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RESEARCH ARTICLE

Analysis of information transmission processes in multimode fiber-optic networks with a token-based access method

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Abstract

Objectives. The study sets out to develop and analyze a mathematical model for information transmission in multimode fiber-optic ring networks using a token-based access method to ensure efficient interaction between Internet of Things (IoT) devices. The work aims to evaluate the probabilistic and time-related characteristics, as well as the reliability and performance of the network infrastructure to optimize data transmission parameters, taking into account the specifics of IoT and the peculiarities of the fiber-optic medium.

Methods. Reliability theory methods are used to assess the network's resilience to failures and increase its operational efficiency, along with techniques from the theory of stochastic processes to model the dynamics of data transmission under varying loads and approaches from queueing theory to analyze traffic distribution and packet queue management. The Laplace–Stieltjes transform is applied to derive functional equations that describe the probabilistic and time-related data transmission characteristics, enabling precise mathematical modeling of network processes.

Results. The information transmission processes occurring in multimode fiber-optic networks with token access in the context of IoT systems were studied. The temporal characteristics of packet transmission for different classes, including critical IoT device data, were analyzed.

Conclusions. The results confirm that multimode fiber-optic media provide an efficient foundation for IoT infrastructure that offers both high throughput and fault tolerance. By incorporating reliability characteristics into the model, it was possible to account for the impact of fiber-optic medium and network node failures on performance. Optimizing the parameters of the token-based access method, including time intervals and token transmission policies, significantly improves overall network performance by reducing collision probability and increasing throughput. The developed mathematical model provides an effective tool for analyzing and designing local networks based on multimode fiber-optic technologies. This fact is especially important for networks serving critical infrastructure.

Keywords: FDDI networks, token-based access method, models, temporal characteristics, failures, performance

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НАУЧНАЯ СТАТЬЯ

Анализ процессов передачи информации в многомодовых оптоволоконных сетях с маркерным методом доступа

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Резюме
Цели. Целью работы являются разработка и анализ математической модели передачи информации в многомодовых оптоволоконных кольцевых сетях с маркерным методом доступа для обеспечения эффективного взаимодействия устройств интернета вещей (Internet of Things, IoT). Работа направлена на оценку вероятностно-временных характеристик, надежности и производительности сетевой инфраструктуры, а также оптимизацию параметров передачи данных с учетом специфики IoT и особенностей оптоволоконной среды.
Методы. В ходе исследования применены методы теории надежности для оценки устойчивости сети к отказам и увеличения ее эксплуатационной эффективности, методы теории случайных процессов для моделирования динамики передачи данных в условиях изменяющейся нагрузки, а также методы теории массового обслуживания для анализа распределения трафика и управления очередями пакетов. Дополнительно использовано преобразование Лапласа – Стилтьеса, позволяющее вывести функциональные уравнения, описывающие вероятностно-временные характеристики передачи данных и обеспечивающие точное математическое моделирование сетевых процессов.
Результаты. Исследованы процессы передачи информации в многомодовых оптоволоконных сетях с маркерным доступом в контексте IoT-систем. Проведен анализ временных характеристик передачи пакетов различных классов, включая критически важные данные IoT-устройств.
Выводы. Результаты исследования подтверждают, что многомодовая оптоволоконная среда является эффективной основой для IoT-инфраструктуры, обеспечивая высокую пропускную способность и устойчивость к отказам. Включение характеристик надежности в модель позволило учесть влияние отказов оптоволоконной среды и узлов сети на производительность. Оптимизация параметров маркерного метода доступа, включая временные интервалы и политику передачи маркеров, существенно повышает общую производительность сети, снижая вероятность коллизий, и увеличивает пропускную способность. Разработанная математическая модель предоставляет эффективный инструмент для анализа и проектирования локальных сетей на основе многомодовых оптоволоконных технологий. Это особенно важно для сетей, обслуживающих критически важные инфраструктуры.

Ключевые слова: FDDI-сети, маркерный метод доступа, модели, временные характеристики, отказы, производительность

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INTRODUCTION

Multimode access methods are a type of data transmission technique in fiber optic systems that are widely used to increase the capacity and efficiency of information transmission. The basic principle consists in the simultaneous transmission of light signals through several independent modes representing different trajectories of light propagation inside the fiber core. Since each mode acts as an independent communication channel, this enables parallel data transmission.

Especially in high-bandwidth systems, multimode access methods enable efficient scaling of transmitted data volumes. With an increase in the number of modes or the bandwidth of each mode, such systems find application in high-speed optical networks, including backbone communication channels and local networks.

The characteristics of data processing and transmission systems in network structures are largely determined by the reliability of the transmission medium, taking into account possible failures and malfunctions [1–3]. However, in many studies, the temporal parameters of transmission are considered in isolation, without taking into account reliability factors, while fault tolerance analysis often does not include the influence of information processing and transmission technologies. Therefore, when studying multimode fiber optic transmission systems, mathematical methods that consider possible failures of the transmission medium are used to evaluate the temporal characteristics. In [1, 2], the authors developed mathematical methods for analyzing the probabilistic-temporal characteristics of data transmission in networks with a token access method, taking into account the impact of failures, as well as methods for assessing the resource loading and performance of such network structures. Due to their versatility and potential, multimode access methods are becoming an important tool for building high-speed optical networks, including backbone communication channels, data centers and local area networks [4–6]. These technologies provide flexibility of scaling by increasing the number of modes, improving transmission quality, and increasing the throughput of each modulation trajectory.

1. MULTIMODE FIBER STRUCTURE

In a multimode fiber optic cable, the core diameter is larger compared to single-mode fibers. This fact enables light to propagate through different modes. Each mode represents a specific path of light propagation within the fiber, determined by physical laws (light entry angle, core and cladding properties).

In multimode method, data is distributed among the available modes. Each mode acts as a separate communication channel, providing independent data transmission [7, 8]. Such transmission methods utilize channel sharing features including:

- wavelength-division multiplexing (WDM), where each mode is allocated a specific wavelength;
- time division multiplexing (TDM), where each mode transmits data in the allotted time slot;
- increase in throughput capacity without significant increase in equipment cost;
- scalability of the system by increasing the number of modes;
- parallel data processing, which is especially important for highly loaded networks [9–11].

Since different modes pass through the fiber at different speeds, temporal blurring of the signal can occur. Multimode fibers are typically used over short distances (e.g., in local area networks) due to high signal loss and dispersion.

Increasing the complexity of signal processing implies the need for specialized equipment for separating modes, eliminating mutual interference between them, and ensuring the stability of data transmission, which requires additional tuning and calibration of the system to achieve optimal signal quality.

In the context of the industrial internet, multimode fiber optic systems are used to provide high-speed data exchange in the presence of a large number of connected devices[1] [12–17].

Multimode systems can be easily integrated with a variety of transmission protocols including Ethernet and Fiber Channel[2]. Increasing the number of modes or upgrading the system can increase network performance at no significant cost.

2. LIMITATIONS OF THE MULTIMODE METHOD

Data transmission in the network is carried out considering packet length requirements, data flow intensity from each node, and time constraints specified by the customer.

To investigate the process of data transmission in the network, the token access method was used. Modeled network parameters were: number of nodes N_{nodes}; intensity of packets arrival in the network nodes for each mode λ_k, $k = \overline{1, N}$; bandwidth of the transmitting medium C; failure rate of the transmitting medium λ_{fail}; length of the transmitted packet L_{pack}; limitation on the

[1] Kleinrock L. To Mario Gerla, the Maestro of Networks. *Ad Hoc Networks*. 2019;88:178–179. https://www.lk.cs.ucla.edu/data/files/Mario%20Gerla%20tribute%20by%20Len.pdf. Accessed June 24, 2025.

[2] Fiber Channel is a family of protocols for high-speed data transmission. The protocols are standardized by the T11 Technical Committee, part of the International Committee for Information Technology Standards.

time of packet transmission of each mode in the network $T_{\text{dir}}^{(1)}$ (directive time). The following parameters were determined for each mode: node polling cycle $Z^{(1)}$; node utilization ρ_k, $k=\overline{1,N}$ and transmission medium R_{medium}; packet delivery time $T_k^{(1)}$; probability of timely packet delivery taking into account the reliability of the transmission medium Q_k, $k=\overline{1,N}$; network performance λ_{tot}.

The total intensity of timely served flow for each mode is chosen as an estimate of network performance:

$$\lambda_{\text{tot}}=\sum_{k=1}^{N}\lambda_k Q_k.$$

Let the bandwidth C, the network architecture with N_{nodes} nodes, N packet flows for each mode with intensities λ_k, $k=\overline{1,N}$, and data transmission time constraints be given.

The packet flows λ_k for each mode and the transmission medium failures λ_{fail} are Poissonian in nature; the buffer devices of the nodes have unlimited capacity. The number of nodes in the network and the number of packet flows are the same for each mode.

3. THEOREM ON THE EVALUATION OF THE POLLING CYCLE IN TOKEN NETWORKS

The polling cycle of network nodes for each mode is directly proportional to the number of nodes, length of a marker, and inversely proportional to the throughput capacity of the transmitting medium and the probability that the medium is free from packet transmission of this mode.

If these conditions of the theorem are fulfilled, the cycle of node polling in the reliable operation mode is described by the following relation:

$$Z^{(1)}=\frac{N_{\text{node}}\dfrac{L_{\text{m}}}{C}}{1-\sum\limits_{k=1}^{N}\lambda_k\dfrac{L_{\text{pack}}}{C}}, \tag{1}$$

where L_{m} is the length of the marker, and taking into account failures of the transmitting medium—by the formula:

$$Z_{\text{fail}}^{(1)}=\frac{Z^{(1)}}{1-\lambda_{\text{fail}}F_{\text{fail}}^{(1)}}, \tag{2}$$

where $F_{\text{fail}}^{(1)}$ is the average time of medium performance recovery after failure.

Proof. Let $T_{\text{pack}}=\dfrac{L_{\text{pack}}}{C}$ is the time of the packet transmission from one node to another. Obviously, the polling cycle of the network nodes (the average interval between two consecutive polls of a node) is equal to:

$$Z^{(1)}=\sum_{k=1}^{N}\left\{\rho_k\left(\frac{L_{\text{pack}}}{C}+\frac{L_{\text{m}}}{C}\right)+(1-\rho_k)\frac{L_{\text{m}}}{C}\right\}= \\ =\sum_{k=1}^{N}\left\{\rho_k\frac{L_{\text{pack}}}{C}+\frac{L_{\text{m}}}{C}\right\}. \tag{3}$$

In the stationary mode, $\lambda_k Z^{(1)}=\rho_k$. Multiplying Eq. (3) by λ_n, $n=\overline{1,N}$, we obtain a system of N linear inhomogeneous equations relative to ρ_n:

$$\lambda_n\sum_{k=1}^{N}\left\{\rho_k\left(\frac{L_{\text{pack}}}{C}\right)+\frac{L_{\text{m}}}{C}\right\}=\rho_n. \tag{4}$$

Let us choose any two equations for ρ_i and ρ_j:

$$\lambda_i\sum_{k=1}^{N}\left\{\rho_k\frac{L_{\text{pack}}}{C}+\frac{L_{\text{m}}}{C}\right\}=\rho_i, \tag{5}$$

$$\lambda_j\sum_{k=1}^{N}\left\{\rho_k\frac{L_{\text{pack}}}{C}+\frac{L_{\text{m}}}{C}\right\}=\rho_j. \tag{6}$$

Multiplying Eq. (5) by λ_j and Eq. (6) by λ_i and subtracting one equation from the other, we obtain $\rho_i\lambda_j=\rho_j\lambda_i$, therefore: $\rho_i=\rho_j\dfrac{\lambda_i}{\lambda_j}$.

Similarly, we can express all ρ_k, $k=\overline{1,N}$ via $\rho_1:\rho_k=\rho_1\dfrac{\lambda_k}{\lambda_1}$. Substituting these relations into the first equation of the system of Eqs. (4), we obtain:

$$\lambda_1\sum_{k=1}^{N}\left\{\rho_1\frac{\lambda_k}{\lambda_1}\frac{L_{\text{pack}}}{C}+\frac{L_{\text{m}}}{C}\right\}=\rho_1, \\ \rho_1\sum_{k=1}^{N}\left\{\lambda_k\frac{L_{\text{pack}}}{C}\right\}+\frac{NL_{\text{m}}}{C}\lambda_1=\rho_1, \tag{7}$$

$$\rho_1=\frac{N_{\text{node}}L_{\text{m}}}{C\left(1-\sum\limits_{k=1}^{N}\left\{\lambda_k\dfrac{L_{\text{pack}}}{C}\right\}\right)}\lambda_1, \tag{8}$$

$$Z^{(1)}=\frac{\rho_1}{\lambda_1}=\frac{N_{\text{node}}L_{\text{m}}}{C\left(1-\sum\limits_{k=1}^{N}\left\{\lambda_k\dfrac{L_{\text{pack}}}{C}\right\}\right)}. \tag{9}$$

The loading of the transmission medium is equal to:

$$R_{\text{medium}} = \sum_{k=1}^{N} \lambda_k \frac{L_{\text{pack}}}{C}.$$

In steady-state mode, the load of the medium is equal to the probability that packets are transmitted in the medium. Accordingly, the value $1-\sum_{k=1}^{N} \lambda_k \frac{L_{\text{pack}}}{C}$ is the probability that the medium is free from packet transmission.

As can be seen, Eq. (9) coincides completely with Eq. (1), which proves the first part of the token network polling cycle theorem.

Functional equations for determining the cycle of local computing systems with token access method taking into account emerging failures have the form [1]:

$$\begin{cases} Z^*_{\text{fail}}(s) = Z^*(\lambda_{\text{fail}} + s - \lambda_{\text{fail}}\Gamma^*_{\text{fail}}(s)), \\ \Gamma^*_{\text{fail}}(s) = F^*_{\text{fail}}(\lambda_{\text{fail}} + s - \lambda_{\text{fail}}\Gamma^*_{\text{fail}}(s)), \end{cases}$$
$$\begin{cases} Z^*_{\text{fail}}(s) = \int_0^\infty e^{-st} dZ_{\text{fail}}(t), \\ \Gamma^*_{\text{fail}}(s) = \int_0^\infty e^{-st} d\Gamma_{\text{fail}}(t), \end{cases} \quad (10)$$
$$\begin{cases} Z^*(\lambda_{\text{fail}} + s - \lambda_{\text{fail}}\Gamma^*_{\text{fail}}(s)) = \int_0^\infty e^{-(\lambda_{\text{fail}} + s - \lambda_{\text{fail}}\Gamma^*_{\text{fail}}(s))t} dZ(t), \\ F^*_{\text{fail}}(\lambda_{\text{fail}} + s - \lambda_{\text{fail}}\Gamma^*_{\text{fail}}(s)) = \int_0^\infty e^{-(\lambda_{\text{fail}} + s - \lambda_{\text{fail}}\Gamma^*_{\text{fail}}(s))t} dF(t), \end{cases}$$

where $Z_{\text{fail}}(t)$ is the distribution function (DF) of the local area network cycle taking into account failures; $Z(t)$ is the DF of the local area network cycle under conditions of reliable operation; $F_{\text{fail}}(t)$ is the DF of the transmission medium recovery time after failures; $\Gamma_{\text{fail}}(t)$ is the DF of the transmission medium occupancy period after failures; s is the complex parameter of the Laplace transform.

Let us differentiate the first functional Eq. (10) by s:

$$\left(Z^*_{\text{fail}}(s)\right)' = \left(\int_0^\infty e^{-(\lambda_{\text{fail}} + s - \lambda_{\text{fail}} G^*_{\text{fail}}(s))t} dZ(t)\right)' =$$
$$= -\int_0^\infty t e^{-(\lambda_{\text{fail}} + s - \lambda_{\text{fail}} G^*_{\text{fail}}(s))t} \left(1 - \lambda_{\text{fail}} \left(G^*_{\text{fail}}(s)\right)'\right) dZ(t),$$

at $s \to 0$ $(Z^*_{\text{fail}}(s))'|_{s=0} = -Z^{(1)}_{\text{fail}}$,

$\lambda_{\text{fail}} + s - \lambda_{\text{fail}}\Gamma^*_{\text{fail}}(s)|_{s=0} = 0$, $(\Gamma^*_{\text{fail}}(s))'\big|_{s=0} = -\Gamma^{(1)}_{\text{fail}}$,

$$-\int_0^\infty t e^{\left\{-(s+\lambda_{\text{fail}} - \lambda_{\text{fail}}\Gamma^*_{\text{fail}}(s))t\right\}} (1 - \lambda_{\text{fail}}(\Gamma_{\text{fail}}(s)') dZ(t)|_{s=0} =$$
$$= -Z^{(1)}(1 + \lambda_{\text{fail}}\Gamma^{(1)}_{\text{fail}}).$$

Therefore,

$$Z^{(1)}_{\text{fail}} = Z^{(1)}(1 + \lambda_{\text{fail}}\Gamma^{(1)}_{\text{fail}}). \quad (11)$$

Differentiating the second functional Eq. (10) by s and finding the limit at $s \to 0$, we obtain the following relation for determining the average value of the occupancy period of the transmission medium after failure:

$$\Gamma^{(1)}_{\text{fail}} = \frac{F^{(1)}_{\text{fail}}}{1 - \lambda_{\text{fail}} F^{(1)}_{\text{fail}}}. \quad (12)$$

Substituting Eq. (12) into Eq. (11), we obtain:

$$Z^{(1)}_{\text{fail}} = \frac{Z^{(1)}}{1 - \lambda_{\text{fail}} F^{(1)}_{\text{fail}}}. \quad (13)$$

Eq. (13) completely coincides with Eq. (2), which proves the second part of the theorem on the cycle of polling of marker networks with regard to failures.

4. PACKET SERVICE CYCLE DEPENDENCE ON THE NUMBER OF NODES FOR DIFFERENT TYPES OF TRANSMITTED PACKETS

The present work investigates information transmission processes in multimode fiber optic transmission media using mathematical methods for calculating network structures with token access method developed earlier by the authors [1]. In the calculations, a four-mode fiber optic transmission medium with a bandwidth of 280 Mbps for each mode was analyzed. The length of the fiber channel can reach 100 km as well as in Fiber Distributed Data Interface (FDDI) networks with tokenized access. The modes were parameterized as follows:

- Length of packets transmitted using the first mode $L_{\text{pack 1}} = 1024$ bit; packet transmission time constraint $T_{\text{dir 1}} = 0.00025$ s; intensity of packets arriving in the network from each node $\lambda_{1i} = 2000$ pack/s.
- Length of packets transmitted using the second mode $L_{\text{pack 2}} = 2048$ bit; packet transmission time constraint $T_{\text{dir 2}} = 0.0005$ s; intensity of packets arriving in the network from each node $\lambda_{2i} = 1100$ pack/s.
- Length of packets transmitted using the third mode $L_{\text{pack 3}} = 4096$ bit; packet transmission time constraint $T_{\text{dir 3}} = 0.00075$ s; intensity of packets arriving in the network from each node $\lambda_{3i} = 590$ pack/s.
- Length of packets transmitted using the fourth mode $L_{\text{pack 4}} = 8192$ bit; packet transmission time constraint $T_{\text{dir 4}} = 0.001$ s; intensity of packets arriving in the network from each node $\lambda_{1i} = 300$ pack/s.

Table. Dependence of packet service time in multimode ring network on failure rate

λ_{fail}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	Without failure
T (L_{pack} = 1024 bit), s	0.003408	0.0004444	0.0001485	0.0001189	0.0001156
T (L_{pack} = 2048 bit), s	0.003765	0.000552	0.0002312	0.0001991	0.0001955
T (L_{pack} = 4096 bit), s	0.004485	0.0008598	0.0004978	0.0004617	0.0004576
T (L_{pack} = 8192 bit), s	0.004669	0.001029	0.0006856	0.0006513	0.0006475

A token-based access method was used to control the transmission of different classes of packets by means of a four-mode fiber ring. The length of the token L_m = 96 bit; the bandwidth of each mode is 280 Mbit/s. In the calculations, it was assumed that the MTBF of the transmission medium can take values of 10^4 s, 10^5 s, 10^6 s, 10^7 s and ∞; the failure recovery time is T_{rec} = 60 s.

In the calculations, the dependence of the packet service cycle, node and transmission medium load, packet service time, the probability of timely service of packets transmitted using different modes, and the performance of a multimode fiber optic network on the number of nodes connected to the transmission medium was investigated. The corresponding graphs are shown in Figs. 1–6.

The dependence of packet service time in a multimode ring network in the critical area of operation (at N_{node} = 110) on the intensity of failures is presented in Table.

As can be seen from the graphs (Figs. 1–6), as the number of nodes increases (with network scaling) in a multimode fiber optic network using the token access method, the load of the transmission medium and network nodes, the node polling cycle, and the transmission time of packets transmitted by different modes also increase; after reaching its maximum value, the network performance begins to drop sharply.

With increasing failure rates in the critical region of operation, with high transmission medium and node loads, all network characteristics change dramatically, in particular, packet service time.

Note that the maximum performance for all four types of transmitted packet is achieved when the number of nodes N_{node} = 100. The amount of timely transmitted information V_{pack} is maximized when the packet length L_{pack} = 8192:

$$V_{pack} = \lambda_{tot} L_{pack}.$$

The packet service time, which increases with packet size, is the longest at a high failure rate of 10^{-4}. For a packet of 1024 bits, the average service time is 0.003408 s, while for a packet of 8192 bits, it is already 0.004669 s.

When the failure rate is reduced to 10^{-5} the packet service time is significantly reduced. For a 1024-bit packet it decreases by almost 8 times (to 0.0004444 s), while for an 8192-bit packet, it decreases more than 4 times (to 0.001029 s).

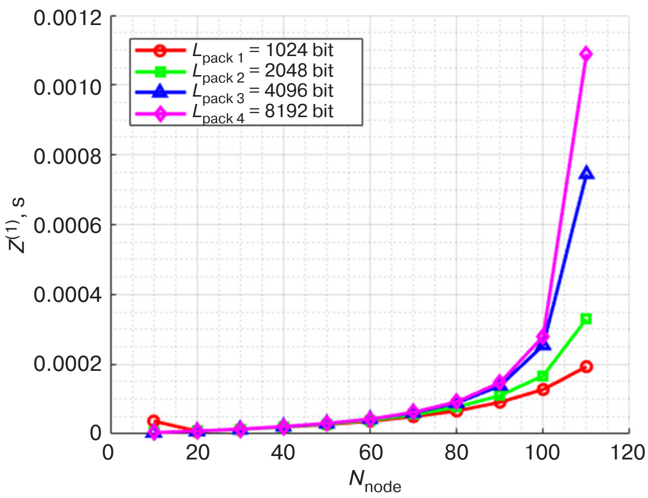

Fig. 1. Dependence of the service cycle $Z^{(1)}$ on the number of network nodes N_{node}

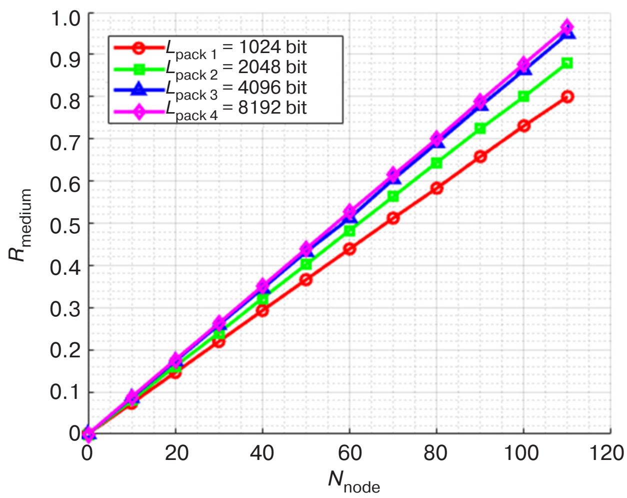

Fig. 2. Dependence of the transmission medium load R_{medium} for each mode on the number of nodes N_{node}

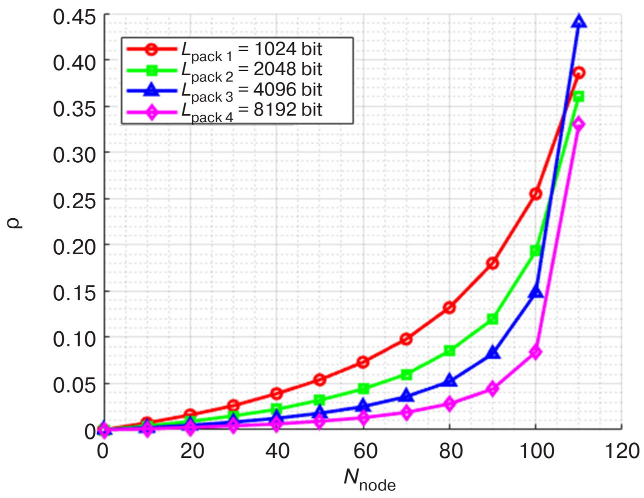

Fig. 3. Dependence of node loading for each mode ρ on the total number of nodes N_{node}

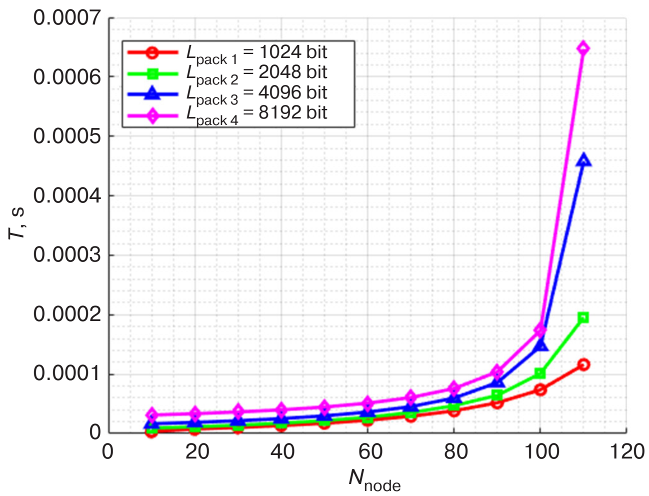

Fig. 4. Dependence of average service time of packets of 4 types T in multimode fiber optic network with token access method on the number of nodes N_{node}

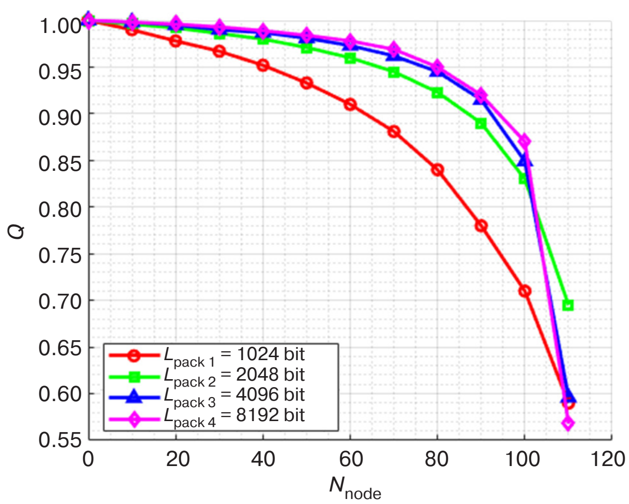

Fig. 5. Dependence of the probability of timely packet transmission Q in a multimode ring network on the number of nodes N_{node}

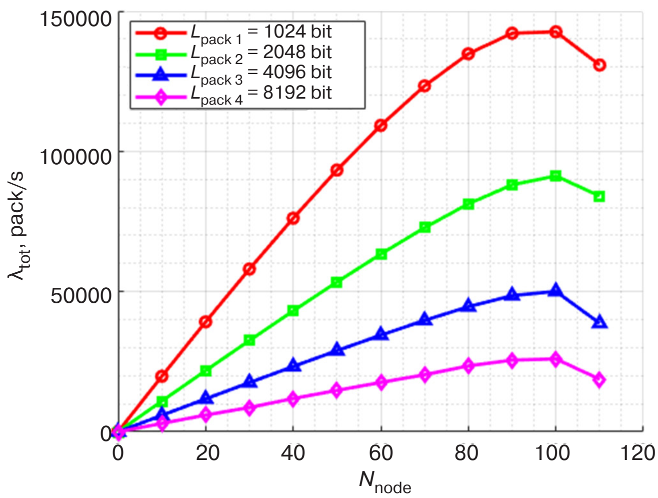

Fig. 6. Dependence of the performance λ_{tot} for each mode on the number of network nodes N_{node}

At failure rates of 10^{-6} and 10^{-7}, the processing time continues to decrease, but not as dramatically as when going from 10^{-4} to 10^{-5}. For example, for a 1024-bit packet, the time drops from 0.0001485 s to 0.0001189 s. This is already a less pronounced decrease.

In the case of no failures, the service time is stable and significantly lower than in the presence of failures. For example, for all packets from 1024 to 8192 bits, service time varies in the range of 0.0001156–0.0006475 s.

Failure intensity, which significantly affects the packet processing time in a multimode ring network, increases significantly at high intensities, especially for large packets. However, when the failure rate decreases to 10^{-6} and below, the processing time approaches the values characteristic of a network without failures.

CONCLUSIONS

This study highlights the key role of development and analysis of a mathematical model for optimization of data transmission processes in ring networks based on multimode fiber optic technology using the token access method.

The use of reliability-theory-, random-process- and mass-service methods, as well as the Laplace–Stieltjes transform, provided a basis for accurate mathematical equations that provide a deep analysis of the network characteristics to identify the key regularities of its operation.

The developed mathematical model takes into account critical parameters of multimode fiber optic medium including bandwidth, time delays, and data loss rate.

In the study, a comprehensive analysis of the operation of a multimode fiber optic network with token access method was carried out, in which the probabilistic and temporal characteristics of information transmission for different classes of packets were studied. In particular, the dependencies of packet service time on the number of nodes connected to the transmission medium, as well as the influence of the bandwidth of each mode and the intensity of packet arrival in the network were considered. The analysis showed that as the number of nodes in the network increases, the utilization of the transmission medium and nodes increases, which, in turn, increases the service cycle and packet transmission time, and decreases the network performance. In addition, increasing the intensity of failures in the critical area of operation dramatically deteriorates the performance of the network – in particular, in terms of increased service time of packets and consequently reduced probability of their timely transmission.

We pay special attention to the issues of network reliability, namely the impact of failures of individual elements on its performance. This aspect is of particular importance for critical applications, where the reliability of data transmission determines the success of the entire system. By introducing reliability characteristics into the model, we were able to develop mechanisms to account for failures and propose ways to minimize them, which increases the resilience of the network to external influences and potential failures.

The results show that by properly tuning the parameters it is possible to significantly improve the overall network performance, reduce the probability of collisions, and increase the throughput. These conclusions confirm the high efficiency of the proposed solutions and their importance for improving network operation quality.

Based on the calculations and simulations, multimode fiber optic medium is confirmed as a promising solution for organizing high-performance local area networks, especially under conditions of increased reliability and information-loss minimization requirements. The developed mathematical model can serve as a universal tool for the analysis, construction and optimization of networks, as well as providing science-based recommendations for their effective use.

Authors' contributions

D.V. Zhmatov has developed the theoretical framework for the study by proving a key theorem on polling cycles in token-passing networks (Eqs. 1–13), calculated the network timing characteristics analytically and plotted the resulting dependencies (Figs. 1–6), analyzed the optimization results for the token-based access method and proposed recommendations to enhance network efficiency.

A.S. Leontiev has defined the problem statement, including data transmission requirements for networks, performed numerical simulations of network parameters (node load, throughput, and probability of on-time delivery), assessed the impact of transmission medium failures on network performance (Table).

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