. The data packet is always preceded by the header (preamble), consisting of 8 bits.

After the packet transfer, all stations are obliged to retain a technological break called IGP (Inter Packet Gap) which for Ethernet technology is equal to 9.6 mks [6]. It is necessary to bring the network adapter to the initial state and to avoid monopoly use of the environment by a single station. Due to delays in signal transmission, obviously, not all stations simultaneously fix the end of the transfer.

According to the method described, it may happen that two stations start data transfer simultaneously, the environment control mechanism and the IGP pause do not guarantee that this situation cannot happen. In this case, a collision is said to have occurred, because the signals representing both packets overlap and the data is damaged.

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In the example in figure 2, the collision can occur when station 1 finds that the medium is free at approximately the same time as station 3 and both stations start transmitting data, not necessarily at the same time. Let station 1 start transmitting first. The signal has not yet reached station 3, and station 3 also finds that the medium is free and starts transmitting its own packet. Collisions are a normal thing for Ethernet networks, this results from the medium access method. If the signals transmitted and received by the station differ, collision detection (CD) takes place. The station that detected the collision interrupts the data transfer and broadcasts on the channel a short jamming signal with the length of 32 bits.

After transmitting the jamming signal, the station makes a pause of random duration t_0, which is determined as

$$t_0 = L\tau, \qquad (1)$$

where τ is the time interval from which the break is calculated. For Ethernet networks, these are 512-bit intervals (it is the time interval between two bits transmitted through the medium) or 51.2 mks (for the speed of 10 Mbps the interval between two bits is 0.1 mks). After this, she tries again to gain access to the environment (Олифер В., et al.,2020).

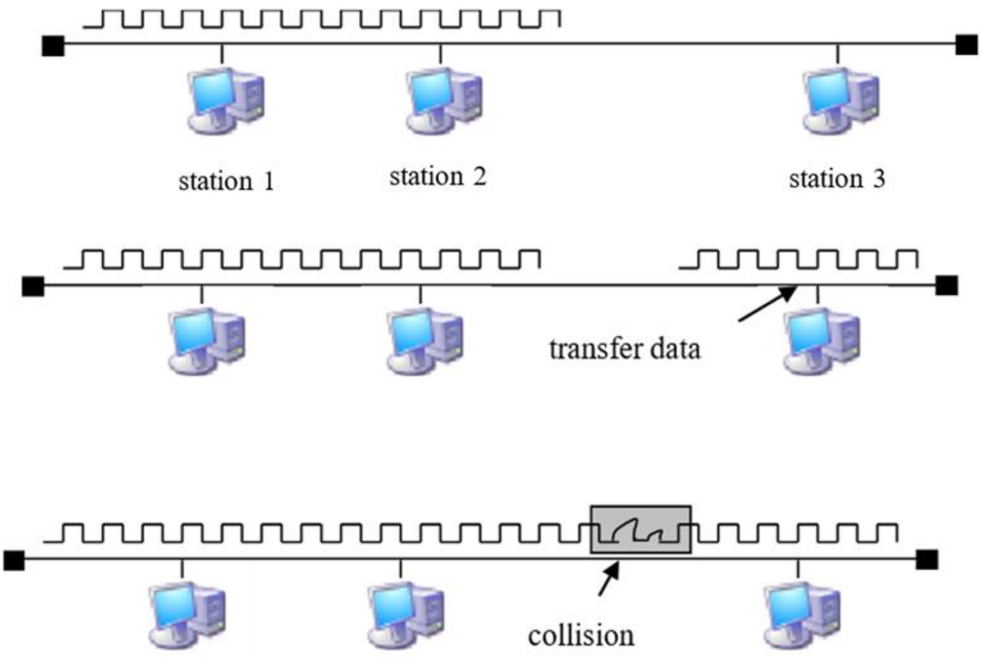

Figure 2. Collision in Ethernet networks.

Source: Prepared by the author

In formula 1, L is an integer from the interval $[0, 2^N]$, where $N = \{1, 2, \ldots 10\}$ is the number of attempts to obtain access to the environment. After the 10th trial, the interrupt duration stops increasing, so the random interrupt can take values between 0 and 52.4 ms. After the 16th attempt, the station stops trying to receive access to the medium and ends the data transmission process. But, after trial 10, the cutoff cannot be greater than 1023. Limiting the range to 1023 quanta prevents excessive delays. This algorithm, called the binary exponential backoff algorithm, was designed to dynamically adapt to the number of stations trying to transmit. If the random generation interval was for all

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collisions 1023, the chance of 2 stations colliding a second time is negligible, but the average waiting time after a collision would be hundreds of quanta, introducing a significant delay.

From the description of the medium access method, it has a random character and the probability of obtaining access to the medium depends on the network load, that is, on the number of stations and the intensity of the data transfer generated by each station. At the time of approval of this standard by IEEE, 1981, the speed of 10 Mbit/s was very high, compared to the need of stations to transmit data, therefore the transmission medium was never overloaded [9]. In the 90's, however, applications were already implemented that worked in real time with multimedia data, which overloaded the network. In such conditions, the number of collisions in the environment increases and the efficiency of the network operation decreases, because a large part of the time is spent trying to obtain access to the environment.

To reduce the intensity of collisions, the data traffic must be reduced, that is, the number of stations in a collision domain, using switches, or increasing the transmission speed, using Fast Ethernet, Gigabit Ethernet, etc.

2.2. Collision detection

Collision detection by all network stations is necessary for the correct operation of the Ethernet network. If any transmitting computer does not recognize the collision and believes that the data packet was transmitted correctly, then this packet will be lost. Due to the overlapping of signals upon collision, the data in the packet will be modified and the packet will be rejected by the destination station due to the mismatch of the checksum and as a result will be retransmitted by the higher layers, for example the transport or application layer. But retransmission by higher layers will waste more time (sometimes a few seconds) compared to a few milliseconds, with which the Ethernet protocol works.

Therefore, in order for collisions to be recognized, the condition $T_{\min} \geq PDV$ must be met, where T_{min} is the minimum volume data packet transmission time, and PDV (Path Delay Value) the time in which the collision signal manages to travel back and forth through the transmission medium between the most removed two stations from the network. That is why this time is called the double rotation time PDV (Олифер В., et al., 2020). If this condition is met, the station transmitting the data packet manages to identify the collision until the end of the transmission of the current data packet. It is obvious that this depends, firstly on the minimum length of the package, secondly on the length of the cable in the network and the speed of the signal transmission through the cable, because for different types of cable this speed is different.

Table 3. Ethernet MAC layer parameters

Parameter	Value
Data transfer speed	10 Mbps
IPG	9,6 mks
Maximum number of attempts to transmit data	16
The maximum number of intervals in which the pause increases	10
Jam packet length	32 biţi
Maximum message length (without header)	1518 octeţi

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Minimum message length (without header)	64 octeţi (512 biţi)
Header length	64 biţi
Minimum length of random break after collision	0 bt
Maximum length of random interruption after collision	524 000 bt
The maximum diameter of the network	2 500 m
Maximum number of stations	1024

Source: Виктор Олифер, Наталья Олифер. Принципы, технологии, протоколы. Учебник

Ethernet standards provide specific values for these parameters. The minimum length of the data field in the packet is 46 bytes, and together with the address fields, the checksum, etc. is 64 bytes, and together with the header, 72 bytes or 576 bits are received. From here we can find the maximum distance between any two stations or, more correctly speaking, between the two furthest stations. So, in the Ethernet network of 10 Mbps the bit intervals, is 57,5 mks. The distance that can be traveled in this time, for example, for the coaxial cable is 13280 m. Because this distance must be traveled twice, the maximum allowed distance for the coaxial cable is 6635 m. In reality, this distance is reduced due to other factors, one of the most important being signal attenuation.

To ensure the necessary signal strength, for the coaxial cable the maximum length of a segment is 500 m. Here PDV = 43.3 < 72 bytes, so this length would still need to be reduced, but considering that different network segments are connected by repeaters, which bring the signal strength back to normal, it was decided not to reduce this length. Given that no more than 4 repeaters can be used for coaxial cable, that is, 5 cable segments can be used, the maximum length in this case is 2500 m.

The values of the basic parameters of the 802.3 standard, which do not depend on the cable used, are given in table 3. If the type of cable is considered, some parameters have much narrower values, in other cases the values shown are more restrictive.

2.3. Channel efficiency in Ethernet Networks

Let us examine the performance of the 802.3 standard under heavy load conditions, when k stations are always ready to transmit. A rigorous analysis of the binary exponential regression algorithm would be complicated. Instead, we will research using the method Metcalfe and Boggs used in 1976 and will assume a constant retransmission probability for each quantum. If each station transmits during a conflict quantum with probability p, the probability A that a station receives the channel in this quantum is $A = kp(1 - p)^{k-1}$ (Tanenbaum, et al., 2021).

A is maximum when $p=1/k$ and $A \to 1/e$ then $k \to \infty$. The probability that the conflict interval has j quanta is $A(1-A)^{j-1}$, so the average number of quanta per conflict is:

$$\sum_{j=0}^{\infty} jA(1-A)^{j-1} = \frac{1}{A}$$

Since each quantum lasts 2τ, the average conflict interval, $w= 2\tau/A$. Let p be optimal. The average number of conflict quanta is never greater than e, so w is at most $2\tau e \approx 5.4\tau$.

When several stations want to transmit frames of average length, then P seconds are required. In this case the channel efficiency is:

$$Channel\ efficiency = \frac{P}{P+2\tau/A} \qquad (2)$$

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As we can see, the maximum cable length influences the productivity of Ethernet networks. The longer the cable is, the longer the conflict interval is. Because of this, the maximum length of a collision domain is imposed.

It is instructive to formulate equation (2) also in terms of frame length *F*, network bandwidth *B*, cable length *L* and signal propagation speed *c*, for the optimal case with *e* conflict quants per frame. With $P = F/B$, equation (2) becomes:

$$\text{Channel efficiency} = 1 / (1 + 2BLe/cF) \quad (3)$$

When the denominator is high, the efficiency of the network will be low. More specifically, increasing bandwidth or distance (*BL* product) reduces efficiency for a given frame length. Figure 3 shows the efficiency of the channel as a function of the number of states ready for transmission, for 2τ=51.2 µs and a data transmission rate of 10 Mbps.

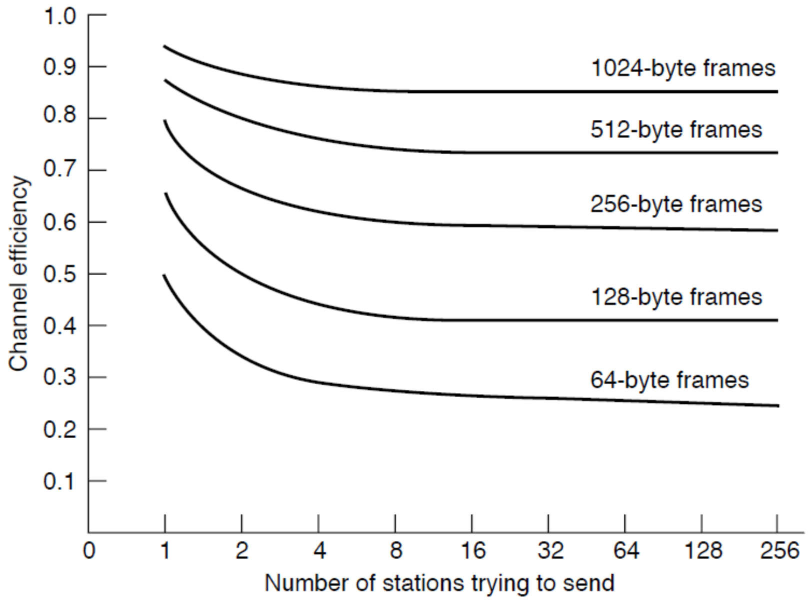

Figure 3. Efficiency of Ethernet at 10 Mbps with 512-bit slot times.

Source: Tanenbaum A.S., Wetherall D.J., Feamster N. Computer networks. 6th ed. 2021

When a station wants to transmit data with a quantum size of 64 bytes, the channel efficiency is about 0,5. But as the number of stations wishing to transmit increases, the efficiency of the channel drops sharply. The ones that mean that 64-byte frames are not effective. On the other hand, with 1024-byte frames and an asymptotic *e*-value of 64 bytes per contention interval, the channel efficiency drops to 0,85. The ones that mean that Ethernet networks work efficiently.

Another way to improve user experience is to use faster networks. As mentioned, Gigabit Ethernet (1000 Mbps) and 10 Gigabit Ethernet networks are currently common. But already, 100 and 200 Gigabit Ethernet standards have appeared.

When local networks appeared, the most used network device was the repeater (hub). Which means that the local network forms a single collision domain (bus topology), in modern networks switches are used that divide the network into several collision domains (star topology). This fact further improves the performance of xEthernet networks, and some restrictions disappear. For example, the size of the network can already be theoretically unlimited, the restriction on the

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maximum length of the cable remains. If the network is very large, for security reasons it can be divided into several networks using VLANs or routers. The most efficient routers divide the local network into several parts, those that allow to increase the level of security, network performance, and in case of problems in one network, segment isolates the other networks from these problems. In the case of a single network, when using repeaters and switches, problems in one network segment spill over into other segments.

3. Efficiency of different environment access protocols

Above we discussed the performance of the CSMA protocol, but it has several versions. Besides this the CSMA protocol is an improvement of the ALOHA protocol. Which in turn, likewise, has many versions. The analyzed protocols are part of multiple access protocols. To increase the productivity of networks it is important which method of access to the environment we use. Therefore, let's do a small comparison of the most popular protocols in the field.

3.1 ALOHA

In the 1970s, Norman Abramson and his colleagues at the University of Hawaii developed an elegant new method for solving the channel allocation problem. Abramson's creation, called the ALOHA system, was used to transmit data between computers on different islands. Because the cable connection of computers on different islands is expensive and difficult to achieve for technical reasons or use radio waves, the wireless connection. We will examine the most popular pure ALOHA and quantized ALOHA methods. In quantized ALOHA the time to send the data frame is divided into discrete intervals, intervals into which any frame must fit. In pure ALOHA it does not require global time synchronization, while quantized ALOHA does.

In pure ALOHA users send data whenever they have something to send. Using this method there will be collisions and overlapping packets must be retransmitted, as it is shown in figure 4. In a LAN, the reaction is immediate. In a satellite network, there is a delay of 270 ms before the transmitter knows whether the transmission has completed successfully. After that, users who have transmitted data, must wait a random amount of time, and retransmit. The wait time must be random, otherwise the same frames will collide over and over, blocking each other endlessly.

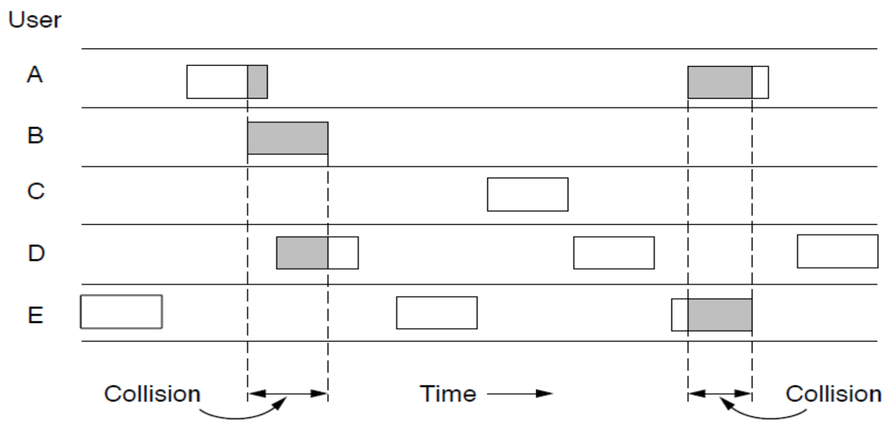

Figure 4. In pure ALOHA, frames are transmitted at completely arbitrary times

Source: Tanenbaum A.S., Wetherall D.J., Feamster N. Computer networks. 6th ed. 2021

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As you can see, with a large number of users, the network efficiency decreases. The more is the number of users, the higher is the probability that we will have a collision again on the next attempt. Let's see how the network behaves depending on the number of attempts. Let we have *N* users and the probability of having *k* transmission attempts per frame interval, including retransmissions has a Poisson distribution, with mean *G* per frame interval. Obviously, $G \geq N$. Then the productivity is: $S = GP_0$, where P_0 is the probability that a frame does not suffer collisions. It was calculated that for pure ALOHA the maximum productivity is 18%, but with the increase in the number of attempts (number of users) the productivity drops dramatically, see figure 5.

In 1972, Roberts published a method for doubling the capacity of an ALOHA system. His proposal was to divide time into discrete intervals, each interval corresponding to a frame. This approach requires users to agree on the quantum size (Nanda K., 1989). One way to achieve synchronization would be for a special station to emit a "beep" at the beginning of each interval, like a clock tick. The given method is called quantized ALOHA, and it essentially reduced the number of collisions. The network productivity in this case is calculated as [4]: $S = Ge^{-G}$. When $G = 1$, with a productivity of $S = 1/e$, i.e. approximately 0.368, double that of pure ALOHA. In this case the probability of an unused quanta is 0.368. The best performance we can expect from quantized ALOHA is: 37% unused quanta, 37% successfully transmitted frames, and 26% collisions.

3.2. Persistent and non-persistent CSMA

During the 80's, when creating Ethernet networks, the ALOHA method was taken, and some changes were made. From the beginning, Ethernet networks used thick and thin coaxial cable, then twisted pair and optical were added. The first protocol is CSMA 1-persistent (Carrier Sense Multiple Access). The basic change is that before transmitting the station listens to the environment. If the medium is free the station starts transmitting. If the medium is busy or there is a collision, the station waits for a random amount of time. The protocol is called 1-persistent, because the probability that a station transmits when it finds a free channel is equal to 1.

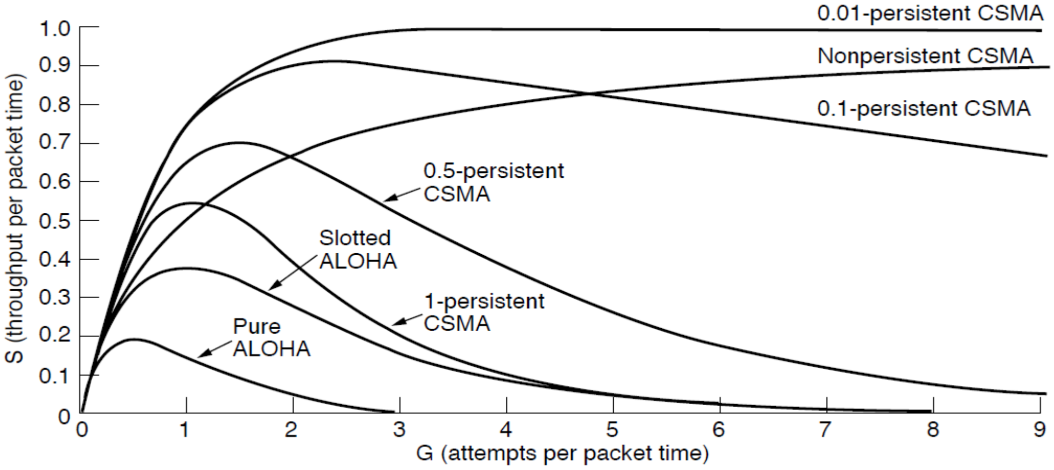

Figure 5. Comparison of the channel utilization versus load for various random access protocols.

Source: Tanenbaum A.S., Wetherall D.J., Feamster N. Computer networks. 6th ed. 2021

In the non-persistent CSMA protocol, the station is less "greedy" than in the previous one. Before broadcasting, the station listens to the channel. If no one is transmitting data, it starts

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transmitting. But if the channel is busy, the station does not remain continuously listening, but waits for a random period and then repeats the algorithm. This algorithm allows a better use of the channel, but also at higher delays than CSMA 1-persistent (Hammond J., et al., 1986).

The following protocol is p-persistent CSMA applied to quantized channels. The station that wants to transmit listens to the channel. If the medium is free - it transmits with probability p and with probability $q = 1\text{-}p$ it will wait for the next quantum. At the next quantum, likewise, it will transmit or wait with probability p and q respectively. Let's see next what the network performance is for different medium access methods (see figure 5).

As can be seen, quantized ALOHA has twice the productivity of pure ALOHA. In addition, it allows the number of attempts to transmit a packet to be greater, which means that it allows the simultaneous work of several users. It is received that quantized ALOHA allows more convenient work (fast transfer) of a larger number of users. But compared to CSMA the ALOHA model is about twice as slow even for the most pessimistic model.

Let's compare different CSMA models, first non-persistent CSMA is better than CSMA 1 and 0.5 persistent. But already for persistent CSMA 0.01 the situation changes. At first, a small number of users cannot load the channel to 100%, and the network productivity increases with the increase in the number of users. Even for a large number of users (attempts per packet), the persistent CSMA 0.01 ensures a productivity close to 100% of the channel bandwidth and does not decrease even as G increases from 2 to 9. This is due to the fact that, when transmitting data, even if the channel is free, the station transmits with probability 0.01 and with probability 0.99 it will wait for the next amount of time. Which ensures ideal productivity even with a large number of users.

Conclusions

From year to year computer networks are used more widely, the speed of data transfer has an important role in economic development. Because of this, every year billions of dollars are spent on maintaining networks, producing network equipment, developing new technologies in the field. Therefore, the efficient use of computer network resources is of great importance. An important factor in the use of resources is the method of access to the environment, which is a factor that depends on the speed of data transfer, the number of users who can work comfortably in the network. Typically, users work from local Ethernet networks. That is why in the paper a comparison was made of the methods of accessing the medium in Ethernet networks and its predecessor the ALOHANET network. A qualitative description and comparison of pure ALOHA, quantized ALOHA, various versions of persistent CSMA and non-persistent CSMA media access methods was made. It has been shown that the CSMA 0.01-persistent method works most efficiently, even in the worst conditions, with a large number of users it works with a high efficiency, close to 100%.

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