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Automated System for Data Transmission Characteristics Management in the Industrial Internet of Things Networks

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Abstract: The purpose of the proposed study is to provide the required data transmission characteristics in the Industrial Internet of Things (IIoT) system. Our efforts are primarily aimed at increasing the probability of message delivery, as well as reducing the likelihood of their duplication in wireless networks based on the Message Queuing Telemetry Transport (MQTT) protocol. The article offers a scheme and description of the automated control system, which is based on the use of original models to assess the probability of delivery and the likelihood of duplicate messages. The control parameters are the quality of service (QoS) level and the number of allowed retransmissions (Nretry). Conducting computational experiments and deploying the system in a real environment have shown that its application makes it possible to improve the requirements for the probability of message delivery by 7.2 percent and the probability of their duplication by 8.6 percent compared to existing adaptive QoS approaches. Due to the results achieved, the proposed system is recommended for use in IIoT networks, which place increased demands on the reliability of data delivery.

Keywords: Automated Control System; Industrial Internet of Thing (IIoT); MQTT Protocol; Network Optimization; Probabilistic Modelling; Quality of Service (QoS); Telemetry Message Delivery; Retransmissions

1 INTRODUCTION

Wireless data transmission systems currently serve as a technical basis for monitoring and control for solving various applied problems[1]. In particular, energy-efficient wireless sensor networks are in demand, on the basis of which the Internet of Things systems operate [2-4]. Such systems provide the collection of data received in the form of telemetry messages from numerous sensors. Internet of Things systems are used in agriculture [5-7], energy [8, 9], medicine [10-12], and many other areas.

Industrial Internet of Things (IIoT) systems are being actively implemented at modern manufacturing enterprises, allowing real-time monitoring of the technical condition and correct functioning of the equipment used. IIoT systems include numerous sensor nodes connected to certain elements of production equipment (mechanisms, machines, process lines). Such sensor nodes contain sensors for measuring parameter values, with the help of which the serviceability and operability of the operating industrial equipment is monitored. Sensor nodes are also equipped with transceiver modules used to receive service messages to configure their operation and send measured telemetry data to the network server of the production process control centre (hereinafter referred to as the control center). To transmit and receive messages, sensor nodes as end devices are connected to the IIoT network, usually using wireless channels.

The use of the IIoT system should be aimed at ensuring preventive management of production technological processes. These processes should be adjusted before failures or emergency situations occur, ensuring the exclusion of negative consequences (harm to workers' health due to mechanical damage, electric shocks or equipment fires, as well as material damage from unplanned downtime of production lines, forced purchase of new equipment or expensive repair of failed equipment). In the process of monitoring the technical condition of functioning production equipment, telemetry data is transmitted from the IIoT network sensor nodes to the control center network device at a certain frequency, as well as when dangerous deviations of the measured parameter values from the required standards are detected.

In order to promptly eliminate the causes of possible emergency situations, it is necessary to ensure a high probability of messages delivery containing telemetry data. At the same time, it is necessary to minimize the receipt of duplicate messages by the control center, as they can lead to incorrect diagnostics of the state of the controlled equipment. It should also be taken into account that the message delivery characteristics deterioration can be caused by an excessive volume of packet traffic transmitted in the IIoT network. In addition, for this reason, the energy consumption of sensor nodes increases significantly, so it is necessary to take measures to reasonably reduce the number of packets transmitted in the network.

One of the most common standards is the MQTT protocol. It is the basis of IIoT systems operation. It provides the implementation of three levels of data transmission quality [13-15]. The lowest level, called QoS-0, does not use retransmissions of corrupted or lost messages. QoS-1 assumes sending confirmations for correctly received information packets, but allows for duplicate messages. The highest level (QoS-2) uses double confirmations and guarantees the absence of duplicates of delivered messages.

The choice of the implemented QoS level significantly affects the characteristics of message delivery in the system. It should ensure the probability of message delivery not lower than the specified value, the probability of message duplicate delivery not higher than the specified value, as well as the minimization of packet traffic transmitted in the IIoT system.

To improve the quality of packet delivery in IIoT networks based on the MQTT protocol, it is proposed to use machine learning capabilities and the concepts of software-defined networks (SND) [16].With this extension, multicast messages are sent simultaneously to a group of subscribers without using a broker [17]. The RT-MQTT extension has been created, which integrates the advantages of SDN and the MQTT protocol. This development allows you to set requirements for the transmission of messages in real time and ensure their fulfillment using network backups [18].

In order to increase the speed and reliability of delivering the most important messages, the p-MQTT extension has been developed [19]. However, the messages that are most sensitive to delivery time are sent earlier than others. To implement this approach, virtual message queues are created. Each queue is assigned a specific priority, according to which the order of message processing is set.

To reduce message delivery delays, data transmission quality settings are adjusted at the software level. At the same time, the services are adapted to the specific applications used [20-22].

An analysis of the above developments has shown that they are not directly aimed at providing the required values for the probability of message delivery in the IIoT network. In addition, the available work does not assess the likelihood of duplicate messages, which should be minimized by duplicating messages, since receiving duplicates may lead to incorrect diagnosis of the condition of the monitored equipment. Based on this, it is proposed to fill the lack of theoretically sound solutions aimed at ensuring the reliability of transmission of telemetry messages in industrial Internet of Things networks.

The purpose of this study is to ensure the required characteristics of data delivery in the industrial Internet of Things network based on the automated control system development for the telemetry message transmission.

2 LITERATURE REVIEW

A literature review on the study topic showed that the lowest level of QoS-0 has the least protocol redundancy [23], [24]. When implemented, it does not use repeated transmissions of distorted or lost information packets, which ensures a low volume of traffic transmitted in the IIoT system.

The QoS-1 level assumes the transmission of confirmations for correctly (error-free) received information packets; in this case, if the confirmation has not been received by the sending device before the timeout expires, then the corresponding information packet is retransmitted. The number of allowed retransmissions Nretry is one of the controlled parameters in the system. The peculiarity of the QoS-1 level is that when it is used, duplication of delivered messages is possible.

QoS-2 is the highest level of data transmission quality, which guarantees the absence of duplicates of delivered messages by using double confirmations of correct packet reception. The disadvantage of this level is that the volume of transmitted traffic is the highest.

Using QoS level and the allowed number of retransmissions, it is necessary to achieve an increase in the message delivery probability in the IIoT system. On the other hand, duplication of delivered messages should be minimized, since it can lead to incorrect diagnostics of the monitored equipment state. In addition, an important criterion is the reduction of transmitted traffic volume. The analysis showed that the issues of choosing the QoS level and the Nretry parameter taking into account the achievement of all the listed requirements in industrial Internet of Things systems are not given enough attention in scientific and technical publications.

Issues of control over the data transmission quality in MQTT networks are the subject of separate developments. In particular, a dynamic controller has been proposed that is capable of assessing the state of the underlying network in terms of end-to-end delay and packet error rate and assigning the best QoS value to a node [25]. In order to support real-time services with MQTT quality of service classes, a set of software extensions has been developed, the use of which allows to increase the timeliness of network traffic transmission [26]. A solution has been proposed that integrates software-defined network (SDN) technology and the MQTT protocol. In this case, user-defined protocol settings are used to ensure the timeliness of data transmission, allowing for setting real-time requirements [27].

An approach is proposed that involves checking the relevance of messages transmitted in the MQTT network. If the message is out of date, the broker requests an updated message from the publisher before forwarding it to subscribers. This approach is useful in industrial control systems, where real-time data transmission is critical. However, implementing this approach requires the transmission of a significant amount of service traffic [28]. A load balancing scheme is proposed that allows for the uniform use of network equipment for processing incoming packets [29]. An adaptive mechanism for selecting MQTT message delivery paths based on reinforcement learning is developed, which makes it possible to increase the reliability of data transmission and limit the consumption of network resources [30].

The existing approaches to creating adaptive QoS in the Internet of Things networks discussed above are implemented in the form of various modifications of the MQTT protocol. The RT-MQTT (Real Time MQTT) extension has been created, which integrates the advantages of SDN and the MQTT protocol [27]. This design allows you to set requirements for real-time message transmission and ensure that they are met using network backups.

In order to increase the speed and reliability of delivering the most important messages, the p-MQTT (Priority MQTT) extension has been developed [19]. However, the messages that are most sensitive to delivery time are sent earlier than others. To implement this approach, virtual message queues are created. Each queue is assigned a specific priority, according to which the order of message processing is set.

Sensor receiving and transmitting devices connected to an IIoT network are usually low-power and have low performance. This ensures their main advantage, which is low energy consumption. In addition, the transmission of messages by these devices is carried out in a wireless environment in which the influence of noise and various interferences is high. To deliver data in conditions of limited resources and unstable communications, an extension adapted for use in wireless sensor networks has been developed. This version of the protocol is called MQTT-SN (MQTT for Sensor Networks) [25, 26]. Unlike the basic protocol, in the MQTT-SN version, the number of retransmissions is a parameter whose values can be changed.

This standard recommends setting these values in the range from 3 to 5, but there are no automated tools that select and set the most acceptable number of retransmissions depending on the current conditions of data delivery in the IIoT network. A brief description of the main approaches to QoS management in Internet of Things networks is presented in Tab. 1.

Table 1 Features Of Qos-Adaptive Modifications Of The MQTT Protoco

Modification	RT-MQTT	p-MQTT	MQTT-SN
Features	Using network backups using an SDN controller	Assigning priorities to transmitted messages	A simplified version of MQTT with the ability to adjust the parameters of repeat transmissions
Advantages	Support for real-time messaging	Improving the speed of delivery of critical event messages	Reduced power consumption, increased reliability of data transmission
Disadvantages	No means are provided to reduce message duplication	There are no means of increasing the probability of message delivery.	There is no automated adaptive selection of Nretry

Thus, the review can be summarized, The existing QoS management solutions allow improving the indicators of communication security, average delay and the number of correctly received packets, but they are not directly aimed at ensuring the required values of the probability of delivery and the probability of duplication of messages in the IIoT system, and do not take into account the intensity of packet traffic. As review result, it can be stated that at present there is a need to improve the process of data delivery in the industrial Internet of Things system. To this end, it is proposed to develop an automated system for a reasonable adaptive choice of the implemented QoS level and the allowed number of retransmissions Nretry. This development should be based on an assessment of the performance characteristics of the IIoT network in accordance with the MQTT-SN protocol.

3 METHODOLOGY

The developed system is based on the use of probabilistic models of the message delivery process in the IIoT system in accordance with the QoS-0, QoS-1 and QoS-2 levels, which are regulated by the MQTT-SN protocol.

3.1 Models for Assessing IIoT-Message Delivery Characteristics

Using QoS-2 level and the Nretry parameter, the message will not be delivered from the sensor device to the network device of the control centre if any of the following event's sequences occur:

- the PUBLISH information packet is correctly received; the PUBREC confirmation packet is correctly and timely received; the PUBREL service packet is incorrectly received; after retransmission, the PUBREL service packet is incorrectly received;
- the PUBLISH information packet was received correctly; the PUBREC confirmation packet was received incorrectly and/or untimely; after retransmission, the PUBLISH information packet was received correctly; the PUBREC confirmation packet was received correctly and timely; the PUBREL service packet was received incorrectly; after retransmission, the PUBREL service packet was received incorrectly;
- PUBLISH information packet received correctly; PUBREC confirmation packet received incorrectly and/or untimely; PUBLISH information packet received correctly after retransmission; PUBREC confirmation packet received incorrectly and/or untimely;
- PUBLISH information packet received correctly; PUBREC confirmation packet received incorrectly and/or untimely; PUBLISH packet received incorrectly after retransmission;
- PUBLISH information packet received incorrectly; PUBLISH information packet received correctly after retransmission; PUBREC confirmation packet received correctly and on time; PUBREL service packet received incorrectly; PUBREL service packet received incorrectly after retransmission;
- the PUBLISH information packet was received incorrectly; after retransmission, the PUBLISH information packet was received correctly; the PUBREC confirmation packet was received incorrectly and/or untimely;
- the PUBLISH information packet was received incorrectly; after retransmission, the PUBLISH information packet was received incorrectly.

Taking these events into account, the probability that the message will not be delivered from the sensor device to the IoT device of the control center can be estimated using the following expression:

$$
\begin{aligned}
P0 &= P1\cdot P2\cdot PC\cdot(1-P2)\cdot(1-P2)+\\
&+P1\cdot(1-P2\cdot PC)\cdot P1\cdot P2\cdot PC\cdot(1-P2)\cdot(1-P2)+\\
&+P1\cdot(1-P2\cdot PC)\cdot(1-P2\cdot PC)+\\
&+P1\cdot(1-P2\cdot PC)\cdot(1-P1)+\\
&+(1-P1)\cdot P1\cdot P2\cdot PC\cdot(1-P2)\cdot(1-P2)+\\
&+(1-P1)\cdot P1\cdot(1-P2\cdot PC)+(1-P1)\cdot(1-P1).
\end{aligned}
\tag{1}
$$

Where $P1$ is the probability of correct reception of the information packet PUBLISH; $P2$ is the probability of correct reception of the confirmation packet PUBREC; PC is the probability of timely receipt of the confirmation package PUBREC, that is, receiving this packet before the timeout expires.

The probability of correct reception of the PUBLISH information packet can be estimated using the expression:

$$P1 = 1 - \left(L1 \cdot BER\right), \tag{2}$$

where $L1$ is the bit length of the physical layer information block in which the packet PUBLISH is encapsulated; BER is the bit error rate in wireless channels used for data transmission.

To calculate the probability of correct reception of the PUBREC confirmation packet, the following expression can be used:

$$P2 = 1 - \left(L2 \cdot BER\right). \tag{3}$$

Where $L2$ is the bit length of the physical layer information block in which the PUBREC confirmation packet or the PUBREL service packet is encapsulated.

In accordance with these models, the probability of message delivery in the IIoT system while ensuring the QoS-2 level can be calculated using the expression:

$$PD2 = \\ = \left\{1 - \left[(1-PP)^{Nretry+1} + PP \cdot (1-P2)^{Nretry+1} \cdot \sum_{i=0}^{Nretry} (1-PP)^{i}\right]\right\}^{2}. \tag{4}$$

Where PP is the probability of correct and timely information reception and confirmation packets, to calculate the value of PP, the expression is used:

$$PP = P1 \cdot P2 \cdot PC. \tag{5}$$

When level QoS-1 is provided and $Nretry = 1$ is set, the message will not be delivered from the sensor device to the control center network device if the PUBLISH information packet is not received correctly during the first attempt and after its retransmission. Taking this into account, the probability of message delivery in an IIoT system implementing the above-mentioned level of data transmission quality can be estimated using the following expression:

$$PD1 = \left[1 - \left(1 - P1\right)^{Nretry+1}\right]^{2}. \tag{6}$$

At QoS-0 level, a message will be delivered in an IIoT system if the PUBLISH information packet is correctly received by the server, then being sent from the sensor device, and then, after being sent from the server, it is correctly received by the network device of the control center. Taking this into account, the probability of message delivery in IioT system at QoS-1 can be estimated using the expression:

$$PD0 = P1^{2}. \tag{7}$$

At QoS-1 level, an important functioning characteristic of the IIoT system is the message duplication probability. As a result of the study, the following expression was obtained to estimate this value:

$$PDUBL = 2 \cdot (1 - PONCE - PNOT) - (1 - PONCE - PONT)^{2}. \tag{8}$$

Where $PONCE$ – is the message delivery probability without duplicates from a sensor device to a server, as well as the message delivery probability without duplicates from a server to a network device of the control center; $PNOT$ is the probability that a message will not be delivered from a sensor device to a server, as well as the probability that a message will not be delivered from a server to a network device of the control center.

The $PONCE$ value can be estimated using the formula:

$$PONCE = \\ = P1\left\{(1-P1)^{Nretry}\left[1 + Nretry \cdot (1 - P2 \cdot PC)\right] + P2 \cdot PC \sum_{i=0}^{Nretry-1} (1-P1)^{i}\right\}. \tag{9}$$

The value $PNOT$ can be estimated using the formula:

$$PNOT = (1 - P1)^{Nretry+1}. \tag{10}$$

So, for the first time, the models presented above reflect the dependence of the probability of delivery and the probability of duplication of telemetry messages on the current characteristics of data transmission in the IIoT network. The mentioned models allow to calculate important characteristics of data transmission in the IIoT network, which include $PD0$, $PD1$, $PD2$ and $PDUBL$. The values of these quantities can be used to select the level of message delivery quality and the permitted number of packet retransmissions. In the process of this selection, it is also necessary to take into account the criteria determined by the specifics of the controlled technological process. Based on the specifics of the production where the IIoT system is deployed, the probability of telemetry message delivery should not be lower than the specified GPD value, and the probability of duplication of delivered messages should not exceed the specified $GPDUBL$ value. For a theoretically justified selection of the message delivery quality level and the permitted number of packet retransmissions, a system of automated control of data transmission characteristics in the industrial Internet of Things network is proposed. The diagram of this system is presented below.

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exceed the specified *GPDUBL* value. For a theoretically justified selection of the message delivery quality level and the permitted number of packet retransmissions, a system of automated control of data transmission characteristics in the industrial Internet of Things network is proposed. The diagram of this system is presented below.

3.2 The Proposed Automated System

The proposed automated system for controlling the parameters of telemetry message transmission in the industrial Internet of Things network is installed on the computing equipment of the control center. The diagram of this system is shown in Fig 1. The functioning of this system is based on the use of Eqs. (1) – (10), which were obtained during the development of message delivery models in the IIoT network.

The telemetry data transmitted by the sensor nodes over the IIoT network are received by the control center network device, then are sent to the *BER* measurement module. The measured *BER* values are transmitted in parallel to the *PD*0 evaluation module, *PD*1 evaluation module, and *PD*2 evaluation module.

In the *PD*0 evaluation module, the current *PD*0 value is calculated using Eq. (5). This value is then fed to the selection criteria fulfillment control module. In this module, the *PD*0 values are compared with the specified *GPD* value. The *GPD* value is set by the network administrator using the selection criteria setting interface. If $PD0 \geq GPD$ is true, the implementation of the QoS-0 level is recommended when exchanging data with the corresponding sensor device, so the value of the recommended data transmission quality level LQoS is assigned the value 0. This value is fed to the LQoS and Nretry setting module. If $PD0 < GPD$, then the selection criteria fulfillment control module sends a request to the *PD*1 evaluation module to calculate the *PDUBL* value.

In the *PD*1 evaluation module, the *PDUBL* value is calculated using Eqs. (6) – (8) for $Nretry = 1$. The calculated *PDUBL* value is led to the selection criteria execution control module, where the PDUBL values are compared with the specified *GPDUBL* value. The *GPDUBL* value is set by the network administrator using the selection criteria setup interface. If $PDUBL \leq GPDUBL$, then the selection criteria fulfillment control module sends a request to the *PD*1 evaluation module to calculate the *PD*1 value. In the *PD*1 evaluation module, using Eqs. (2) and (4), the *PD*1 value is calculated for $Nretry = 1$.

If $PD1 \geq GPD$, then when exchanging data with the corresponding sensor device, it is recommended to implement the QoS-1 level, therefore the value of the recommended level of data transmission quality LQoS is assigned the value 1. This value and the value $Nretry = 1$ are led to the LQoS and Nretry setup module. If $PD1 < GPD$, then the selection criteria execution control module sends a request to the *PD*1 evaluation module to calculate the *PDUBL* value when $Nretry = 2$. Then the operations are performed in the above sequence until the condition $PD1 \geq GPD$ is met. If the condition $PDUBL > GPDUBL$ is true, then the selection criteria fulfillment control module sends a request to the *PD*2 evaluation module to calculate the *PD*2 value.

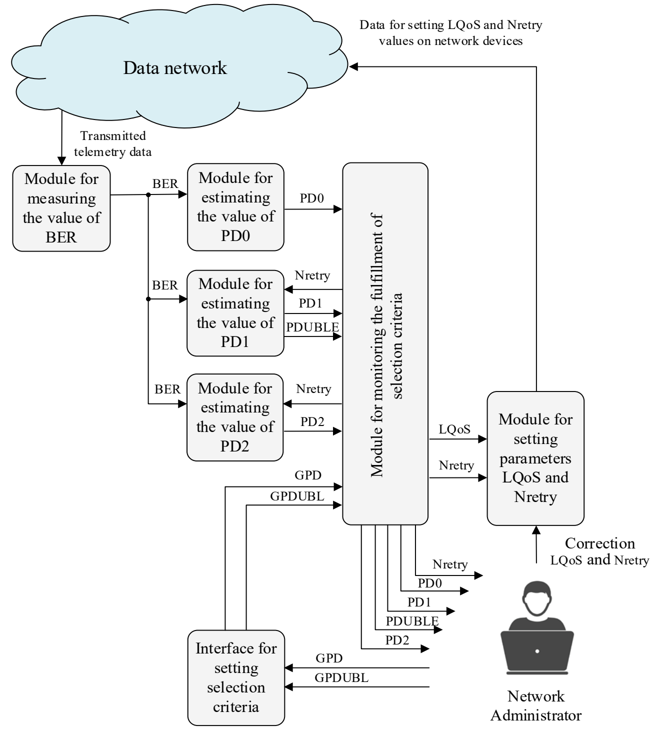

Figure 1 Scheme of automated control system

In the *PD*2 evaluation module, the value PD2 is calculated using Eqs. (1) – (3) when $Nretry = 1$. This value is then sent to the selection criteria fulfillment control module. In this module, the *PD*2 values are compared with the specified *GPD* value. If $PD2 \geq GPD$, then when exchanging data with the corresponding sensor device, it is recommended to implement the QoS-2 level, therefore the value of the recommended level of data transmission quality LQoS is assigned the value 2. This value is led to the LQoS and Nretry setup module. If $PD2 < GPD$, then the selection criteria fulfillment control module sends a request to the *PD*2 evaluation module to calculate the *PD*2 value when $Nretry = 2$, etc., until the condition $PD2 \geq GPD$ is met.

The recommended values of LQoS and Nretry can be adjusted by the network administrator if necessary. To provide this possibility, the calculated values of *PD*0, *PD*1, *PD*2, *GPDUBL*, LQoS and Nretry are provided to the network administrator from the selection criteria fulfillment control module. The LQoS and Nretry setup module transmits service data on the recommended values of the data transmission quality level and the permitted number of packet retransmissions to the sensor device. Based on this data, the recommended values of the above-mentioned telemetry message transmission parameters are set in the sensor device settings.

4 RESULTS AND DISCUSSION

The logic of the evaluation modules *PD*0, *PD*1 and *PD*2 and the module for monitoring the fulfilment of selection criteria is implemented in the form of software in the Python language version 3.12.5. Using this software, a series of computational experiments were carried out with the following initial data: $L1$ =256 bits; L2 = 128 bits; PC = 1; GPD = 0.9; GPDUBL = 0.1. Fig. 2 shows some results of software functioning.

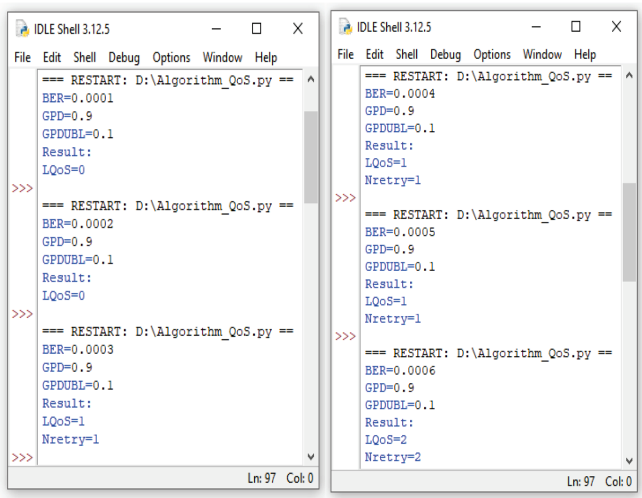

Figure 2 Results of computational experiments

As a result of experiments, it was found that in the IIoT system, with BER values not exceeding 2×10^{-4} it is recommended to use the QoS-0 level, with BER values from 3×10^{-4} to 4×10^{-4} the QoS-1 level and Nretry = 1 should be used, and with BER from 6×10^{-4} to 10×10^{-4} the QoS-2 level and $Nretry$ = 2 should be used.

Then, the second series of computational experiments was conducted, which checked the fulfillment of the specified data delivery requirements and estimated the packet traffic in the IIoT system without and with the proposed algorithm. In this case, the values of V were estimated, i.e., the average number of packets transmitted in the IIoT system within 1 hour. It was assumed that the packet traffic was generated by 1000 sensor devices, each of which transmitted 4 telemetry messages within 1 hour.

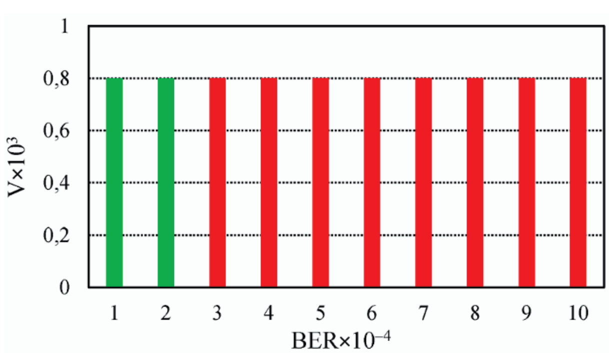

Figure 3 Diagram of the dependence of the value of V on the BER values when implementing the QoS-1 level

The obtained results are presented in the form of diagrams in Figs. 3-6. In these diagrams, the experiments results in which the telemetry message delivery requirements were met are marked by green, and the experiments results in which these requirements were not met are marked by red.

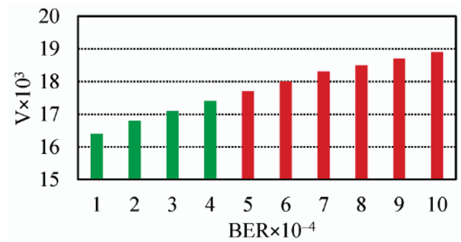

Figure 4 Diagram of the dependence of the value of V on the BER values when implementing the QoS-1 level and $Nretry$ = 1

Figs. 3-5 show diagrams obtained without using the proposed automated control system. These results were observed at fixed values of the data transmission quality level and the permitted number of packet retransmissions. Fig. 6 shows the results of computational experiments conducted using the proposed automated control system.

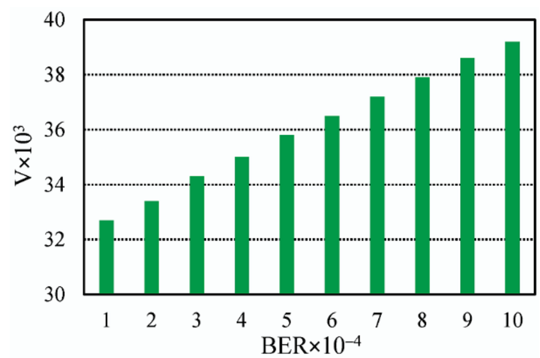

Figure 5 Diagram of the dependence of the value of V on the BER values when implementing the QoS-2 level and Nretry = 2

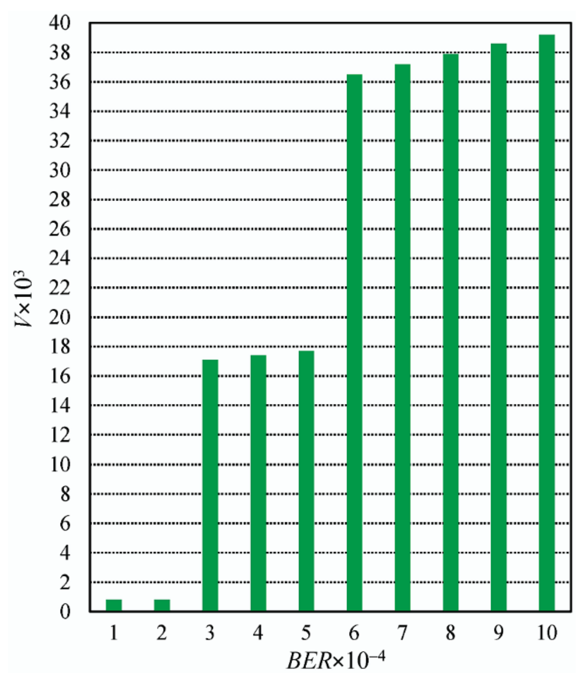

Figure 6 Diagram of the dependence of the value of V on the BER values when using the proposed automated system

Then, using the developed software, experiments were conducted in a real IoT network. 20 network LoRaWAN devices with LW002-TH temperature and humidity sensors were connected to the eight-channel gateway MKGW2-LW. The MQTT-SN protocol was used to control data transmission at the application level in QoS-0, QoS-1 and QoS-2 modes. To change the *BER* level, we increased or decreased the distance between the sensor network devices and the gateway. The GW C-1200 protocol analyzer for LoRa wireless networks was used to measure the Bit Error Rate. The period of sending messages by each touch device was 1800 seconds. As a result of the experiments conducted in real conditions, the data presented in Tab. 2 were obtained. Analysis of these data showed that they correspond as much as possible to the simulation results.

Table 2 Comparison of Results of Computational Experiments

Conditions for computational experiments	Message delivery requirement fulfillment percentages (confidence intervals with a confidence probability of 0.95)	Average traffic intensity, thousands of packets per hour
Fixed level QoS-0	20	0.8
Fixed level QoS-1	40	17.78
Fixed level QoS-2	100	36.06
Application of automated control system	100	24.32

The analysis of the table shows that in cases of setting fixed levels of data transmission quality without using an automated control system, the implementation of the QoS-0 level allows fulfilling the data delivery requirements only by 20% and is accompanied by an average traffic intensity of 0.8 thousand packets within 1 hour. The implementation of the QoS-1 level allows fulfilling the data delivery requirements by 40% with an increase in the average traffic intensity to 17.78 thousand packets within 1 hour. The implementation of the QoS-2 level allows to fulfill the data delivery requirements by 100% with an increase in the average traffic intensity to 36.06 thousand packets within 1 hour. The use of an automated control system allows for 100% achievement of the required data delivery characteristics and, compared to the implementation of the fixed QoS-2 level, makes it possible to reduce the average traffic intensity by 32.5% (to 24.32 thousand packets within 1 hour).

Table 3 Comparison of the Results of the Proposed Approach and the Adaptive QoS Algorithm Based on SDN Technology

Indicators	Percentage increase or decrease
Average Message Delivery Rate	Decrease by 18.2 - 20.4
Duplicate Messages	Decrease by 6.4 - 8.6
The Probability Of Message Delivery	Increase by 5.8 - 7.2
Power consumption of network devices	Decrease by 4.5 - 5.3

Tab. 3 shows experimental data showing how much the results of using the proposed approach increase or decrease compared to the results of using the adaptive QoS algorithm based on SDN technology [27]. The results are presented as percentages in confidence intervals with a confidence probability of 0.95.

A comparative analysis shows that the use of adaptive QoS based on SDN gives better results in the speed of message delivery, which is important for ensuring timely data transmission in real-time applications. In situations where it is necessary to increase the probability of message delivery and reduce their duplication, the use of the proposed system provides more preferable results.

5 CONCLUSION

Thus, the presented automated system for parameters management of telemetry message transmission in the IIoT network provides a theoretically justified choice of the level of message delivery quality and the allowed number of packet retransmissions depending on the current bit error rate. The use of the system allows us to provide the specified values of the delivery probability and the message duplication probability, while significantly reducing the average traffic intensity compared to the implementation of a fixed level of data transmission quality with double confirmations.

Further research within the considered topic framework will be devoted to the substantiation of the values of the telemetry message delivery probability and the delivered messages duplication probability, which will preferably be used in the automated control of data transmission characteristics in the Industrial Internet of Things network deployed at a specific manufacturing enterprise. In the future, this will make it possible to use the proposed automated system for managing the transmission of telemetry data messages in the IIoT network, taking into account the criteria determined by the specifics of the controlled technological process.

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