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FEATURES OF IoT TECHNOLOGIES USED IN ENERGY CARRIER METERING SYSTEMS

A. Pysarets, O. Pysarets
National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
E-mail: anna.v@ukr.net, pysarets.alexander@lll.kpi.ua

The rapid development of information technology is facilitating the creation of information-measuring systems. These systems allow combine measurement and data transmission. This, in turn, enables their fast real time processing and analysis.

Transmission of measurement data is achieved using network technologies, among which the Internet of Things (IoT) is becoming increasingly popular.

Using of IoT technologies enables the processes automation in various fields of human activity. These include energy production, power generation, industry, housing and utilities, education, medicine, trade, transportation, logistics, the service sector, and more. They are used in street lighting control systems, atmospheric monitoring, soil control et al.

The aim of the work is to study the possibilities of using IoT technologies for constructing energy carriers metering systems.

The purpose of such systems is, on the one hand, to collect, transmit, process, and analyze instrument readings, and on the other, to provide a comprehensive situational analysis. The latter is based on the use of various sensors to measure and analyze environmental and process parameters, facilitating optimal decision-making.

The creation of automated energy carriers metering systems serves as a convenient working tool for obtaining prompt and reliable information, provided by automatic and virtually simultaneous polling of all remote devices, the ability to analyze current data in the form of tables, graphs, and diagrams, as well as excluding of the "human factor" influence in reading and processing data.

The paper examines the structure of automated energy metering systems; identifies the specifics of designing systems using various wireless technologies; conducts a comparative analysis; evaluates the advantages and limitations of their use; and provides recommendations for their creation.

***Keywords:** energy carriers; accounting; readings; energy carrier metering systems; data transmission technologies; IoT; architecture.*

Introduction. Problem statement

The high-quality accounting issues of energy resources consumption (water, natural gas, heat amount) still remain relevant. Previously, such problems were caused due to the lack of metering units, especially in the housing and communal services. In such cases, bills were generated according to different algorithms based on meter readings or specific rules. The examples of these rules are tariffs that take into account the number of consumers or an area of the premises and others.

Today, most consumers are equipped with metering units for various purposes (from private homes to industrial enterprises). The installation of metering units allows you to pay only for the energy resources consumed and involves the process of transmitting meter readings at a certain frequency or upon request if necessary.

But at this stage many issues are arise. The most common among them are the following:

– The difference between the readings of the general domestic meter and the total consumption of all metering units installed at the facility;
– The difference between actual consumption and that indicated on the bill.

To a certain extent, these issues are related to errors in information transmission, caused mainly by human factors. A reliable way to solve such issues is to implement automated systems for transmitting readings from metering instruments.

Such systems combine measurements and the transmission of their results over a distance, which, in turn, allows for the prompt processing and analysis of data, including in real time.

A convenient tool for creating systems in this case is the Internet of Things (IoT) technologies use, which allows combining various devices with unique identifiers into a single digital network. Within this chain, all elements can interact with each other without human intervention through the use of IP connectivity.

The use of IoT technologies facilitates the automation of processes in various areas of human activity, such as energy resource extraction, power generation, housing and utilities, education, medicine, industry, trade, transport, logistics, the service sector etc.

They have found application in street lighting control systems, for monitoring atmospheric parameters, controlling soil parameters and many others.

The aim of the work is to study the possibilities of IoT technologies using for the creation of automated energy carriers consumption metering systems.

Actual scientific researches and issues analysis

The authors of works [1 – 5] conducted thorough studies of the possibilities of using IoT technologies in various areas of human activity, in particular, healthcare, agriculture, industry, education, critical infrastructure, within the concept of Smart Home and Smart Cities.

Researchers note the limited energy resources of devices, the need to ensure wide coverage, support a large number of devices [5], low computing power, vulnerability to hacker attacks, and incompatibility of devices from different manufacturers among the main issues.

In work [2], as well as in [5 – 7], issues of application security and data vulnerability associated with cyber attacks on critical infrastructure systems are discussed.

In the paper [6] the hierarchy of the IoT architectures, which consist of three, four and five levels, is considered. The last of the mentioned architectures addresses issues of data security and privacy. It is noted that security remains the weakest point of the IoT. Potentially vulnerable components of such systems are identified.

The article [7] is devoted to the analysis of data packets in Internet of Things protocols and standards to assess the impact of encryption on their sizes.

Metering instruments (such as meters and flow meters) are the basis of the automated energy carrier metering systems structure. Therefore, manufacturers of such measuring instruments try to offer their own options for creating systems [8 – 10]. The prefix “smart-” in the name of products from the corresponding catalogues is a sign of the possibility of using the measuring instrument as part of the IoT system [8 – 11].

Using IoT technologies to create automated energy metering systems

Any remote metering system of energy carriers can be considered as three-level architecture [3 – 5].

At the first (lower) level are located the so-called end points, which include:

- Measuring instruments (meters or flow meters),
- Physical quantity sensors (temperature, pressure, humidity, lighting, tank level etc.),
- Status sensors (door or window opening triggers),
- Indicators,
- Actuators (valves, servo drives etc.).

The main requirement for instruments at this level is the presence of one of the electrical interfaces. This allows the conversion of a physical quantity into an electrical signal or digital code, or vice versa for actuators.

The pulse output of a water or gas meter is an example of a simple interface. It is implemented using a magnet and a reed switch. In this case, the readings are "encoded" by a number of electrical pulses, which is a multiple of a certain volume of energy carrier that has passed through the meter.

The structure second level includes data transmission channels. At the physical level, they can be divided into two groups: wired and wireless data transmission channels.

Wired data transmission channels are usually used where reliability and failure-free data transmission, as well as absolute security of this data are necessary. Their disadvantages include:

- Limited transmission range. This value depends on the cable length due to the cable's physical properties. Specifically, capacitance increases with cable length. High capacitance distorts the digital signal, making it impossible to decode the data received from the remote instrument.
- Relatively small number of end instruments connected to a single network (usually no more than 250 pieces).

The wireless group is significantly larger in terms of existing technologies range. Most of them provide data transmission on the “last mile” via the Internet.

The third level of the architecture is the level of accumulation, processing, and analysis of received data. At this level the data received from end devices is deciphered, distributed among users, and so on.

In recent years, two IoT standards have been most frequently used to create automated metering systems: LoRaWAN and NB-IoT [10 – 15].

In both cases, a typical network contains metering instruments, base stations (gateways), a network server and an application server [13 – 15]. The deployed networks have a point-to-point topology.

The use of LoRaWAN (Long Range Wide Area Network) technology allows for the transmission of small amounts of data over long distances (up to 10 – 15 km) and provides simultaneous servicing of a significant number (tens of thousands) of metering instruments [13, 16].

To connect a device to a LoRaWAN network, it must be equipped with a built-in or external radio module and an appropriate interface for communicating with it. In this case the data transmission quality depends significantly on the direct visibility and the distance from the end point to the base station.

Each base station has a permanent connection to the Internet, which ensures uninterrupted receiving of meter readings and their transmission to the network server.

The top-level software allows you to obtain the necessary information about every meter, which is stored on a network server, using the application server.

A key feature of the LoRaWAN network is the ability to simultaneously use equipment from different manufacturers. All network elements operate in the unlicensed 868 MHz frequency band [12, 15, 16].

The characteristic features of LoRaWan technology are [12, 15, 16]:

– Operation in an unlicensed frequency range;
– Long signal range in open space;
– Reliable protection of transmitted information;
– Using a single base station to serve up to several thousand devices;
– Long battery life (can last up to 10 years);
– Autonomous operation of the device when using solar panels until its lifespan expires.

However, the limitations of the technology application are as follows [15 – 18]:

– Relative complexity in deploying and configuring the system;
– Poor indoor coverage. Due to the use of 868 MHz frequencies, the signal may have difficulty penetrating thick walls and ceilings, significantly limiting its use in basements, wells, and reinforced concrete buildings;
– In networks with a very high density of end devices, the number of collisions (packet losses) may increase, requiring careful network planning.

The NB-IoT (Narrow Band Internet of Things) network is deployed on existing 4G/LTE mobile network equipment.

Connecting metering instruments to the NB-IoT network requires the use of special modems with a SIM card from the corresponding mobile operator. The connection between the meter and the NB-IoT modem is carried out via a radio channel or using the meter's pulse output. In addition, meter models with integrated modems and eSIM have begun to appear [19]. The mobile operator acts as a transport infrastructure that ensures the transmission of readings from the meter to the energy supplier's server.

The main advantages of devices with NB-IoT technology are [14, 15]:

– Low power consumption (5-10 years of battery life);
– High network capacity (tens and hundreds of thousands of connected devices per base station);
– Low cost of the end equipment (modems);
– Simple and quick determination of the signal strength at the project location using a regular mobile phone.

These standards differ significantly in the frequencies and radio equipment used for data transmission. At the same time, the difference is practically imperceptible for the user. It’s justified as follows:

- The transmission range is determined by the density of the base stations (gateways);
- The operating time from a single set of batteries is similar and can last up to 10 years;
- Used meters are equipped with a pulse output or with a built-in radio module of the appropriate standard.

The automated systems creation for monitoring process parameters enables data accounting, control, and recording, as well as system safety and reliability. This ensures convenience and ease of use for the end user.

In the residential sector of our country, energy carriers metering units (water, natural gas, and heat amount) are the property of the consumer.

In such cases, the organization of automated accounting systems is determined by financial feasibility. Therefore, they are primarily installed in new buildings.

At the same time, even within a single apartment in a multi-apartment building, the use of IoT technologies makes it possible to monitor air parameters (temperature, humidity), manage the power supply of electrical appliances according to a selected schedule (boiler, underfloor heating), adjust lighting depending on the time and light level etc.

For example, a thermostat built into a boiler can maintain a set water temperature. A thermostat installed on a radiator is another automation example. This simple mechanical device can maintain a comfortable temperature in a room.

But even simple digitalization of these processes contributes to more economical energy consumption. In this case, it is enough to connect the boiler through a timer socket, which will turn on only when the cheap tariff is in effect. As a result, the cost of hot water will be lower than with a standard connection. An electronic radiator thermostat can be programmed to significantly reduce the room temperature when no one is home, and then raise the temperature to a comfortable level before returning to the room. A slight temperature reduction at night is also considered for healthy sleep. Such measures can save up to 15 - 20 % of heating energy.

In the electronic devices given examples, their programming or configuration is performed manually using buttons and a display. This is not always convenient.

Such devices are easier to configure using a smartphone. To do this, they must be equipped with one of the common radio interfaces: Bluetooth, Wi-Fi or Zigbee. These interfaces parameters are given in Table 1.

Table 1. Data transfer protocol parameters [20 – 23]

Parameters	***Wireless communication standard***		
	Wi-Fi	*Bluetooth*	*ZigBee*
Frequency change range	2.4; 5 GHz	2.4 GHz	2.4 GHz
Data transfer rate	≤ 9.6 Gbps	1 – 2 Mbps	250 kbps
Maximum data transmission range	30 – 100 m	up to 10 m	up to 20 m
Power consumption in active mode	150 – 400 mA	5 – 15 mA	20 – 40 mA
Power consumption in sleep mode	1 – 20 mA	5 μA	3 μA
Network topology	star	point-point	star; tree, mesh
Maximum number of nodes	from 1 to 253 and more (depending on the router)	7	65000
Safety standard	WPA2, WPA3	AES-128	AES-128

Wi-Fi is the commonly used name for the IEEE 802.11 standard for wireless local area networking [20].

Such devices operate on 2.4 and 5 GHz frequencies. However, the vast majority of IoT devices use exclusively the 2.4 GHz band, as these waves is significantly better at penetrating physical obstacles (such as walls or furniture) and providing a greater coverage range.

As a result, in apartment buildings, dozens of routers, microwave ovens, and other devices operate on the same frequency. This causes interference, which can lead to lost data packets, delays in device response, or their temporary disappearance from the network.

Bluetooth is a wireless data transmission standard based on IEEE 802.15.1 [22]. It operates in the 2.4 GHz frequency range. The topology is point-to-point. The phone acts as the main device (hub). The end device only receives commands and executes assigned tasks.

Unlike the classic Bluetooth standard, which focuses on a constant connection and continuous streaming of data, Bluetooth Low Energy (BLE) was designed for the occasional exchange of short messages [23]. The BLE architecture allows the microcontroller and radio module to remain in a deep sleep state almost entirely.

A device equipped with BLE, such as a temperature sensor, instantly wakes up for just a few milliseconds to transmit a small packet of information, after which it powers down the antenna again. This allowed the devices to operate for extended periods of time on a single, tiny coin-cell battery.

ZigBee is a specialized wireless communication standard developed for the creation of reliable and autonomous networks, based on the IEEE 802.15.4 [21] wireless data transmission standard, characterized by low power and low data transfer rate (approximately 250 kbps).

This speed is acceptable for transmitting data from temperature or motion sensors, while minimizing command delays.

The ZigBee network uses the AES-128 (Advanced Encryption Standard) encryption algorithm [21].

The most widespread use of this standard is in the global 2.4 GHz band, which ensures compatibility between devices worldwide. ZigBee divides this band into narrow channels to prevent interference from neighboring Wi-Fi and Bluetooth networks.

Let's consider options for constructing a system that contains:

– Radiator thermostat;
– Temperature sensor;
– Humidity sensor;
– Window/door opening sensor;
– Light sensor;
– Motorized valve;
– Socket (allows you to control the operating mode of any household appliance; this could be a boiler, air conditioner, coffee machine etc.).

Case 1. All system elements are equipped with a Wi-Fi interface. This configuration requires no additional equipment, just a Wi-Fi router, and is characterized by ease of connection and operation.

Connecting a Wi-Fi device to a network can take longer (up to several seconds to establish a connection). In addition, the standard itself does not have hard limits. In practice, the number of devices is often limited by the hardware capabilities of household routers (many budget models start to work unstable when connecting more than 30 – 40 devices).

The disadvantages of such system include:

- limitation on the devices number with which the router can maintain a stable connection;
- star network topology;
- The technology is energy-intensive (devices with autonomous power supply require very frequent battery replacement, estimated at approximately once every few weeks).

Case 2. All system elements are equipped with a Bluetooth interface. In this case, connecting to each device requires a separate software application. Furthermore, there are limitations on the distance between the device and the smartphone. Therefore, connecting such devices is impossible due to the lack of standard software. Therefore, the Bluetooth standard has not gained widespread adoption in the area under study, but it remains a convenient channel for quickly configuring devices.

Case 3. All system elements are equipped with a ZigBee interface. Any ZigBee network consists of end devices and a single network gateway.

The network and all devices within it are managed from a smartphone or PC using special software, which communicates via Wi-Fi, Ethernet, USB, or Bluetooth.

The basic transmission range between two nodes of such a network is about 20 m, but due to the mesh topology, this disadvantage of the Zigbee protocol is leveled out.

In this architecture, each powered device (such as a smart plug or lamp) functions as a repeater. The signal is transmitted from node to node, automatically avoiding obstacles and expanding coverage throughout the building.

The characteristic features of such a network are [21]:

- Self-healing properties – that is, if one of the nodes fails, the system finds an alternative route for data delivery;
- Ultra-low power consumption (the battery can operate for several years without replacement).

If the ZigBee network is managed from a smartphone, the network gateway is connected to a local Wi-Fi or Ethernet router to access the Internet.

All endpoints are connected to a cloud service provided by the software application manufacturer. The user's smartphone is also connected to this service.

This scheme is extremely easy to implement for the user. However, its drawbacks include critical dependence on internet access and speed at all stages of the command flow and response.

Connecting a network gateway directly to a PC and running the appropriate software on it ensures immediate response to any event on the network. Furthermore, data does not transfer outside the network (premises). The disadvantages of this connection type include the need for 24/7 PC activation to ensure endpoint software scripts are executed promptly.

The investigated cases demonstrate the use of combined data transmission systems, where information from endpoints is collected by a network gateway using any wireless interface. Its connection to the internet is then established via Wi-Fi, Ethernet, or USB or Bluetooth if the network gateway is directly connected to a personal computer.

Conclusions

According to the rapid development of information technology, especially data transmission technologies, more and more areas of human activity are being automated.

A typical smartphone serves as a "control center" for a variety of equipment. This could be a door sensor that instantly transmits a message about unauthorized door opening, with an unlimited range. The user could be located on another continent (the main requirement is Internet access). Or it could be a complex scenario involving a huge number of endpoints.

The paper examines the structure of energy metering systems; identifies the specific application features of various IoT technologies; provides a comparative analysis of systems built on wireless technologies; and evaluates their advantages and limitations.

It has been found that the use of automated energy carriers metering systems based on IoT technologies is an appropriate and convenient method in the case of monitoring technological processes for energy resource suppliers and their consumers. This enables measurements, commercial accounting, and control of energy consumption; remote control of facilities in real time; monitoring of the state of system elements (for example, water supply companies can balance water consumption between certain zones depending on the time of day or the state of pumping equipment); detection and monitoring of emergency situations; reduction of the number of maintenance personnel (controllers) and, simultaneously, decrease the human factor impact on the quality of consumption metering.

A prospect for further research is to study the possibilities of creating a system that combines meters for different energy sources.

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А. В. Писарець, О. Є. Писарець
Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», Київ, Україна

ОСОБЛИВОСТІ ЗАСТОСУВАННЯ IoT ТЕХНОЛОГІЙ У СИСТЕМАХ ОБЛІКУ ЕНЕРГОНОСІЇВ

Стрімкий розвиток інформаційних технологій сприяє створенню інформаційно-вимірювальних систем, які дозволяють поєднати вимірювання та передачу їх результатів на відстань, що у свою чергу дозволяє здійснювати їх оперативну обробку та аналіз, в тому числі, у реальному часі.

Передача вимірювальної інформації здійснюється застосуванням мережних технологій. Серед яких усе більшої популярності набуває Інтернет Речей (Internet of Things – IoT).
Застосування IoT технологій дозволяє автоматизувати процеси у різних галузях діяльності людини, зокрема, при видобутку енергоресурсів, у енергетиці, житлово-комунальному господарстві, освіті, медицині, промисловості, торгівлі, транспорті, логістиці, сфері обслуговування тощо. Їх застосовують у системах керування освітленням вулиць, для моніторингу параметрів атмосфери, контролю параметрів ґрунту тощо.
Метою роботи є дослідження можливостей застосування технологій IoT для побудови систем обліку енергоносіїв.
Завданням таких систем є, з одного боку, збирання, передача, обробка та аналіз показань вимірювальних приладів, з іншого – поєднання різноманітних первинних перетворювачів для вимірювання та аналізу параметрів навколишнього середовища і технологічних процесів, що дозволяє здійснити всебічний аналіз ситуації і сприяє прийняттю оптимального рішення.
Створення автоматизованих систем обліку енергоносіїв слугує зручним робочим інструментом для отримання оперативної та достовірної інформації, що забезпечується автоматичним та фактично одночасним опитуванням усіх віддалених приладів, можливістю аналізувати поточні дані у вигляді таблиць, графіків, діаграм, а також виключенням впливу «людського фактору» при зчитуванні та обробці даних.
У роботі розглянуто побудову автоматизованих систем обліку енергоносіїв; виявлено особливості побудови систем із застосуванням різних бездротових технологій; здійснено порівняльний аналіз систем, побудованих на підґрунті бездротових технологій; оцінено їх переваги та обмеження застосування; обґрунтовано рекомендації по створенню.
Ключові слова: енергоносії; облік; показання; система обліку; технології передачі даних; IoT; архітектура.

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