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CITY STREET LAYOUT DEVELOPMENT UNDER THE CONTROL OF "SMART STREET" DATA ACQUISITION SYSTEM

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Background. One of the urgent tasks of local authorities is to reduce the use of energy and human resources in the field of street services. The solution of this problem requires the development of a control system prototype that will allocate the resources needed to maintain the street in proper form more efficiently. The development and implementation of such a system is possible through the use of the concept of the Internet of Things.

Objective. The purpose of the paper is creating advanced street management system prototype.

Methods. Particular attention of the study is directed to the data exchange protocol selection, step-by-step system topology layers configuration, and mobile street layout development.

Results. A few assembled and personally programmed end node modules were designed as a part of the first system topology layer.

Conclusions. The paper proposes the use of the LoRaWAN protocol for data transmission from the designed sensors to the processing center. Developed control system prototype testing showed satisfactory results in the field of communication reliability, sensors operating time from the internal power supply and the possibility of different subsystems integration.

Keywords: Internet of Things; smart street management; monitoring system; LoRaWAN protocol.

I. INTRODUCTION

Today, an important and demanding task is to improve the quality of people's life in megacities. The number of people who prefer urban living conditions is increasing every year, while human-service systems are not reforming. This creates an additional burden on utility systems, while wasting a lot more resources than is really necessary. This list includes human, temporary and energy resources. Therefore, at this stage in the development of solutions to solve this problem, a popular way to improve the lives of citizens is to use automated management systems. Abroad, municipal authorities are already successfully experimenting with such prototypes - for example, in Barcelona, smart irrigation systems for parks and lawns have reduced the city's total water consumption by a quarter.

According to Cisco's research, 500 billion devices will be connected to the Internet by 2030 [1]. Each such device may contain several sensors or servos for scanning and changing environmental conditions. Moreover, such devices are a powerful source of data, and access to the global network helps transfer the received information to other nodes of the system for processing. A cluster of such devices forms the Internet of Things (IoT) - a network, in which devices interact with each other limiting human participation. An operator who monitors the network is still making a decision - however, advanced systems offer full automation of the necessary processes.

IoT technologies exploitation can help city authorities achieve resources usage efficiency. The installation of data collection and analysis systems makes it possible to significantly reduce the cost of water resources, control the congestion of roads and parking lots. Besides these, weather data, lighting management, atmosphere quality control and early earthquake detection are used. In addition to the obvious financial and social benefits, officials receive an increase in the public confidence rating. A useful bonus of implementing the Internet of Things is the collection of all depersonalized helpful data kinds, so that authorities, mobile operators and client-oriented companies better understand the audience by offering high-quality demanded services. On the other hand, already installed system infrastructure allows developing new helpful features.

II. BACKGROUND

According to the study [2], a possible scenario for the "Kiev Smart City" concept development is to design an automated elements management system prototype

for the "Smart Street". The next controlled spheres introduction are proposed:

- street lightining maintence, based on the illumination parameter;
- the parking spaces congestion degree checking;
- garbage containers cleaning scheduling.

This choice is due to the following factors practical: in Barcelona, smart lighting technology can save up to $ 37 million a year parking spaces booking applications allow the city to earn 50 million euros a year. In addition, it simplifies the search for electric vehicles charging station for, and it is easier for municipal authorities to control traffic congestion [3]. In Chicago, the sensors installed in garbage containers allowed to reduce the number of garbage ignitions by 32%.

To improve the functioning of the customized system and expand the range of capabilities and for the additional testing of new functions, the following steps are proposed:

- to expand the number of sensors: add ones, that monitor the atmospheric parameters of the street;
- to add devices, that fix the traffic, on the basis of which it is possible to develop a street safe crossing system;
- to create a mobile demonstration platform that allows to synchronize the operation of all subsystems and test the quality of communication, fault tolerance and ease of management.

The development of the platform, as well as the addition of new types of sensors, involves the step-by-step execution of the following tasks:

- selection of data transfer protocol and study of its architecture;
- assembly and programming of devices complementing the system;
- the base station and network server setting up;
- expanding the capabilities of the application server.

The conditions, that must be observed when choosing a data transfer protocol are the following:

- sensors do not require the use of external energy for the operation for 3 or more years;
- prototype provides information from sensors in real-time mode;
- protocol allows to adapt existing systems to the proposed model of communication.

III. DATA EXCHANGE PROTOCOL SELECTION

Comparative analysis of the advantages and limitations of data exchange protocols between the sensors and the processing center will allow choose a technology that meets the requirements of the system. Given the need for monitoring system to work in conditions of energy shortage of end devices, it is advisable to consider data exchange protocols in LPWA (Low Power Wide Area) networks. The most widespread protocols are SigFox, LoRaWAN, NB-IoT, and Weightless-P.

SigFox allows communicate with low energy consumption over long distances (up to 10 kilometers in the city). Ensuring a low level of transmitter power is achieved by using a narrow frequency band to connect devices to the network. Data exchange between devices takes place in the unlicensed band (868, 8 MHz), which allows the use of technology by private users. The technology uses an AES encryption algorithm with HMACs. The limitations of the protocol include: the technology is not open for implementation and prohibits the use of unlicensed sensors; the maximum message length is 12 bytes, and the number of uplink messages cannot exceed 140/day, while downlink ones reach only 8/day. In addition to these disadvantages, SigFox devices are not mobile (for example, they cannot be used to track the location of objects).

LoRaWAN (Long Range Wireless Area Network) is an LPWA network protocol that allows devices to exchange small amounts (up to 254 bytes per message) of information at low (0.3 - 50 kbps) speeds [4]. The compromise between range and speed of messaging allows longer use of energy resources of sensors. The technology uses data encoding with broadband pulses using chirp. This allows the receiver to be resistant to frequency deviations and reduces the requirements for the clock generator, which allows the use of inexpensive quartz resonators. The frequency standard for Europe (including Ukraine) is 868 MHz, which is not licensed under the law; channel frequency band could be extended up to 500 kHz. LoRaWAN networks provide mandatory two-level data encryption (AES-128) to preserve the integrity of messages; the use of a unique network connection key encrypted according to the AES-64 algorithm prevents the interception of data transmitted by end devices. The range of coverage in the urban environment reaches 5 km, and the duration of the sensors from the battery can exceed 10 years [5]. An important advantage of the protocol is openness - users are not limited by the number and speed of messages, and choose the necessary settings within the standard.

NB-IoT is a technology that expands the capabilities of mobile stations to combine data from cellular users and IoT devices. The advantages of NB-IoT include the availability of coverage in the city and high (200 kbit/s) data transfer rate. The use of a narrow frequency band

and low transmitter power provide a significant service life of the devices (up to 7 years). Disadvantages that do not allow individuals and organizations to use NB-IoT include the cost of updating the software of cellular stations and the use of licensed spectrum. In addition, due to this data rate each sensor consumes twice as much energy than, for example, LoRaWAN.

Weightless-P is an LPWA technology for systems that require high-density end devices, long-term battery life, and two-way communication between sensor and gateway. Weightless-P operates in the unlicensed range (ISM), and allows deploy coverage up to 2 km in the city. The transmission speed is 0.1 - 100 kbit/s; the AES-128 algorithm is used for data encryption and the AES-256 for device authentication. A significant advantage of the Weightless-P protocol is the wide scalability: compared to other LPWAN technologies in the range up to 1 GHz, the Weightless-P allows 30% of transmitters to be served by one base station. The main disadvantage of this technology is the limited license of the manufacturer to use components at all levels of the system topology.

It should be noted that SigFox, LoRaWAN, and NB-IoT are asynchronous technologies, and Weightless P is synchronous one.

The processed results of comparative analysis are shown on Fig. 1:

Specifications	SigFox	NB-IoT	LoRaWAN	Weightless P
Range	ISM	Licensed	ISM	
Speed	100 bit/s	1-200 kbit/s	0,3-50 kbit/s	0,2-100 kbit/s
Band	Narrow band, 100 kHz	Narrow band, 200 kHz	Wide band, 500 kHz	Narrow band, 12,5 kHz
Maximum operating time of sensors	Up to 15 years	Up to 7 years	Up to 15 years	Up to 5 years
Frequency range	868,8 MHz 915 MHz 433 MHz	700 MHz 800 MHz 900 MHz	868,8 MHz 915 MHz 433 MHz	868,8 MHz 915 MHz 433 MHz
Maximum data transmission range in the city, km	10	-	2,5	2

Fig 1 Widespread protocols analysis results

Thus, it was found that the most suitable for the monitoring system development is LoRaWAN technology. It is important for local monitoring that according to the standard set in the LoRaWAN network, the collection of information from the sensors is safe for humans, because the transmitter power is less than 25 mW. Also, due to the prevalence of technology at the moment, the market offers the largest number of types of sensors, and their sizes are much smaller than analogues that use other protocols for data transfer

Compared to other protocols, LoRaWAN has the following advantages:
- Compared to SigFox: LoRaWAN has an unlimited number of messages and their transmission speed, which is an important criterion for monitoring the chemical and radiation composition of atmospheric air in the city. Unlike SigFox, LoRaWAN does not force licensing of devices and is a protocol open to study and upgrade;
- Compared to NB-IoT: devices in the LoRaWAN network work longer in conditions of energy shortage and are mobile in contrast to NB-IoT sensors. An important advantage of LoRaWAN is the use of unlicensed spectrum and the availability of encryption of messages and keys to connect devices to the network;
- Compared to Weightless P: significant advantages of the LoRaWAN protocol are longer autonomy of devices and greater range of coverage in the city.

In addition, an important feature of LoRaWAN is the ability to simultaneously receive multiple orthogonal signals with the same frequency but different data rates. This provides a much larger number of simultaneously processed messages, despite the limitation of the standard number of reception channels (8 or 16).

Given the results of the comparative analysis and the described advantages of the LoRaWAN protocol, the paper identifies and proposes the use of LoRaWAN technology for data transmission in the Smart Street monitoring system.

IV. LoRaWAN PROTOCOL SPECIFICATIONS

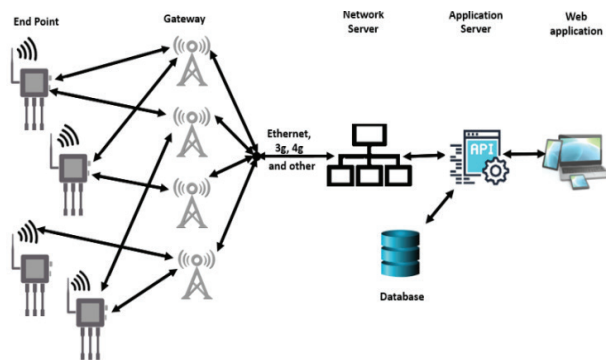The protocol has a "star" topology (Fig. 2) [6]:

Fig. 2 LoRaWAN protocol "star" network topology

The hierarchy of communication nodes consists of an end node, a base station (gateway), a network server and an application server [7]. The sensor is combined

with a data reception-transmission module and a controller that processes the data packet, encrypts it and sends it to the gateway. Sequential data encryption at the sensor level allows the base station to securely transmit data to a network server by converting the radio signal to a digital stream. The server regulates the interaction of sensors and base stations, in particular their timely interview. The application server is used to decode information, sort, store and visualize data [8].

It is worth noting that the LoRa stack (Long Range) is responsible for the physical level of radio communication of the modules. LoRa is patented by the French manufacturer Semtech and work under the principal of extended spectrum modulation, similar to CSS (Chrip spread spectrum) modulation. CSS is an extension of the spectrum in which information is encoded using broadband pulses of linear frequency modulation. In particular, the IEEE 802.15.4a standard defines CSS as a method for use in low-speed wireless personal area networks (LWPANs) [9].

Unlike the physical LoRa layer, the LoRaWAN standard is a media access control (MAC) protocol. The main application of the MAC protocol occurs at the network level of the OSI model for routing and control of communication between the base station and end devices.

Thus, LoRaWAN defines the communication protocol and system architecture for building a distributed network, while the physical layer of LoRa is responsible for transmitting messages over long distances. LoRaWAN also provides control of communication frequencies, data rates and power of all network devices. Typically, end devices operate in asynchronous mode, and transmit information only when data has been accumulated or on a set schedule.

V. SYSTEM COMPONENTS INTEGRATION

Today, the active development of integrated circuit design and production systems allows to choose device components from a wide range of combined products. In addition, the patented integrated circuit protects the development from copying and illegitimate use, which is contrary to the LoRaWAN standard.

Thus, it is of interest to choose the integrated components of the prototype, which will ensure the correct operation of the device. To perform the tasks, the radio modem must provide a long time of operation from a stand-alone power supply, have analog and digital outputs for connecting sensors.

The set of the end node components can be reduced to the following [10]:
- modem;
- receiver;
- transmitter;
- microcontroller;
- non-volatile memory (EEPROM);
- analog and digital outputs;
- sensors according to the field of use.

Due to the mentioned integration trend, modem, receiver and transmitter are united into one tranceiver module. The chip RFM95W provides operation of synchronous and asynchronous modes of the device and performs the necessary signal transformations according to the selected modulation method LoRa.

As an energy consumption experiment two types of microcontrollers were chosen: Arduino Uno and STM32F103C8T6, that are compatible with RFM95W tranceiver. Also, both of them can provide power supply for all of the components in city street layout and have enough analog and digital outputs for sensors and servos set up. EEPROM memory is considered to be installed for saving connection configurations during sensors hibernation mode utilization.

Sensors required for automated operation of the system are: ultrasonic, luminosity, meteorological (in particular, temperature, humidity, pressure, gases - ozone, benzene, carbon monoxide, nitrogen dioxide). Meteorological indicators can be measured using a BME280 sensor connected via the Serial Periferal Interface. It is proposed to monitor gas parameters using correctly configured MQ-131 and MQ-135 sensors. A feature of the device is the ability to respond to several contaminants at once. This is achieved due to the difference of standard concentrations of gases in the air, which allows to set the thresholds of the analog voltage, which is proportional to the change in resistance of the sensitive element of the sensor.

The elements of the layout on Fig. 3 are created with the help of 3D-printing technology.
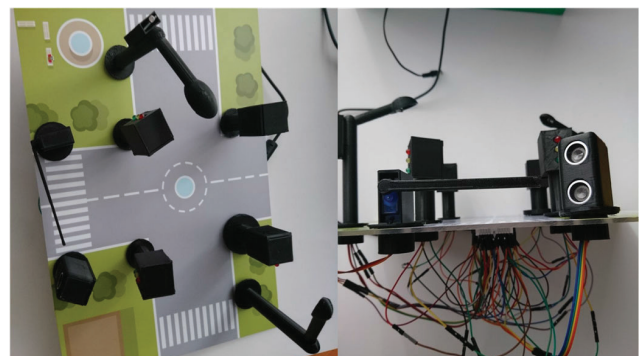

Fig. 3   City street layout prototype

The digital 3D-models, which are sensor housings, were designed using Tinkercad software. This development environment allows to visualize the necessary components of the street (traffic lights, park

registration system, adapt lighting system) and import modules to the 3D-printer.

As a result of combining printed models and sensors, as well as connecting power to the platform, there is good example of using sensors to help regulate resources to maintain the street. The generated data has to be transmitted to the base station over the air according to the topology (Fig. 1). Registration of transceivers controlled by microcontrollers is carried out using the exchange of technical messages, accompanied by encryption and calculation of checksums.

Cisco Wireless Gateway for LoRaWAN was chosen as the base station (Fig. 4). The main technical characteristics of the device are:

- support for end nodes of all classes (A, B, C), automatic channel switching, standard SF, adaptive baud rate settings;
- the presence of a GPS - positioning module, which with the help of TDoA (Time of Arrival) and RSSI (Received Signal Strength Indicator) can work even at the minimum battery level;
- possibility of NTP (Network Time Protocol) synchronization;
- additional: Ethernet (up to 1 Gbps);
- the presence of software components to protect the operating system;
- two SX1301 transmitter modules;
- 16 channels of receiving messages;
- FPGA-module is installed, which allows working directly with the FPGA, which controls the device.

Fig. 4 Cisco Wireless Gateway for LoRaWAN

The Cisco Wireless Gateway for LoRaWAN requires a converter power of 48-60 V. An additional and more convenient power option is PoE (Power over Ethernet), when the RJ-45 cable receives power from the base station and at the same time converting radio signals to digital, forwards message packets to the network server.

It is important to note that the coverage area of the BS strongly depends on the connection of the receiver amplifiers, so it is necessary to connect the antennas.

To set up a base station, an RG45-RS232 cable and a serial port on personal computer are required. Connection to the base station operating system interface is recommended using the PuTTY program (Fig. 5). PuTTY is a client application for communication of various remote access protocols (SSH, Telnet, rlogin) which allows to work through the serial port. It is necessary to choose connection speed 115200 baud, connection to gateway through serial port and to select it from the list. To select the correct serial port simulation via the USB port, it is recommended to find the new device in the connections, identify it and adjust the speed, which will be specified in the connection speed in PuTTY.
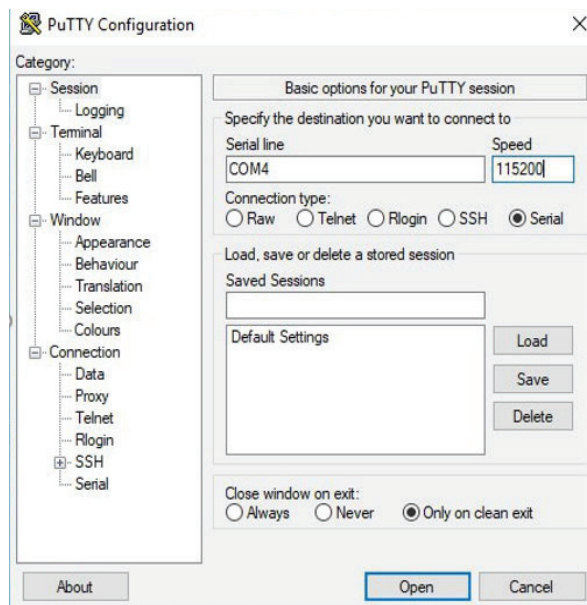

Fig. 5 PuTTY configuration window

After connecting the computer to the base station interface, further settings are possible. It is recommended to restart the base station after starting the PuTTY client.

It is worth noting that the forwarding of packets from end devices is done using special hardware and software. LRR (Long Range Receiver) is equipment that includes one or more transceivers that comply with the standards of the MAC access protocol of the LoRaWAN network. The software that is required to include the base station in the LoRaWAN network is Packet Forwarder, which provides LRR management and forwarding of messages from end devices to servers, networks and applications. The Packet Forwarder and its public authentication key installation provided by PuTTY connection and gateway command line

interface. It is highly recommended to keep saving every step of setting up the interface.

VI. RESULTS

During the investigation the local network for monitoring street resources usage was established. The connection between assembled and programmed end nodes and the base station has shown stability of the data flow, and network server logger reports about delivering all of the packets.

For demonstrating advantages of the proposed solution the city street layout was projected. It is generates data about the number of empty parking places, light intensity level based on the luminosity parameter and human presence, allows to manage garbage containers fullness, automatically regulate traffic on the modeled road and scan atmospheric parameters.

Decoding and processing data is performed in the developed application server. NI LabVIEW environment allows manipulating with all kinds of data and is useful for modeling virtual panels during testing. For the study's results handling and real-time data observing the virtual instrument "Smart Street 2.0" was created (Fig. 6).
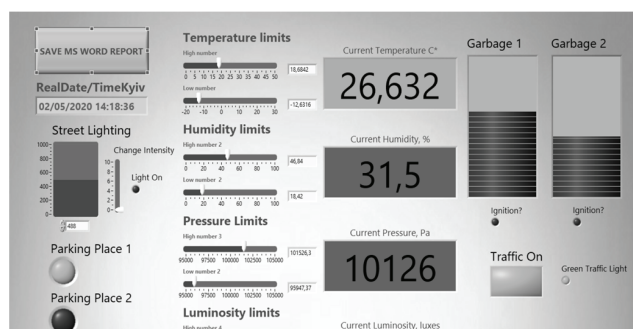

Fig. 6 Smart Street management system application

The developed application (Fig. 6) allows:
- TCP / IP requests for data directly to the network server;
- Transferring data using the client-server interface from the MQTT-broker;
- Decoding of encrypted data;
- Storing information to a local database or to the MySQL environment;
- Working with Microsoft Word and Excel reports;
- Logging of accepted queries to the journal;
- Graphical and analytical information representation;
- Alarm settings customizing tools;
- Established targets violation warnings on specified electronic mailboxes.

VII. CONCLUSION

In this work, the city street layout under the control of monitoring system construction with the LoRaWAN protocol for transmitting data from sensors to the processing center implementation is proposed. The main implementation achievement is the improvement of previous hardware and software versions, extending the number of used sensors and finding better solutions for system energy consumption. STM32F103C8T6 showed up to 14% hibernation mode efficiency, which is a significant result that forwards to the Arduino microcontroller rejecting in further works. The next step of the study may be to receive and process enough traffic road data for creating a street movement regulating neural network. A new sensors implementation according to the European standards is also an important development breach. In addition, the new software modules functionality development, as well as their further integration into a single control application is planned.

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Копанєв М.М., Живков О.П., Галицький І.І., Акопян П.Г.
Розробка макету міської вулиці під управлінням системи збору даних «Smart Street»

Проблематика. Одним із нагальних завдань місцевої влади є скорочення використання енергії та людських ресурсів у сфері вуличних послуг. Вирішення цієї проблеми вимагає розробки системи управління прототипом, яка дозволить більш ефективно розподілити ресурси, необхідні для підтримки вулиці у належному вигляді. Розробка та реалізація такої системи можлива завдяки використанню концепції Інтернет речей.

Мета досліджень. Метою роботи є створення вдосконаленого прототипу системи управління вулицями на основі 3D-макету міста.

Методика реалізації. Особлива увага дослідження приділяється вибору протоколу обміну даними, покроковому налаштуванню топологічних шарів системи моніторингу та розробка і об'єднання компонентів макету вулиці.

Результати досліджень. Кілька зібраних та персонально запрограмованих модулів кінцевих вузлів були розроблені як частина першого шару топології системи.

Висновки. У статті пропонується використовувати протокол LoRaWAN для передачі даних від розроблених датчиків до центру обробки. Тестування розробленого прототипу системи управління показало задовільні результати у галузі надійності зв'язку, часу роботи датчиків від внутрішнього електроживлення та можливості інтеграції різних підсистем.

Ключові слова: Інтернет речей; розумне управління вулицями; система моніторингу; протокол LoRaWAN.

Копанев Н.М., Живков А.П., Галицкий И.И., Акопян П.Г.
Разработка макета городской улицы под управлением системы сбора данных «Smart Street»

Проблематика. Одной из важных задач местной власти является сокращение использования энергии и человеческих ресурсов в сфере уличных услуг. Решение этой проблемы требует разработки прототипа системы управления, которая позволит более эффективно распределить ресурсы, необходимые для поддержания улицы в надлежащем виде. Разработка и реализация такой системы возможна благодаря использованию концепции Интернет вещей.

Цель исследований. Целью работы является создание усовершенствованного прототипа системы управления улицами на основе 3D-макета города.

Методика реализации. Особое внимание исследования уделяется выбору протокола обмена данными, пошаговой настройке топологических слоев системы мониторинга, а также разработке и объединению компонентов макета улицы.

Результаты исследований. Несколько собранных и персонально запрограммированных модулей конечных узлов были разработаны как часть первого слоя топологии системы.

Выводы. В статье предлагается использовать протокол LoRaWAN для передачи данных от разработанных датчиков в центр обработки. Тестирование разработанного прототипа системы управления показало удовлетворительные результаты в области надежности связи, времени работы датчиков от внутреннего электропитания и возможности интеграции различных подсистем.

Ключевые слова: Интернет вещей; умное управление улицами; система мониторинга; протокол LoRaWAN..