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AUTOMATED RESOURCE MANAGEMENT SYSTEM FOR THE UTILITY SECTOR BASED ON WIRELESS SENSOR NETWORKS

The subject of this study is methods, tools and automated resource management systems for the housing and communal sector. The object of research is the process of controlling resource consumption at housing and communal facilities. **The aim of the study** is to develop an automated resource management system for the utility sector based on wireless sensor networks. To achieve this goal, the following tasks were **solved**: a review and analysis of existing methods, tools and automated resource management systems; selection of system components based on technical requirements and taking into account the selected LoRaWAN wireless connection technology; development of a structural diagram and algorithm for the operation of an automated resource management system based on wireless sensor networks; modelling of the process of managing the resources of the utility sector using a wireless sensor network based on t The following **methods** are used in the work: critical analysis of LoRa technology and other wireless IoT technologies, FOREL and K -means clustering methods. The following results were **obtained**: a general description of the automated resource management system was carried out, its composition and main tasks were determined, and technical requirements for it were established, wireless data transmission technology was selected, on the basis of which the automated resource management system was built, an in-depth comparative analysis of the most effective modern wireless technologies – LoRaWAN and NB-IoT – was carried out, system components were selected, a structural diagram and algorithm for the automated resource management system were developed, and the process of the automated resource management system was modelled. **Conclusions**: the application of the proposed automated resource management system provides high-quality control of energy consumption at the facilities of the housing and communal sector, makes it possible to control their volume, monitor and analyse energy consumption data, and manage the entire energy supply network as a single system, which is especially necessary in martial law. This approach allows rationalising the consumption of resources by household consumers, which means that the financial costs of energy supply will decrease and the level of energy savings in the country will increase.

Keywords: energy supply; wireless sensor network; automation; gateway; monitoring; sensor node; base station.

Introduction

The current state of the housing and communal sector of Ukraine requires innovative approaches in the technological aspects of energy management.

The studied concept of an automated resource management system based on wireless sensor networks (WSNs) is used to modernise the system of accounting for household subscribers and maintenance of in-building supply networks for resources (electricity, hot and cold water, gas, heating), to manage their supply and to provide information services to consumers of the supplying company.

Given the challenging economic situation in Ukraine amidst martial law and active hostilities, it became necessary to initiate a regime of rational and economical use of resources.

A modern method of solving the problem of regulating energy consumption is to create an automated resource management system (ARMS) based on the WSN with the ability to remotely monitor resource consumption and store the information received in an independent audit and control service centre.

Thus, the integration of functionally different wireless devices (meters, sensors, sensors) into a single system for accounting and management of resource consumption is in line with the global trend of smart grids based on the principles of energy saving and energy efficiency, and the construction of such grids at housing and communal services (HCS) facilities [1].

Resource conservation is the most effective way to modernise HCS. The total cost of generating one kilowatt of aggregate capacity through energy saving measures is less than 10% of the required investment in the construction of the corresponding generating capacity. The energy saving potential of HCS is 65%. More than 50% of this potential can be realised through the introduction of system metering based on modern innovative IT technologies.

Today, suppliers and utilities have an unprecedented opportunity to transform their supply networks into smart grids that allow them to manage the entire supply network as a single system. At the same time, consumers can not only receive a reliable report on the resources consumed online, but also directly participate in regulating energy consumption in their homes and

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apartments. This is facilitated by a new generation of smart metering devices and devices that support a bidirectional communication and control interface [2].

Thus, the task of developing an ARMS for the utility sector based on WSNs is relevant.

Analysis of recent research and publications

Most modern flow control systems are a complex of functionally integrated hardware and software and include sensor nodes with built-in data collection and transmission devices based on wireless technologies (Wi-Fi, GSM, LoRa, NB-IoT, etc.). The information is sent to the control and data transmission units (gateways or base stations), where it is read, processed and transmitted to the network server for further provision to external software applications, in particular, automated workstations for dispatch control.

The concept discussed in this article is very relevant and has been widely discussed in many scientific papers. For example, paper [3] provides a literature review of recent research on energy management systems and classifies works based on several factors, namely, energy management goals, approaches adopted for energy management, and solution algorithms. In addition, the paper discusses some of the most advanced methods and methodologies adopted or developed to address the energy management problem and provides a table for comparing such methods. The paper concludes by explaining the current challenges and limitations of energy management systems and outlines future research directions.

Paper [4] identifies external factors that influence the perception of the Building Energy Management System (BEMS) from the management perspective. An extended model based on the Technology Acceptance Model (TAM) was created to assess the implementation of BEMS in manufacturing industries. The model is analysed using the structural equation modelling (SEM) approach, where the external variables are taken as compatibility, features, technology complexity and perceived risk, and the internal variables are five dimensions: perceived ease of use, perceived usefulness, attitude, user satisfaction and behavioural intentions.

The study [5] describes the use and importance of energy management systems (EMS) used by utilities and end-users as a means of controlling electricity use and achieving energy savings. This approach also involves a comparative analysis of existing systems and devices, as well as the growing use of EMS in the latest smart grids.

Paper [6] investigated ways to increase the data rate in WSNs using LoRa and obtained analytical dependencies for building a signal structure taking into account the overlap factor and inter-symbol interference.

Article [7] describes smart grid projects implemented in Europe and presents their technological solutions with a priority on the use of smart metering in low-voltage networks. The article considers the telecommunication technologies chosen by several European utilities to implement smart meters at the national level. Further research will be conducted on the basis of European smart grid projects, highlighting their technological capabilities. The range of projects analysed includes both those that include smart metering and those in which smart metering applications play a significant role in the overall success of the project.

There are automated energy management systems and tools from Smartico. The company actively develops and manufactures hardware devices for IoT. These devices help solve many technological problems in both the industrial and utility sectors. The devices operate using the latest algorithms for energy-efficient LPWAN radio networks – LoRaWAN and NB-IoT.

Main areas of activity:

– development and production of smart meters for gas, water, electricity, heat with wireless data transmission and the ability to remotely block energy supply;

– telemetric energy management systems (ASCOE, ASTUE) to monitor the consumption of gas, heat, water, electricity with further analytics during the processing of the data, generation of reports and data transfer to the company's accounting systems;

– control systems for the receipt, storage and delivery of fuel for the company's process vehicles (equipment of fuel and lubricants depots);

– development of telemetry radio terminals for remote control of technological facilities (mobile and stationary objects, GPS monitoring);

– control of technological parameters of mining special equipment (car video surveillance and adaptive driver assistance systems);

– control over the operation of fuel dispensers (equipment with automated mobile fuel dispensing modules);

– development and production of devices for the Internet of Things. Production of sensors with autonomous power supply and wireless data transmission;

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– implementation of integrated solutions for the organisation of intelligent industrial and street lighting ("smart light");

– contract manufacturing of electronic equipment using its own production lines;

– development of equipment according to customer specifications;

– construction of wireless broadband transmission systems (organisation of wireless systems in the bands from 2 GHz to 5 GHz at speeds up to 200 Mbit/s);

– assistance in the development of technical specifications for the construction of control systems and control systems for technological equipment of various categories of complexity;

– process automation systems (solutions for automation of control, management and analytics processes at the enterprise);

– SCADA systems for automated and supervisory control of technological processes (automated process control systems using logic controllers and software);

– systems with the use of human-machine interfaces (HMI, Human-machine interface) for monitoring, controlling and programming technological processes;

– software development for automation of a wide range of technological processes for the enterprise [8].

There are also automated monitoring systems from YASNO. The management system allows us to increase control over the use of energy resources and reduce energy consumption through organisational measures, staff training, and the introduction of energy-efficient approaches in all key business processes.

Energy management involves building a mechanism for continuous improvement in reducing resource consumption based on the "plan – do – check – adjust" principle.

Advantages of monitoring systems from YASNO:

– cross-platform – the systems are capable of running on different devices and can be integrated into existing infrastructure;

– wireless transmission – information on energy consumption from the object of measurement is transmitted via GSM communication;

– versatility – control of electricity, water, gas, heat consumption, analysis of temperature, humidity, pressure, CO2 and other resources;

– visualisation – flexible and customised dashboards for analysing and tracking consumption trends;

– measurement accuracy – the ability to use proven devices for commercial metering with a guaranteed low level of error;

– notifications – warning messages in case of emergencies, e-mail and messenger notifications;

– archiving and export – archiving of metering data for three years and the ability to export information to files.

It is also possible to integrate monitoring systems to meet customer needs. It is used when there are clear requirements for:

– flexibility of interface configuration;

– the ability to connect existing equipment;

– high metrological accuracy.

All the company’s offers include:

– system design – monitoring the energy consumption of devices from small businesses to large industrial enterprises;

– equipment package – depending on the project, the system may include smart meters, sensors, modems, controllers, etc;

– installation and integration – installation of equipment, integration into existing infrastructure, software configuration;

– analytics and reports – assessing the potential for savings in the event of changes in consumption or equipment [9].

The results showed that various topics are directly or indirectly related to the application of smart metering, such as smart home/building, energy management, network monitoring, and integration of renewable energy sources (RES).

Material and study results

The main task of ARMS is to fully or partially automate the processes of monitoring information and managing the results of the volume of consumed resources (electricity, gas, heating, hot and cold water) at HCS facilities using special metering devices, as well as creating a database of data obtained for previous periods, monitoring the state of the energy system of HCS facilities.

ARMS plays an important role in informing the policy of resource conservation and cost rationalisation in the process of interaction between executive authorities, supplier companies and consumers.

The system has the following tasks:

– high-quality remote monitoring of resource consumption, as well as reading and transmitting data from heat, hot and cold water, electricity and gas metering devices;

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– operational dispatch management and control of the HCS facility's power system.

An automated resource management system consists of:

– resource consumption metering devices (sensors, flow meters, etc.)

– pulse radio modem (gateway);

– hub (base station);

– ARMS server.

The proposed resource management system consists of sensors, recorders, means of collecting, transmitting, displaying and processing information.

To implement the function of collecting data from metering and control devices, ARMS provides for bi-directional signal transmission in the areas "metering device – radio modem – hub – server".

Information is transferred from the metering devices to the server automatically at a specified frequency or upon request from the server.

ARMS transmits the stored data from metering devices to external automated systems, service companies and consumers.

The software of the server, concentrators and radio modems must be adaptive to function with different metering devices via a digital interface.

To ensure information security, the data transmission channels between the radio modem, hub and server must be encrypted and noise-resistant coding must be applied to transmit the data.

The radio modems and hub contain a universal control and wireless communication unit for wireless data transmission.

Communication is one of the most important parts of any resource management system. Today, there are a significant number of wireless communication standards, but not all of them meet the necessary requirements for their use in ARMS. The main such standards are power consumption, coverage radius and bandwidth. A comparison of technologies in terms of range and operating frequency range is shown in Figs. 1 i 2.

Fig. 1. Wireless communication technologies by range

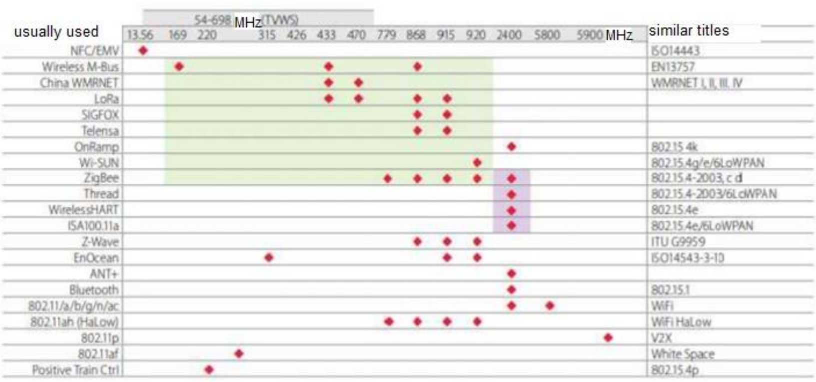

Fig. 2. Operating frequency ranges of wireless technologies

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Most standards, such as ZigBee, WiFi, etc., have a short range. And others, such as 3G and LTE, are very power-hungry and their range is not guaranteed. Although these technologies and communication modes are suitable for certain projects, they have limitations, such as difficulties in using them in areas without cellular coverage (GPRS, EDGE, 3G, LTE/4G) and the need for licensing. The parameters of the technologies are shown in Table 1.

Table 1. *Parameters of wireless technologies*

Parameter	LoRaWan	LTE-M	Sigfox	NB-IoT	BLE	Wi-Fi	Z-Wave	ZigBee
Communication standard	own	3GPP	own	3GPP	Bluetooth SIG	802.11	own	IEEE 802.15.4
Frequency	433 MHz, 868 MHz, 915 MHz.	from 700 MHz up to 2,2 GHz. from 452,5 MHz up to 467,5 MHz	868 MHz, 915 MHz, 921 MHz.	from 700 MHz up to 2,2 GHz, from 452,5 MHz up to 467,5 MHz	13,56 MHz.	2,4/5,0 GHz	from 868 MHz up to 926 MHz.	2,4 GHz
	RX 290 bit/s TX 50 Kbit/s	1 Mbit/s	0,1 Kbit/s	~200 Kbit/s	from 125 Kbit/s up to 2 Mbit/s	up to 150 Mbit/s	100 Kbit/s	250 Kbit/s
Transmission speed	star	star	star	star	P2P	star	Mesh	Mesh
Network topology	very high	very high	very high	very high	20	100	232	250+
Number of devices	from 5 km up to 15 km	5 km	from 10 km up to 50 km	5 км	from 40 m up to 1000 m	from 40 m up to 100 m	from 40 m up to 100 m	from 40 m up to 100 m
Radius of action	medium	high	medium	high	low	medium	medium	medium
Power consumption	mobile/local	mobile/local	mobile/local	mobile/local	local	local	local	local

Having analysed the characteristics of modern wireless communication technologies, as well as the technical requirements for modern resource management systems, it can be concluded that the ARMS under development requires an effective communication environment that meets the technical requirements, in particular, low power and wide range, as well as low cost, security and ease of deployment.

LPWAN technologies are most effective for connecting devices that need to transmit small amounts of information over long distances while ensuring long battery life. The low power consumption of these devices allows them to perform tasks at a low cost and with very little battery replacement. This distinguishes LPWAN from other wireless network standards such as Bluetooth, RFID, and ZigBee [10].

Fig. 3 shows a diagram of the bandwidth and range of various wireless standards. For example, Wi-Fi, with its high bandwidth of several Mbit/s and limited range of 100 m to 200 m, is most often used to form wireless local area networks within an office or apartment, but will be ineffective for use in large control system networks.

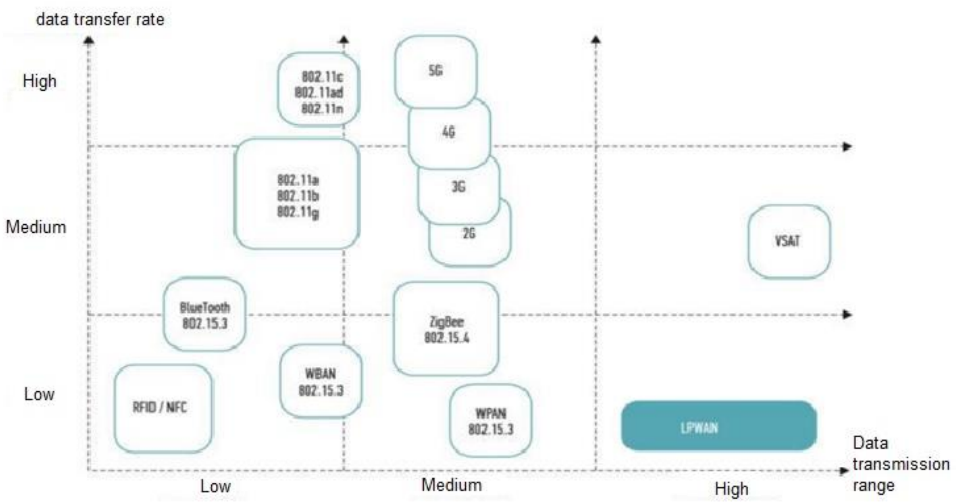

Fig. 3. Wireless technologies in terms of range and data transmission speed

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When choosing the optimal LPWAN technology for ARMS, the following factors should be taken into account: quality of service, battery life, latency, scalability, payload duration, coverage area, range, deployment, and cost.

Let's take a closer look at the characteristics of two similar modern LPWAN standards, namely LoRaWAN and NB-IoT, which are best suited for the resource management system being developed [11].

LoRaWAN is an open-architecture LPWAN system developed and standardised by the LoRa Alliance, a non-profit association of companies with more than 500 members. LoRa is a modulation technology applied at the physical layer that enables long-distance transmission of information using CSS (Chirp Spread Spectrum) modulation, which spreads narrowband signals over an extended channel, and provides high resilience and low signal-to-noise ratios.

NB-IoT operates in a licensed band and, similar to LTE, uses frequency division multiple access (FDMA) in the uplink, orthogonal FDMA (OFDMA) in the downlink, and QPSK (Quadrature Phase Shift Keying) modulation.

Both LoRaWAN and NB-IoT devices reduce their own power consumption when they go into sleep mode. However, as a synchronous protocol, NB-IoT consumes more power during operation than LoRaWAN, which is an asynchronous protocol, and for measurements with the same bandwidth, NB-IoT uses a higher peak current required for OFDM/FDMA modulation.

One of the factors that affects the cost and efficiency of LoRaWAN and NB-IoT is the better penetration of LoRaWAN in buildings. The maximum communication loss (MCL) for LoRaWAN uplink and downlink is 165 dB. At the same time, the loss for NB-IoT ranges from 145 dB to 169 dB for the uplink and 151 dB for the downlink, depending on the device class [12].

The lower energy potential of the communication line in NB-IoT leads to a significant reduction in battery life.

In addition, flexibility is a significant advantage of LoRaWAN technology. Unlike NB-IoT, LoRaWAN offers the deployment of a local network, i.e. a local network using a LoRa gateway, as well as the operation of a public network through base stations.

LoRaWAN technology has a fairly wide range (up to 20 km), meaning that it requires only three base stations to cover an entire city.

NB-IoT has a shorter coverage radius (i.e., the range is less than 10 km). The focus is on a class of devices that are installed in places far from the typical reach of cellular networks. Another problem is that NB-IoT deployment is limited to LTE base stations. This means that this technology cannot be used in rural or suburban areas where there is no LTE coverage.

Both technologies can compete in terms of service, as shown in Table 2 and Fig. 4.

It is also important to take into account the following types of costs: spectrum (licence), network/deployment and device costs (Table 3).

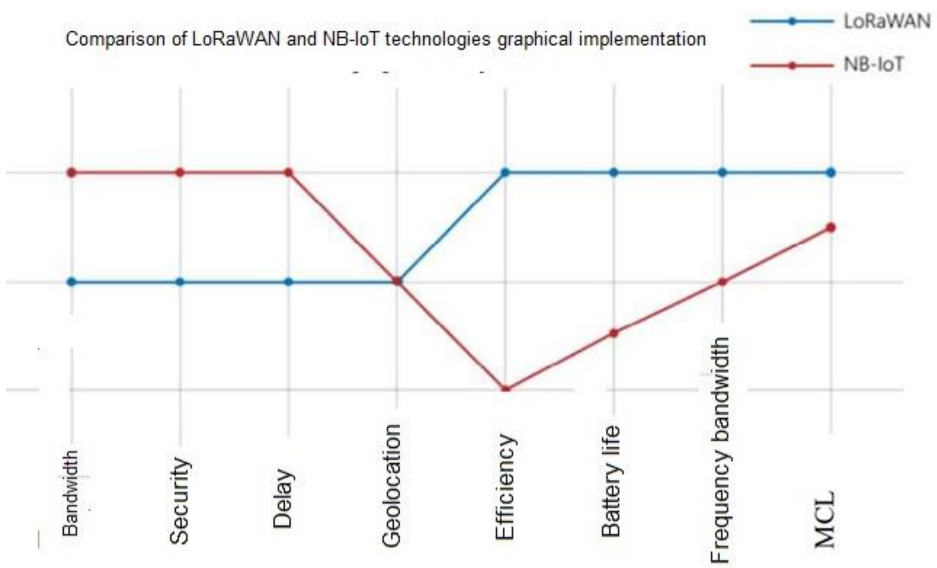

Fig. 4. Graphical visualisation of the comparison of LoRaWAN and NB-IoT technologies

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Table 2. *LoRaWAN and NB-IoT technical specifications*

Technical characteristics	LoRaWAN	NB-IoT
Modulation method	CSS	OFDMA/DSSS
Range	ISM	lisensed
Speed	from 0.3 kbit/s up to 50 kbit/s	UL: 1 kbit/s to 144 kbit/s DL: 1 kbit/s to 200 kbit/s
Autonomy	more than 10 years	up to 10 years
Range of action, km	5 (urban), 20 (rural)	1 (urban), 10 (rural)
Frequency band, kHz	125	180
MCL, dB	165	164
Peak current, mA	32	120
Current in sleep mode, µA	1	5
Safety	AES 128 bit	3GPP from 128 біт up to 256 bit
Cost efficiency	high	middle
Support	LoRa Alliance, IBM, Cisco, Actility, Semtech…	3GPP, Ericson, Nokia, Huawei, Intel…
Private network permission	yes	no
Ecosystem	Communication services are available in 40 countries and 250 cities. LoRaWAN is already an IoT network standard in many countries. The LoRa Alliance covers more than 500 companies.	According to the GSMA, in April 2017, 40 NB-IoT networks were tested worldwide, and only four networks were fully operational.

Table 3. *Types of LoRaWAN and NB-IoT costs*

	LoRaWAN	**NB-IoT**
Spectrum cost, €	free	> 500 / MHz
Cost of deployment cost, €	>> 100 / gateway	> 15 000 / base station
Cost of the end device, €	> 1000 / base station	> 20

After analysing the information in Tables 2 and 3 comparing the two technologies, it becomes obvious that, unlike NB-IoT, LoRaWAN is optimal in most respects for its implementation in the ARMS under development.

Study results and their discussion

After selecting the communication standard, the ARMS structural diagram was created, and the main operating functions of each element of the system were identified and analysed (Fig. 5).

The end devices (sensor nodes) are connected to the LoRaWAN gateway in a star topology, and signals are transmitted between them using LoRa modulation. Within the LoRaWAN technology, this topology allows for the connection of new sensor nodes, and their number is not determined by the power consumption of the latter. Thanks to the peer-to-peer point-to-point connection, the star topology is more efficient and cheaper to implement than the mesh topology. The level of network security is much higher because endpoints operate independently. In the event of an attack on a node, the rest of the network will remain intact [13].

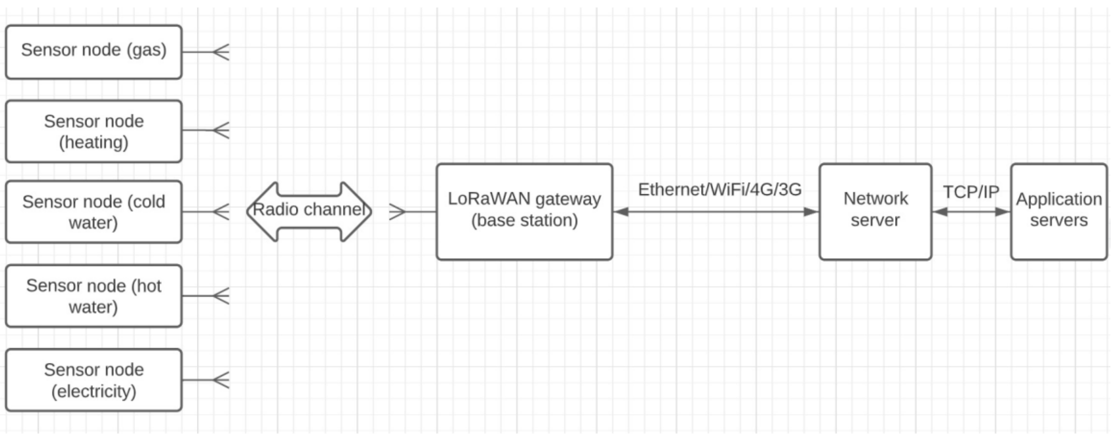

Fig. 5. Block diagram of an automated resource management system

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In addition, it should be noted that this topology allows you to offload the server, and the probability of collisions is very low due to the peculiarities of the base station (BS). This is because in this case, frequency channels are switched in an unlicensed frequency range.

Thus, the star topology network is optimal for minimal power consumption and provides the longest battery life on the sensor node side.

Sensor nodes perform control and measurement functions [14]. They include the necessary sensors and controls. Sensor nodes can be located at a considerable distance from the gateway and are powered by a battery. Each of them establishes communication with the gateway via the LoRaWAN radio channel, which allows for a large number of connections.

A gateway (BS or hub) is a device that receives signals from sensor nodes via a radio channel and sends them to a transit network. The transit network can be Ethernet, WiFi, 3G, 4G, or mobile radio networks. The gateway and sensor nodes form a star network topology. The gateway has many multi-channel receivers to process signals in several channels simultaneously or even several signals in one channel. Accordingly, several such devices provide network coverage and transparent information transfer between sensor nodes and the server [15].

The network server performs the following control functions in the network: speed adaptation, storage and processing of information.

The application server can also remotely monitor the operation of sensor nodes and collect the necessary information from them.

The element base for the automated resource management system was selected, where the LoRaWAN Conduit IP67 from Multi-Tech was chosen as the main base station or gateway. The gateway kit includes a 12 V power supply, a 3G/LTE antenna, microUSB and Ethernet cables, a manual, and a LoRaWAN module (MTACLORA-868).

Pin antennas for the 868 MHz band are used in security alarm devices and operate in the range from 868 MHz to 868.2 MHz. The W1063 antenna is recommended by MultiTech for use with MTDOT-868 LoRa modules and LoRaWAN gateways. The 868 MHz antenna with a circular radiation pattern and 5 dB gain is used as a "base" antenna in data collection systems with a short communication range.

The Metromatic™ WSII water meter was chosen – an ultrasonic flow meter for measuring the consumption of cold and hot water in residential or commercial premises. The meter is supplied with an integrated communication system with low power consumption over long distances, LoRaWAN or NB-IoT, as well as a wireless backup OMS. Data is collected in real time, processed automatically and made available to the IoT service provider.

We chose a Smartico Gas Meter ultrasonic gas meter for domestic use. Such meters are available in the G-1.6, G-2.5, G-4, G-6 size range and are used to measure the volume of natural and liquefied gas. The meter allows for visual and remote data acquisition.

A three-phase electricity meter was selected – MTX direct connection with a built-in LoRaWAN radio module. The device is designed to measure the consumed and generated active and reactive electricity in AC networks with a rated voltage of 3x220/380 V and automatically transmit the readings to the supplier.

A compact heat meter HYDROCAL-M4 was selected for energy measurement. The device is used for heating and/or cooling in premises served by centralised systems. The processing of data on the temperature difference between the supply and return pipes (DT), together with data on the volume of heat transfer fluid used by each user, allows for an accurate calculation of the amount of energy consumed.

The Jooby universal interface radio module with a pulse counter was selected. The purpose of the radio module is to read pulses from all types of resource meters. The information is transmitted to the server via the LoRaWAN wireless network, where it is converted into indicators. Intelligent sensors detect external interference with the radio module and immediately alert you. The radio module is fixed near the metering devices in several ways: with a DIN rail, cable tie, or screws to the wall. After that, the device is activated in the installer’s mobile application. The whole process takes a few minutes and does not require the meter to be removed.

An ARMS algorithm has also been developed, consisting of six main sequential stages (Fig. 6).

At stage I, the end devices measure the flow rate.

At stage II, the information is transmitted to the gateway via a radio channel.

At the third stage, the gateway processes the information.

Stage IV – data transfer from the gateway to the network server.

The following stages involve the server processing the information and then transferring it to the application servers.

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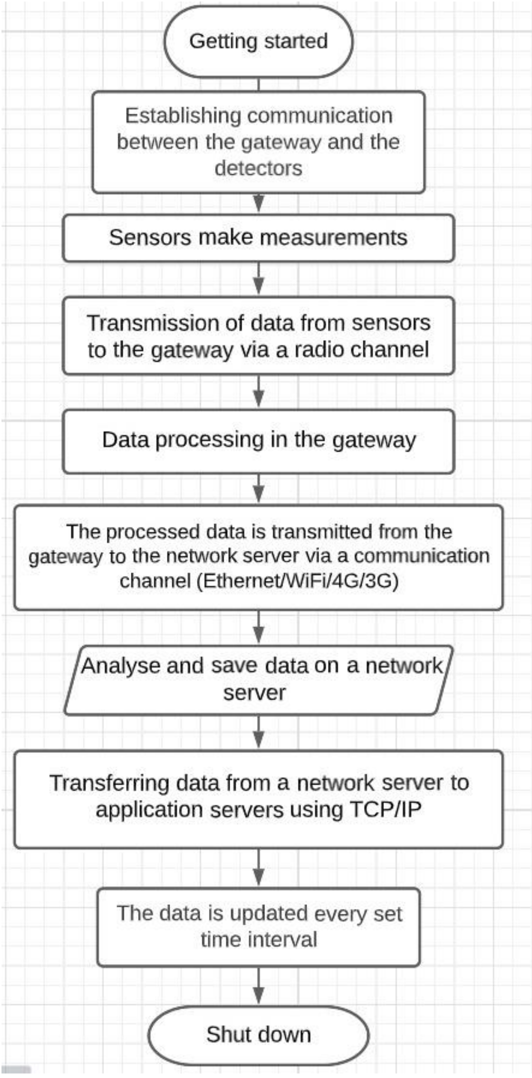

Fig. 6. The ARMS operation algorithm

After completing these stages, the information is updated after a specified period of time.

The clustering of nodes around the base stations was carried out using the FOREL and K-means methods.

The use of both of these basic clustering algorithms allows us to obtain accurate and independent results that can be further analysed and compared.

For this purpose, we consider a network of 20 thousand nodes in a city area with sides of 7 km. All nodes are randomly distributed according to a uniform distribution law. The maximum range of a gateway is 824 m. The FOREL clustering method was used to determine the gateway locations.

This method solves the problem of minimising the total distance between the centres of mass of the clusters and the elements of these clusters (1–2).

$$\{x_i, y_i\} = \arg\min_{x_i, y_i} \sum_{j=1}^{k} \sum_{r=1}^{n_j} d\left(C_j, e_{j,r}\right), \; i = 1...k, \quad (1)$$

where $\left(C_j, e_j, r\right)$ is the distance between the centre of mass of the j-th cluster C_j and the r-th element of the j-th cluster e_j, r.

Coordinates of the centre of mass of the j-th cluster

$$C_j = \{x_j, y_j\}, \; x_j = \frac{1}{n_j} \sum_{r=1}^{n_j} x_{j,r} \quad y_j = \frac{1}{n_j} \sum_{r=1}^{n_j} y_{j,r}, \quad (2)$$

where n_j – number of elements in j-th cluster;

$x_{j,r}$, $y_{j,r}$ – coordinates of the r-th element in j-th cluster.

This algorithm determines the coordinates of the centres of mass of the clusters, which can be used as positions for the placement of gateways.

The FOREL clustering modelling resulted in a network containing 25 clusters (base stations). The result of this modelling is illustrated in Fig. 7, *a*.

The network clustering was also modelled using the K-means method [16]. For 25 base stations, this method divided the network into clusters as shown in Fig. 7, *b*.

In Fig. 8 (*a* – for the K-means clustering method, *b* – for the FOREL clustering method – a formal element) shows the relative distribution of IoT devices in the considered LoRaWAN network for both algorithms. The vertical axis in Fig. 8 indicates the number of IoT devices, and the horizontal axis indicates the relative distance between the IoT device and the cluster centre.

A negative value of the relative distance in the figures indicates that the device is located to the right of the cluster centre. As we can see in Fig. 8, IoT devices are mostly distributed around the cluster centre for both clustering methods.

Therefore, the average number of nodes in each SF zone can be determined. Fig. 9 shows the average number of nodes in each SF zone for different clustering methods: *a* – for the K-means clustering method, *b* – for the FOREL clustering method.

In addition, the capacity of the LoRa base station was calculated (results in Table 4).

Let us calculate the capacity of a LoRa base station for the two clustering methods considered, where the nodes are distributed differently by the area of radio coverage zones (Fig. 10).

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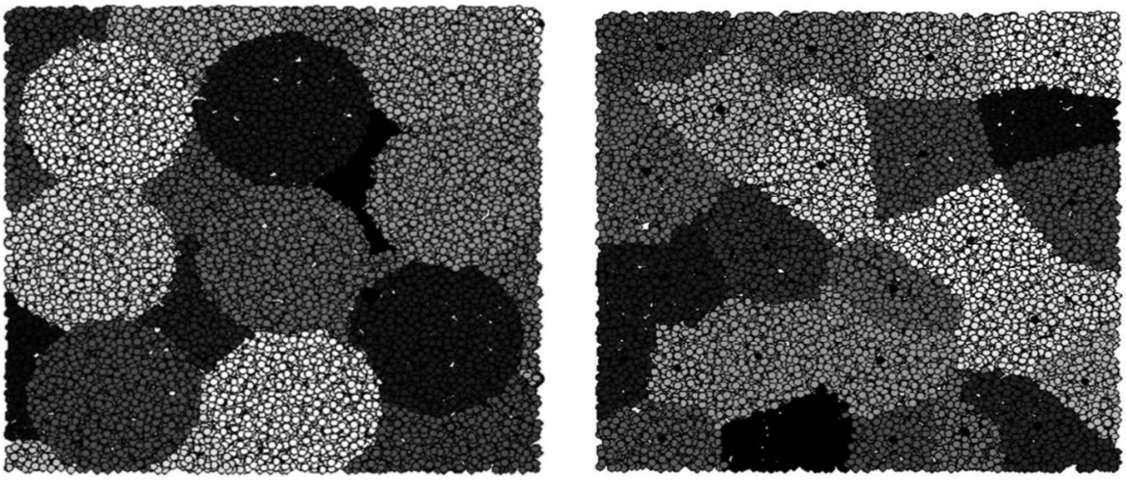
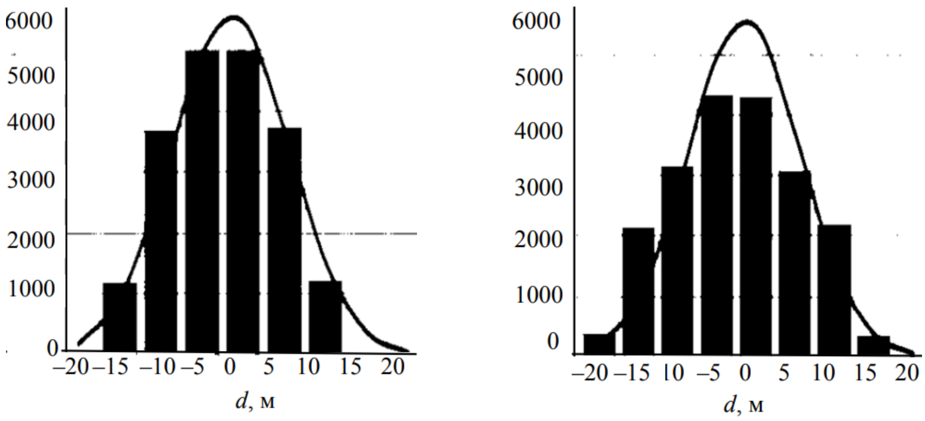


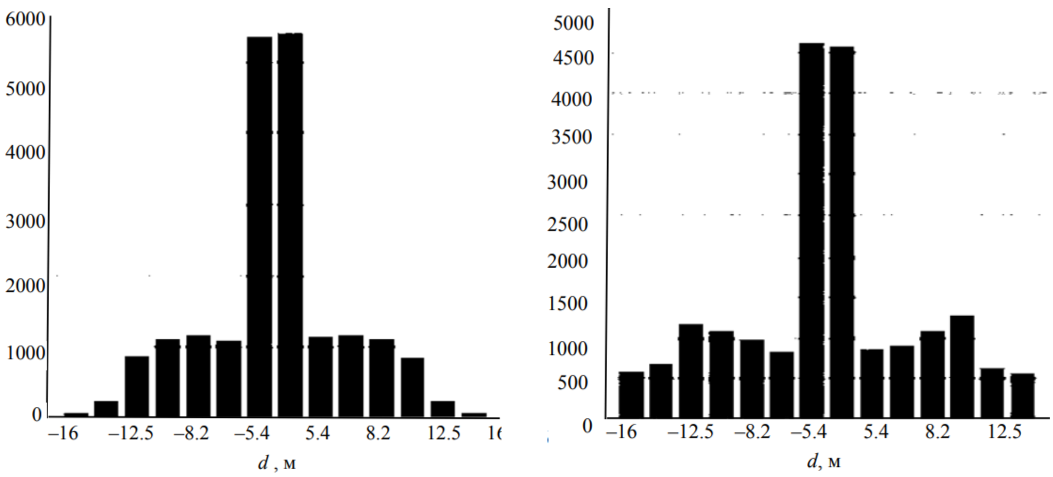
a) b)

Fig. 7. Modelling results: a) FOREL clustering method; b) K -means clustering method



a) b)

Fig. 8. Relative distribution of IoT devices in the considered network:
a) for the K -means clustering method; b) for the FOREL clustering method



a) b)

Fig. 9. Average number of nodes in each SF zone for different clustering methods:
a) for the K -means method; b) for the FOREL method

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Table 4. *Results of calculating the capacity of the BS*

Clustering method	N_{ENpac} per day	Flow intensity λ at $P_{los}=2\%$	Number of packets per day	Number of devices per BS
FOREL	24	0,01	79223	3300
K-means	24	0,01	92292	3845

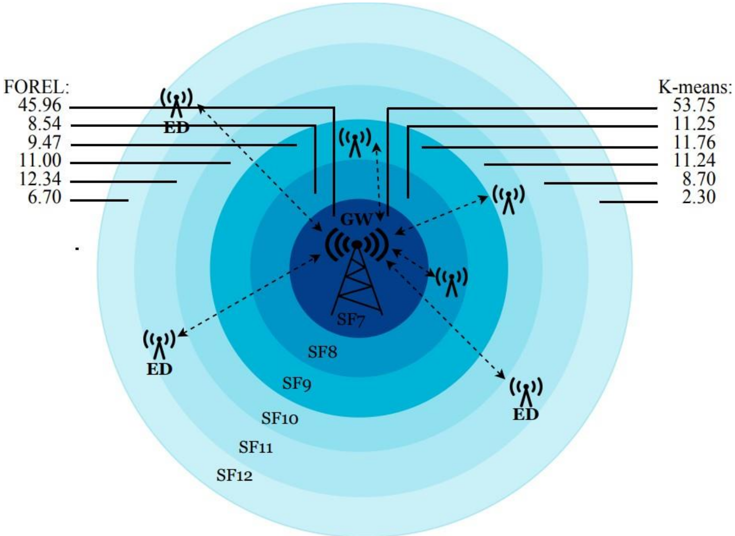

Fig. 10. The probability of using nodes in different *SF* zones if they are distributed by two methods of clustering

Fig. 10 shows the probability of using nodes in different SF zones if they are distributed according to the FOREL method, which is 45.96%, 8.54%, 9.47%, 11%, 12.34%, 6.7 For the K-means method, the probability of node utilisation is 53.75%, 11.25%, 11.76%, 11.24%, 8.7%, 2.3%.

Conclusion

Thus, the main modern technologies and standards of wireless information transmission are considered. A comparative analysis of them is carried out and the main advantages and disadvantages in the process of their use in modern commercial wireless systems for monitoring and management of resources present in the Ukrainian market are identified. The wireless data transmission technology has been selected, on the basis of which an automated resource management system has been built.

An in-depth comparative analysis of the most effective modern wireless technologies LoRaWAN and NB-IoT for building such a system was carried out. To create an automated resource management system, the LoRaWAN technology was chosen, which proved to be optimal for most technical requirements.

The simulation results made it possible to calculate the capacity of the LoRa base station for the two clustering methods considered and, accordingly, the number of end nodes per base station.

Implementation of the proposed automated resource management system at HCS facilities has the following advantages: reduction of resource consumption; transmission of information in different modes with a given frequency or at the request of the server; free access to viewing the volume of costs for dispatchers of service organizations and for consumers; notification of emergency situations and a quick response to them; increasing the energy efficiency of HCS facilities; creation of an effective dispatching system; reduction of operating costs of the HCS facility; forecasting of the future. The use of the system ensures rational consumption of resources by household consumers, which means that the financial costs of supplying resources will decrease and the level of energy savings in the country will increase.

In the future, the automated resource management system can be improved by modernising and expanding its functionality and increasing its overall efficiency. This can be achieved by adding additional types of sensor nodes to the system (ventilation, lighting, fire alarm, leakage sensors, etc.), expanding and optimising the software, adding backup power supplies, and replacing the standard antennas with more powerful ones.

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АВТОМАТИЗОВАНА СИСТЕМА УПРАВЛІННЯ РЕСУРСАМИ ДЛЯ КОМУНАЛЬНОГО СЕКТОРА НА БАЗІ БЕЗДРОТОВИХ СЕНСОРНИХ МЕРЕЖ

Предметом дослідження є методи, засоби й автоматизовані системи управління ресурсами для житлово-комунального сектора. **Об'єктом** є процес контролю витрат ресурсів на об'єктах житлово-комунального господарства. **Мета статті –** розроблення автоматизованої системи управління ресурсами для комунального сектора на базі бездротових сенсорних мереж. Для досягнення поставленої мети вирішені такі **завдання**: розглянуто й проаналізовано наявні методи, засоби автоматизованих систем управління ресурсами; обрано компоненти системи на основі технічних вимог до неї та з урахуванням обраної технології бездротового з'єднання LoRaWAN; розроблено структурну схему й алгоритм роботи автоматизованої системи управління ресурсами на базі бездротових сенсорних мереж; проведено моделювання процесу управління ресурсами комунального сектора з використанням бездротової сенсорної мережі на базі технології LoRa. У роботі застосовано такі **методи:** критичний аналіз технології LoRa та інших бездротових технологій IoT, методи кластеризації FOREL і K-means. Здобуто такі **результати:** здійснено загальний опис автоматизованої системи управління ресурсами, визначено її склад та основні завдання, а також встановлено технічні вимоги до неї, обрано технологію бездротової передачі даних, на основі якої побудовано автоматизовану систему управління ресурсами, проведено глибокий порівняльний аналіз найефективніших сучасних бездротових технологій – LoRaWAN та NB-IoT, обрано компоненти системи, розроблено структурну схему й алгоритм роботи автоматизованої системи управління ресурсами, змодельовано процес управління ресурсами комунального сектора з використанням бездротової сенсорної мережі на базі технології LoRa. **Висновки:** застосування запропонованої автоматизованої системи управління ресурсами забезпечує якісний контроль енерговитрат на об'єктах житлово-комунального сектора, дає змогу контролювати їх обсяг, проводити моніторинг та аналіз інформації про енерговитрати, керувати всією мережею енергопостачання як єдиною системою, що особливо необхідно в умовах воєнного стану. Такий підхід допомагає раціоналізувати споживання ресурсів побутовими споживачами, а це означає, що фінансові витрати на енергопостачання зменшаться, а рівень економії енергоресурсів у державі загалом зросте.

Ключові слова: енергопостачання; бездротова сенсорна мережа; автоматизація; шлюз; моніторинг; сенсорний вузол; базова станція.

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