https://doi.org/10.31891/csit-2024-3-6
UDC 004.942: 681.518

Oleksandr SAI, Kyrylo KRASNIKOV
Dniprovskyi state technical university, Kamianske, Ukraine

FUZZY MODEL OF ELECTRICITY CONTROL WITH WIRELESS INFORMATION PROCESSED ON GPU

Methods of processing information transmitted through wireless networks with software development are investigated in the work. Innovative methods of data transmission such as optical technologies, quantum data transmission and wireless data transmission technologies are disclosed. It is noted that in the modern understanding, the concept of distributed computing defines the process of convergence (convergence) of distributed processing methods, such as GRID, cloud and fog computing, with the combination of virtual cluster systems (grid clusters, cloud clusters and fog clusters) into a single information communication and computing system . It is emphasized that, unlike cellular modems, ZigBee technology nodes have microcontrollers with a pre-installed operating system and flash memory, which allows solving simple computational tasks in real time before sending data. It is advisable to solve such tasks within the framework of a multi-agent approach, which will increase the efficiency of the use of sensor nodes and the entire sensor network. The advantages of the multi-agent technology of fog computing based on sensor nodes of the wireless network of the ZigBee standard are revealed. The method of multi-agent processing of sensory information and its main components are described. The architecture of the system of distributed sensor data processing is outlined, which includes 4 hardware and software levels: Terminal sensor nodes and controllers of measuring devices and automation devices that implement fuzzy calculations; Coordinators, sensor segment routers and cellular modems that collect, protect and transmit sensor data to the processing center; A data processing center that includes a cluster of servers for GRID calculations and a cloud data storage server; Client devices to access cloud storage, computing cluster servers, and distributed fog computing terminals. It is emphasized that indicators and forecast results can be stored on distributed sensor nodes or transmitted for accumulation in cloud storage for further extraction and intelligent processing in the GRID cluster of the data center.

Keywords: fuzzy model, information processing, wireless network, software.

Олександр САЙ, Кирило КРАСНІКОВ
Дніпровський державний технічний університет, Кам’янське, Україна

НЕЧІТКА МОДЕЛЬ УПРАВЛІННЯ ЕЛЕКТРОЕНЕРГІЄЮ З ОБРОБКОЮ БЕЗДРОТОВОЇ ІНФОРМАЦІЇ НА GPU

У роботі досліджено методи обробки інформації переданої через бездротові мережі із розробкою програмного забезпечення. Розкрито інноваційні методи передачі даних, такі як оптичні технології, квантову передачу даних та бездротові технології передачі даних. Зазначається, що у сучасному розумінні концепція розподілених обчислень визначає процес зближення (конвергенції) способів розподіленої обробки, таких як GRID, хмарні та туманні обчислення, з поєднанням віртуальних кластерних систем (grid-кластерів, хмарних кластерів та туманних кластерів) в єдину інфокомунікаційну та обчислювальну систему. Наголошується, що на відміну від модемів стільникового зв'язку вузли технології ZigBee мають мікроконтролери з попередньо встановленою операційною системою та флеш-пам'яттю, що дозволяє вирішувати нескладні обчислювальні завдання в режимі реального часу перед відправкою даних. Вирішення таких завдань доцільно виконувати в рамках мультиагентного підходу, який дозволить підвищити ефективність використання сенсорних вузлів та всієї сенсорної мережі. Розкрито переваги мультиагентної технології туманних обчислень на базі сенсорних вузлів бездротової мережі стандарту ZigBee. Описано метод мультиагентної обробки сенсорної інформації та основні його складові. Окреслено архітектуру системи розподіленої обробки сенсорних даних, яка включає 4 програмно-апаратних рівня: Термінальні сенсорні вузли та контролери вимірювальних приладів та приладів автоматики, що реалізують туманні обчислення; Координатори, маршрутизатори сенсорних сегментів та модеми стільникового зв'язку, що здійснюють збір, захист та передачу сенсорних даних до центру обробки; Центр обробки даних, що включає кластер серверів для обчислень GRID і сервера хмарного зберігання даних; Клієнтські пристрої для доступу до хмарного сховища, серверів обчислювального кластера та терміналів розподілених туманних обчислень. Підкреслено, що показники та результати прогнозу можуть зберігатися на розподілених сенсорних вузлах або передаватися для накопичення в хмарному сховищі з метою подальшого вилучення та інтелектуальної обробки у GRID кластері центру обробки даних.

Ключові слова: нечітка модель, обробка інформації, бездротова мережа, програмне забезпечення.

Introduction

The emergence of a huge number of sensors and measuring devices in complex technical systems has led to an exponential increase in the amount of data that needs to be processed and analyzed in real time. According to Cisco, a system such as a jet engine can generate 10 terabytes of data about its activity and condition within half an hour. Sensors installed in a modern car generate up to two petabytes of data per year. Transferring this data to GRID server computing clusters or cloud service systems in real time and then transmitting the results to users imposes too high a demand on network bandwidth, which is almost impossible to provide, resulting in significant delays.

Literature review

The formulation of scientific thought in the area of high-quality processing of information transmitted via wireless networks is heterogeneous and extensive. In the modern scientific field, there are works devoted to the study of modern methods and algorithms for their implementation in intelligent systems for the stable operation of the latter.

In [1], the principles of forming a stable data transmission channel on the Internet are studied. Models, methods, and algorithms for implementing data transmission on the Internet are revealed. The principles of forming a data transmission network are described. It is emphasized that such a parameter as the speed of data packet transmission on the Internet is controlled by the data flow and, at the same time, by indirect measurements.

In [2], a combined method of processing and grouping training data was obtained that ensures the accuracy of object recognition without increasing the amount of training data. The authors investigate the impact of similar redundant information in different categories of objects on recognition accuracy.

ZigBee technology and its standards are discussed and described in [3]. Possible network topologies are shown.

Among foreign authors, it is worth noting the works of such scientists as: Jijie Zheng, Xinjian Xiang [4], Sreelekshmi K., Pranitha J., Unimaya K, Vijita S. [5], Wu Jia-Lun, Lu Tsung-Tao, Li Ching-Tan, Sun Zo-Shun, Lin Xin-Piao, Hwang Yu-Shiang, Sun Wen-Cai [6], Hussein Noon, Nlabaci Armstrong [7], Kiran Huma, Sekhar Amna, Khan Maskan [8] and others.

Regarding fuzzy logic there is research [9], in which corresponding rules are applied to the smart home system. The approach allows automatic controlling of electric devices in the house. In the paper [10] authors propose prediction model of peak electricity consumption, which is useful in energy-limited situations for electric system to be ready.

However, despite the scale of scientific research, the issue of high-quality processing of information transmitted via wireless networks is relevant and requires further research. The aim of the work is to study the methods of processing information transmitted over wireless networks with the development of fuzzy model.

Methodology

In today's environment, information transmission is a relevant area of development. Innovative methods of data transmission include optical technologies, quantum data transmission and wireless data transmission technologies.

Optical networks use light signals to transmit data through cables. The advantages of optical data transmission include high transmission speeds, high bandwidth, and no electromagnetic interference. However, limitations include the high cost of installing and maintaining fiber optic cables, as well as their vulnerability to damage.

Quantum information transmission utilizes the quantum properties of particles, such as quantum state and superposition, to transmit data. The basic principle of quantum transmission is the use of quantum bits, which can be in a state of 0, 1, or a superposition of both states at the same time. Prospects for the use of quantum information transmission include the creation of quantum networks with a high degree of protection against hacking and eavesdropping.

The development of mobile networks, such as 5G and Wi-Fi 6, opens up new opportunities for wireless data transmission with high speed and reliability. However, it also brings challenges, such as frequency spectrum congestion, low immunity to interference, and limited coverage. Despite this, wireless technologies still have great potential for use in various information networks.

The evolutionary development of information, telecommunication and Internet technologies is moving towards the transition to Ubiquitous Networks and Internet of Things networks with the ability to transmit information according to the 4A principle (Anytime, Anywhere, Anything, Anybody). The concept of Internet of Things is taking shape today, thanks to the development of the technological base of pervasive wireless sensor networks and models of distributed computing. There are three basic models of distributed computing: parallel computing (GRID computing), cloud computing, and fog computing. The latter model is often identified with cloud computing [4]. GRID computing is based on the architecture of traditional computer networks or multiprocessor systems and is the organization of a parallel computing process when parts of a task are distributed over currently available resources and allow solving tasks that are difficult for a single node.

Cloud computing effectively defines a model for providing ubiquitous network access to a shared pool of configurable resources. It should be noted that the cloud computing model emerged as a development of the GRID computing model, and currently cloud computing is defined as a distributed computing technology in which information is stored in the cloud storage but cached on the client side for analytical processing. Fog computing is a development of GRID computing technology, when the process of data processing and storage is shifted to the lower level of the computing process organization directly to terminal devices with limited computing and energy resources.

Thus, in the modern sense, the concept of distributed computing defines the process of convergence of distributed processing methods, such as GRID, cloud and fog computing, with the combination of virtual cluster systems (grid clusters, cloud clusters and fog clusters) into single information, communication and computing system.

The creation of new generation SCADA systems for the automation of new generation energy supply processes involves the implementation of the fog computing model within the concept of the Internet of Things. This means decentralizing the processes of collecting and processing sensor data, with the transfer of a part of the computational process of analytical data processing from the center's servers to sensor modules and/or programmable logic controllers of automation devices.

Modern sensor nodes are powerful enough computing devices to be effectively used only for data collection and transmission operations. Unlike cellular modems, ZigBee nodes have microcontrollers with a preinstalled operating system and flash memory, which allows them to solve simple computing tasks in real time before sending data. It is advisable to solve such tasks within the framework of a multi-agent approach, which will increase the efficiency of using sensor nodes and the entire sensor network.

The main advantages of the multi-agent fog computing technology based on sensor nodes of the ZigBee wireless network are:

– use of a wireless sensor network operating in the license-free 2.4 GHz band;

– financial and operational independence from cellular providers when organizing a transport environment for data transmission from remote energy monitoring facilities;

– addressing information security issues in the transport environment without involving third-party organizations;

– reducing server cluster load and reduction of communication channel congestion;

– reducing the amount of data in the cloud storage;

– increasing the efficiency of sensor data processing and obtaining results directly from the monitored objects in real time;

– reduced response time to emergency situations.

The primary processing of sensor data from sensors, metering devices, and measuring instruments is to calculate aggregate energy indicators and to forecast their dynamics in the short term based on retrospective data in software agents.

Agents are installed on sensor nodes:

– at the stage of firmware of the sensor node (prohibition of the migration process);

– during system operation using portable equipment;

– by remote downloading through the communication channels of the sensor network.

The model of distributed multi-agent data processing based on a wireless sensor network can be represented as a hypergraph with two subsets of vertices and edges and extended properties.

The development of the method determines the creation of next-generation information and telecommunication technologies, when sensor nodes, industrial controllers, and mobile devices will be able to communicate independently in the Internet of self-organizing things to solve analytical problems and exchange data. The multi-agent concept of fog data processing is based on the system-synergistic principle of managing information processes in complex open systems. The convergence of multi-agent technologies, distributed computing and data storage models determines the achievement of a synergistic effect on increasing the efficiency of processing large sensor data in a network environment and allows identifying new emergent properties of the distributed information and communication environment.

The architecture of the distributed sensor data processing system includes 4 software and hardware levels:

1) Terminal sensor nodes and controllers of measuring and automation devices that implement fog computing.

2) Coordinators, routers of sensor segments and cellular modems that collect, protect and transmit sensor data to the processing center.

3) Data center, including a cluster of servers for GRID computing and cloud storage servers.

4) Client devices for accessing cloud storage, servers of the computing cluster, and distributed fog computing terminals.

For the interaction of fog computing software agents with the GRID computing cluster, a broker mechanism is implemented. The broker implements the functions of accumulating data and the results of primary processing, encrypting them, managing keys, routing, and transmitting them. Brokers are installed on the coordinators of sensor segments and routers of the sensor network. To support the work of brokers, it is advisable to use the MQTT (Message Query Telemetry Transport) protocol, which is a messaging protocol designed for use in networks with a minimum of energy and computing resources. The central coordinator of the sensor network acts as a gateway connecting the sensor environment with the data center computing cluster.

For effective regulation in the control system for remote monitoring of electricity consumption in a room, it is proposed to use a fuzzy controller. The regulator built on this principle has characteristic features, which is associated with the peculiarity of solving problems using fuzzy logic methods.

Input parameters of the model are:

– (Voltage, T={Low, Medium, High}, X=[210 .. 240])

– (Current, T={Low, Nominal, Excessive}, X=[0 ... 4])

Output parameters are:

– (Energy consumed, T={Low, Normal, High}, X=[0 .. 1])

– (Power factor, T={Small, Medium, Large}, X=[0 ... 1])

The diagram of the fuzzy model of the device is shown in Fig. 1.

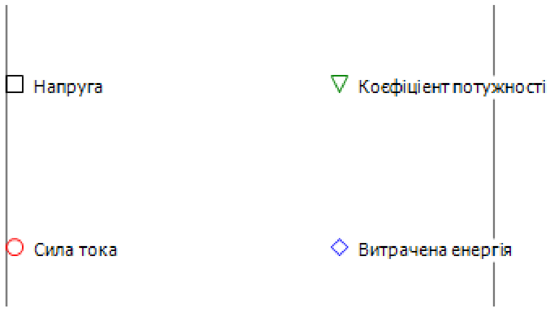

Fig. 1. Scheme of the fuzzy model of the electricity consumption in the room

Define the membership function and its arguments. For voltage parameter (Fig. 2):

1) µLow = trimf (195,210,225)
2) µMiddle = trimf (210,225,240)
3) µHigh = trimf (225,240,255)

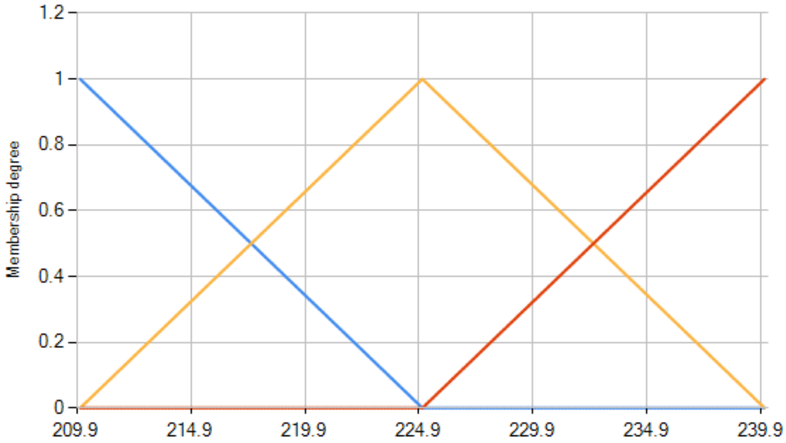

Fig. 2. Membership functions of the Voltage

For the parameter Electric current functions are (Fig. 3):

1) µLow = trimf (-2,0,2)
2) µNominal = trimf (0,2,4)
3) µExcessive = trimf (2,4,6)

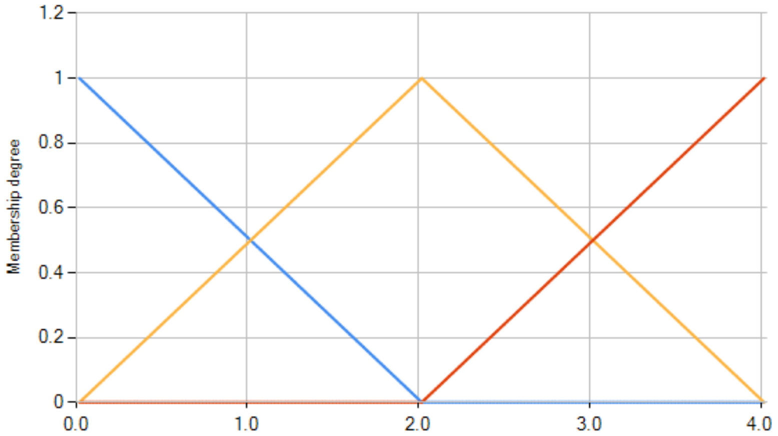

Fig. 3. Membership functions of the Voltage

For the consumed energy (Fig. 4): µLow = trimf (-0.5,0,0.5); µNormal = trimf (0,0.5,1); µToomuch = trimf (0.5,1,1.5)

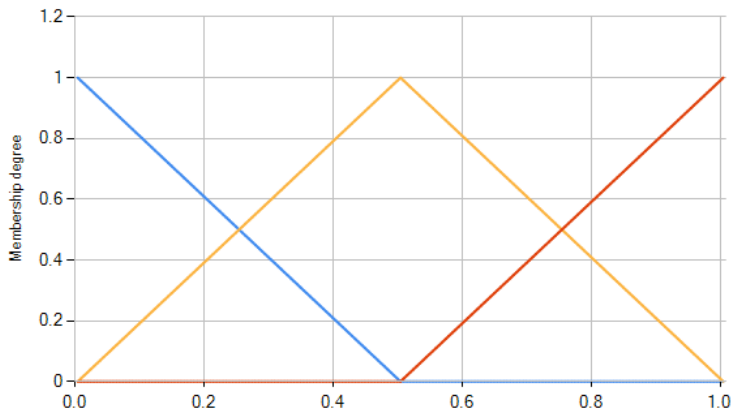

Fig. 4. Membership functions for the Consumed energy

Power factor membership functions (Fig. 5):

1) µSmall = trimf (-0.5,0,0.5)
2) µMedium = trimf (0,0.5,1)
3) µLarge = trimf (0.5,1,1.5)

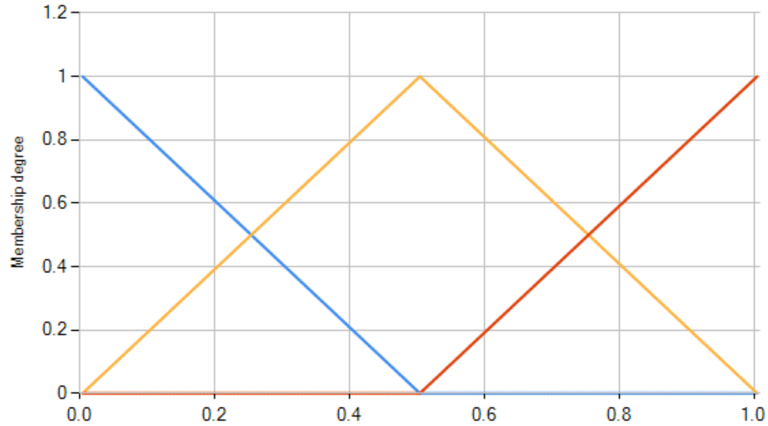

Fig. 5. Membership functions for the Power factor

The following fuzzy rules are defined for the fuzzy model:

1. IF Voltage is Low AND the Current is Low THEN Energy Consumed is Low
2. IF Voltage is Medium AND Current is Low THEN Power Factor is Small
3. IF Voltage is Medium AND Current is Nominal THEN Energy Consumed is Normal
4. IF Voltage is High AND Current is Excessive THEN Energy Consumed is High
5. IF Voltage is High AND Current is Excessive THEN Power Factor is High

A front panel has been developed on which the program controls are located, allowing you to enter the data of the part and the bar blank using the mouse and keyboard, select the discrete and analog I/O outputs of the microcontroller involved in the program, and set up a serial communication channel between the computer and the Arduino. A flowchart is essentially a program that graphically illustrates the algorithm of actions of a future virtual device. This part is created using the G language, where all commands, loop statements, and comparisons are represented as separate graphical icons (Fig. 6).

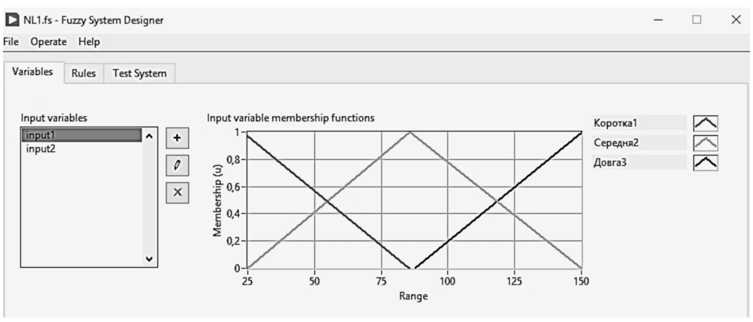

Fig. 6. Membership functions for inputs

Objects placed on the front panel appear as terminals on the flowchart. All elements of the program are interconnected by links through which data is transferred. Thus, in the process of developing the source code of a virtual tool, the concept of "data flow" (DataFlow) is used. This approach in LabVIEW allows you to create programs of any orientation and complexity, where you can take measurements, analyze signals and control actuators in real time (Fig. 7).

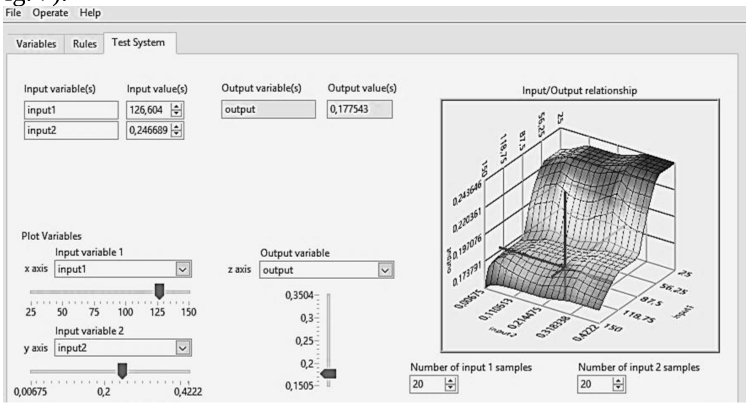

Fig. 7. Testing the system control algorithm embedded in a fuzzy controller

Let`s use GPU to process wireless information about electricity availability in the city. The map image of overall electricity availability can be constructed from wireless information about houses which have electricity. Each house is represented by single pixel (dot) on the image with size of 1024x640 (size is adjustable), which allows representing even big cities (dozens kilometers wide with millions of people). On such a large map a single house is almost invisible but its light contribution must be taken into account. So the proposed algorithm includes putting all houses, where electricity is available, gathering wireless information. Then GPU applies Laplacian operator to get image that represents large scale map. In the result one sees regions, where electricity is available (Fig. 8). The software is developed in Visual Studio 2019 using DirectCompute technology to access GPU computing capabilities.

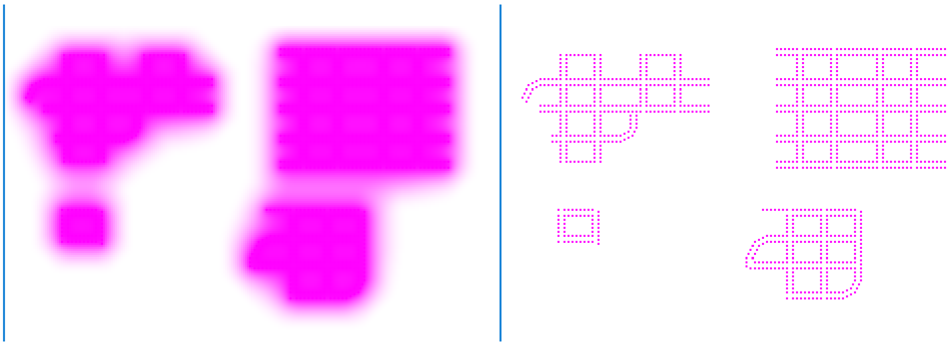

Fig. 8. GPU-processed information (left) and original (right) data of electricity availability

Conclusions

The developed controller based on fuzzy logic interacts with an electronic control system for monitoring electricity consumption. It allows the consumer to monitor the use of electricity and use it economically. Application of GPU processing of wireless information allows real-time updating of electricity availability on the large area of territory with thousands of households (thanks to massively parallel architecture of GPU). This approach can be applied to other similar problems too.

The paper investigates methods of processing information transmitted via wireless networks with the development of software. The principles of information transmission are determined, it is noted that the primary processing of sensor data from sensors, metering devices and measuring instruments consists in calculating aggregate energy indicators and short-term forecasting the dynamics of their change based on retrospective data in software agents. Indicators and forecast results can be stored on distributed sensor nodes or transferred for accumulation in cloud storage for further extraction and intelligent processing in a GRID cluster of a data center.

Further research is based on the development of software aimed at collecting data on electricity consumption and performing calculations for its optimization.

References

1. Ozerchuk I. Formation of a stable data transmission channel in the Internet. *COMPUTER-INTEGRATED TECHNOLOGIES: EDUCATION, SCIENCE, PRODUCTION*. 2021. P. 212-217. DOI: 10.36910/6775-2524-0560-2021-43-35.

2. Denisov R., Popovych P. Features of pre-processing and grouping of neural network training data to improve the accuracy of object recognition based on MOBILENETV2. *Technologies and Engineering*. 2024. С.9-20. DOI: 10.30857/2786-5371.2023.5.1

3. Sharma Asmita, Singh Bharat. ZigBee Technology and its Standards. *Online International Interdisciplinary Research Journal*, 2024. № 13. P. 37-42.

4. Jijie Zheng, Xinjian Xiang. Data analysis and research on ZIGBEE wireless sensor network system based on complex event processing technology // 2010 3rd International Conference on Computer Science and Information Technology. 2010. DOI: 10.1109/ICCSIT.2010.5565015.

5. Sreelekshmi K., Pranitha J., Unnimaya K., Vijitha S. Road Safety and Inter-vehicular Surveillance using V2V Communication. 2023. P. 337-344. DOI: 10.21467/proceedings.160.44.

6. Wu Chia-Lun, Lu Tsung-Tao, Lee Chin-Tan, Sun Jwo-Shiun, Lin Hsin-Piao, Hwang Yuh-Shyan, Sung Wen-Tsai. Novel AMI in Zigbee Satellite Network Based on Heterogeneous Wireless Sensor Network for Global Machine-to-Machine Connectivity. *Electronics.* 2024. № 13. P. 14-21. DOI: 10.3390/electronics13081421.

7. Hussein Noon, Nhlabatsi Armstrong. Living in the Dark: MQTT-Based Exploitation of IoT Security Vulnerabilities in ZigBee Networks for Smart Lighting Control. *IoT*. 2022. №3. P. 450-472. DOI: 10.3390/iot3040024.

8. Kiran Huma, Sehar Amna, Khan Muskan. Wireless Sensor Network with ZigBee Application: *Literature Review*. 2022. DOI: 0.22541/au.165944356.69836365/v1.

9. Hovorushchenko, T., Aleksov, S., Popov, Y., & Bachuk, V. (2023). DECISION-MAKING METHOD FOR TEMPERATURE CONTROL IN THE SMART HOME. *Computer Systems and Information Technologies*, (3), 6–11. https://doi.org/10.31891/csit-2023-3-1

10. Kholiavka, Y., & Parfenenko, Y. (2023). FORECASTING PEAK LOAD ON THE POWER GRID. *Computer Systems and Information Technologies*, (3), 12–22. https://doi.org/10.31891/csit-2023-3-2

Oleksandr Sai **Олександр Сай**	master graduate of Systems Software Department, Dniprovskyi State Technical University, Kamianske, Ukraine, e-mail: alexcdsay@gmail.com	магістрант кафедри програмного забезпечення систем, Дніпровський державний технічний університет, Кам'янське, Україна.
Kyrylo Krasnikov **Кирило Красніков**	PhD, Associate Professor of Systems Software Department, Dniprovskyi State Technical University, Kamianske, Ukraine, e-mail: kir_kras@ukr.net https://orcid.org/0000-0002-4241-0572	кандидат технічних наук, доцент кафедри програмного забезпечення систем, Дніпровський державний технічний університет, Кам'янське, Україна.