Reducing the power consumption of sensor nodes in a wireless sensor network

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Abstract. The article presents a comparative analysis of existing methods of building wireless communication networks implementing the concept of "Internet of Things". A new method for reducing the power consumption of sensor nodes is proposed, which consists in the fragmentation of the wireless sensor network followed by the logical combination of separate local wireless networks. In the proposed method, it is possible to operate sensor units with battery power in a mode of reduced power consumption with the possibility of transmitting and retransmitting messages at any time.

1. Purpose of work

Development of the technology of wireless interaction of heterogeneous elements, providing the minimum necessary power consumption of end nodes and the possibility of end-to-end transmission of information in real time.

2. Statement of the problem

In recent years, important tasks related to monitoring of territorially distributed objects and their management can be combined within the framework of the "Internet of Things" (IoT) concept. The relevance of this direction for our country can be confirmed, for example, by the studies of the IDC consulting company, which shows that by 2021 the costs of the Internet of things in Russia will exceed 9 billion dollars. Among these tasks, a special place is occupied by tasks related to the implementation of monitoring and management of various territorially distributed objects. In this case, it is necessary, firstly, to monitor in real time that the specified key parameters of the environment or the object itself (for example, temperature, humidity, unauthorized access, etc.) are within the specified limits, and secondly, to carry out storage and analysis of these key parameters, and thirdly, to signal to responsible employees about certain critical situations. Features of such tasks are also the need to transmit relatively large amounts of data (for example, individual photographs of the territory or sound file), the availability of requirements for autonomous operation even in the absence of connection to the control loop, the need to control the actuators (camera drives, climate devices). There are a lot of different technical means that can individually solve these problems. However, the vast majority of them require the presence of wired communication channels. The organization of these channels, for example, for apartment buildings, large enterprises, museums, large warehouses or protected areas of considerable size, is extremely difficult. Therefore, to solve these problems the use of radio-infrastructure created within the framework of self-organizing data transmission networks utilization is considered to be rational [1, 2].

3. Existing technologies and solutions

There is a large number of technologies that can individually solve the above-mentioned tasks. However, a vast majority of them require the presence of wired communication channels or the use of a radio network of data transmission containing a distributed network of base stations. In this paper, we propose an alternative approach related to the use of high-speed sensor networks. At the same time, it should be noted that, despite the considerable interest in this subject in recent years, there are very few technologies available to implement wireless network interaction of a large number of elements, and all of them, as will be shown below, have significant drawbacks from our point of view. In connection with what has been said, we believe that the task formulated earlier, the solution of which is directed at research, is topical.

3.1. Existing technologies

Consider the existing technologies, which are currently used to solve the problems of network interaction of various devices.

3.1.1. GSM /GPRS technology. The technology, based on packet data transmission over cellular channels, assumes the use of the corresponding GSM/GPRS modems (3G, 4G, etc.) according to the principle of operation is similar to the Internet [3]: the data is divided into packets and sent to the recipient (not necessarily the same route), where they are assembled. The GPRS protocol is transparent for Internet protocols TCP/IP, so the integration of GPRS with the Internet is invisible to the end user. The main advantage of solutions based on the use of GPRS, is the universality of the applied modules. For their autonomous and reliable operation, only the presence of GSM communication and power supply is required. However, meeting these obvious requirements for final measuring devices leads to significant installation costs. In addition, the cost of the devices themselves and traffic to date remains very significant. All this is an insurmountable obstacle for the large-scale deployment of IoT solutions based on GSM technologies.

3.1.2. Adapted WiFi protocol. This protocol allows large amounts of data (including video data) to be transmitted over short distances [4]. It is believed that the WiFi for IoT protocol will be compatible with existing WiFi standards, that is, operate at its 2.4 and 5GHz frequencies. The key disadvantage of WiFi is the high demands on power consumption, which do not allow creating devices that would use autonomous power sources for a long time.

3.1.3. Bluetooth protocol. The Bluetooth 4.x, 5.x protocol and its promising implementations have low power consumption modes that allow it to work for years from standard power sources. Bluetooth technology by default provides network operation with topologies "star", i.e. does not imply a procedure for retransmission of transmitted information. All this limits the range of the network. The developers of Bluetooth 5.0 announce the inclusion in the protocol of the additional opportunity to organize a self-tuning network (standard 0.9 for mesh mesh networks), transmitting information at speeds of up to tens of kbps [5]. In addition, in 2018, the Bluetooth protocol mode, which implements simple cascaded networks, should be standardized. However, in these modes, the data transfer rate is very low (up to several kb/s), and the transmission range is limited (up to tens of meters).

3.1.4. ZigBee and Thread Technology. Protocols of self-organizing networks ZigBee and Thread support the work in a mesh network (transmission speed is tens of kb/s), which contains network elements with battery power. However, the implementation of routing procedures in these networks is provided by using network elements powered by the household network. At the same time, network elements with battery power do not participate in the retransmission of information [6]. This, as well as restrictions on the size of the network (up to 32 nodes - routers) create serious obstacles for application of these technologies.

3.1.5. LPWAN and LORA protocols. These protocols allow the transmission of small (speed up to 1 kb/s) volumes of information for significant distances up to 10 km [7]. They represent one of the most promising areas of the IoT, but they have fundamental limitations on customization (in particular, they do not allow the organization of sensory networks on their own basis) and, due to the use of the ultra sensitive radio part, are distinguished by a high price. A serious drawback of these solutions is the difficulty in organizing feedback to the final nodes, necessary, for example, to manage them. In addition, when using these protocols, there are significant difficulties in the translation of the signal in the presence of strong radio interference and complex terrain.

3.1.6. Protocols 5G (NB-IoT). NB-IoT are designed to interface IoT devices with existing LTE and promising 5G mobile towers. These protocols assume a centralized, short-term information retrieval from distributed devices. In this regard, NB-IoT protocols, as well as LORA and LPWAN, presuppose asymmetric work based on the use of specialized base stations for collecting accumulated information. Implementing remote management of certain devices using these network protocols is currently extremely difficult. The key shortcoming of NB-IoT is the dependence on the existing infrastructure of the base stations. The lack of such an infrastructure or its insufficient density significantly reduces the possibility of using NB-IoT.

3.1.7. A comparison of the presented protocols. The table below presents a comparative analysis of the presented protocols. Attention is paid not only to the technical characteristics of these protocols, but also to the opportunities that arise when using them.

Specifications	Swift	Lora	SigFox	NB IoT	WiFi	GSM/3G /LTE
Range	up to 10 km. *	up to 12 km. *	up to 10 km.*	up to 6 km. *	up to 100 m.	up to 12 km.
Frequency	868 MHz	433, 868 MHz	868 MHz	900 MHz	2.4 G Hz	2. 4 GHz
Data transfer rate (UpLink)	50 bps	0.1 - 50 kB/s	10-1000 b/s	1-20 kB/s	0.2-200 Mb/s	9.6 kB/s - 19.2 MB/s
Autonomy	8 years **	6 years **	10 years **	4 years **	1 month	1 month
Upgrade by air	Yes	Yes	no	Yes	Yes	Yes
Ability to transfer data	no	no	no	no	No	no
Practical ability to transfer data to modules (DownLink)	no	yes (for C class devices)	no	Limited by network capabilities	Yes	Yes
Possibility of transfer of media information	no	no	no	no	Yes	Yes
The ability to dynamically separate data packets to ensure maximum data transfer speed	no	no	no	no	no	no
The ability to protect the transmitted information	no	no	no	no	At the applicati on layer	At the application layer
The ability to program scenarios for advanced network segment management	no	no	no	no	no	no

* Data from open sources. In urban conditions, the range is significantly reduced
** Based on a single survey module per day and emergency wake up every two days

The data presented in the table show that existing solutions do not fully solve the problem of information transfer and interactive interaction with each other especially in conditions of limited energy consumption.

3.2. Existing solutions

The presented brief analysis makes it possible to understand that, despite the various IoT technologies present already in the coming years, there remain a number of problems, the solution of which is impossible using only these technologies. Among these tasks, one can single out the task of transferring relatively large (up to several megabytes) volumes of information through a self-organizing dynamic sensor network, which includes elements using only autonomous power. This task occurs for example when transmitting information control blocks, images, voice fragments, small video files between geographically distributed sensors and actuators. The use of only existing technologies, including those listed above, involves creation of a specialized infrastructure and requires significant installation and operating costs. Therefore, there are various ways to build wireless networks with reduced power consumption. Let us consider these most characteristic ways.

3.2.1. A method for selectively activating field devices in a low-voltage wireless mesh network. Selective inclusion of field devices in a low-voltage wireless mesh network. The method [8] is that the wireless mesh network for data transmission periodically exits the waiting state, i. e. from the state where the power of the receiver and the transmitter of the wireless mesh node is off. The drawbacks of the described method include: 1) the relatively long periodic stay of wireless mesh network nodes in the on state, which is caused by the need to wait for data from the host computer, even in the absence of them; 2) the necessity to transfer all nodes of the wireless mesh network to the switched on state, even if they do not participate in the current communication session; 3) the inability at any time to perform data transfer. Thus, the first and second items contribute to the excessive consumption of the energy of the power source (battery).

3.2.2. A method optimizing reception of call/broadcast notification messages by wireless communication devices with autonomous power. A method of operating a wireless communication device [9], i. e. when a wireless battery-powered device is switched into a low-power state with the ability to receive a repeating awakening information signal. The drawbacks of the described method include:

1) a relatively long period of the wireless device’s on-time stay, which is caused by the need to wait for the awakening information signal;

2) the wake-up information signal at a particular time can only transmit one wireless communication device, since the simultaneous operation of the two wireless communication devices will result in the loss of transmitted information and the impossibility of detecting the fact of wake-up;

3) a wireless battery-powered device cannot wake up other wireless devices with battery power, which greatly limits the capabilities of the wireless network.

3.2.3. A method for tracking and communicating mobile terminals using a wireless network infrastructure with autonomous power. Method [10], in which the sensor nodes are powered by a battery. The disadvantage of the method is the use of a procedure for periodically turning on the transmitter of the sensing unit, which contributes to the excessive consumption of the energy of the power source (battery), and in the event of loss of synchronous operation of neighboring sensor units, it is possible to simultaneously transmit the beacon with several sensor nodes, which will require additional active time of the sensor nodes with additional flow energy source of power to restore the normal mode of operation.

4. The proposed solution

In order to avoid the drawbacks of these methods of reducing power consumption and to enable the transmission of large information packets in real time, we propose that one describes the operation of sensory nodes in a wireless network as a change in the various states associated with performing various functions and with different power requirements from the battery pack. Such states can include the following steps:

- a), which transfers the transmitter and receiver of the sensor node to a power-off state, in order to minimize power consumption;
- b), which includes powering the sensor node receiver during a limited scan time interval to detect a beacon, and when detected, an output from the minimum power state is performed,

the contents of the beacon being neither received nor processed by the receiver, since only the radio signal is detected on a given frequency channel with a quality higher than a predetermined one, which allows the sensor node to work in the case of simultaneous transmission of a beacon by several other sensory nodes. In addition, the time interval for scanning here is sufficiently small, since the actual reception of the message is not performed;

- c), which includes the power supply of the transmitter of the sensor node during a limited time interval for transmitting the beacon Tm to act on adjacent sensory nodes and temporarily transferring them from the minimum energy consumption state to the active working state, the awakening state. A beacon is a message that lasts for Tm, with unprincipled content, because the effect is achieved by its continuous transmission;
- d), which includes powering the sensor node receiver, powering the sensor node transmitter for a limited transmission time interval or relaying the message to/from the central server, which is actually the awakening state in which the sensor node interacts.

4.1. Principle of operation

It should be noted that steps a) and b) are repeated intermittently with a period T that is less than the limited time interval of the Tm beacon transmission, which allows the sensory nodes to confidently detect the beacon. In most cases, the purpose of sensory networks is the transmission of information about the physical impact on the central server and the transfer of target designations from the central server to the sensory node, in some cases, involve the interaction of some sensory nodes with each other. Proceeding from the foregoing, in the proposed method, a wireless sensor network is logically divided into k functionally separate wireless sensor local networks that operate on their own local frequency channel in steps a) -c) and use the procedure for relaying messages within the wireless sensor local area network. To provide information exchange between the wireless sensor local area networks and the central server, n wireless repeaters are additionally introduced, with one or more wireless sensor LANs being assigned to one wireless repeater. All wireless repeaters operate on the frequency channel of retransmission, use the mode of acknowledgment of receipt of the message with the possibility of retransmission, use the permanently switched on power of the receiver and transmitter, which allows providing guaranteed information delivery. The first wireless repeater is connected to the central server using standard interfaces (for example, a virtual com-port over the USB interface). An exemplary network topology is shown in Figure 1. When a message is sent from the central server to a given sensor node of the specified wireless sensor local area network, the address of the sensor node, the local frequency channel number, and the number of the wireless sensor local area network are included in the message. The message is then transmitted to the first wireless repeater and using the relay process, the message through the wireless repeaters transmits it to the wireless repeater behind which the wireless sensor local area network indicated in the message is attached. After these operations, this wireless repeater changes the frequency channel of the relay to the local frequency channel of the wireless sensor local network indicated in the message, sends the beacon to the original frequency channel of the relay for a limited time interval of the beacon transmission. In this case, those sensor nodes that detect the beacon are switched to the composite awakening step e), at which the transition to step c) is performed, the beacon is transmitted, switched to step d), the local frequency channel is changed to a frequency relay channel and at a random time interval, times the transmission time of the label, send a label. A delay in the transmission of a label to a random time interval is necessary for a time-separated transmission process by several sensor nodes that simultaneously detected a beacon. The label includes the address of the sensor node and the number of the wireless sensor LAN. Further, other sensor nodes of the wireless sensor LAN that detect the beacon from the

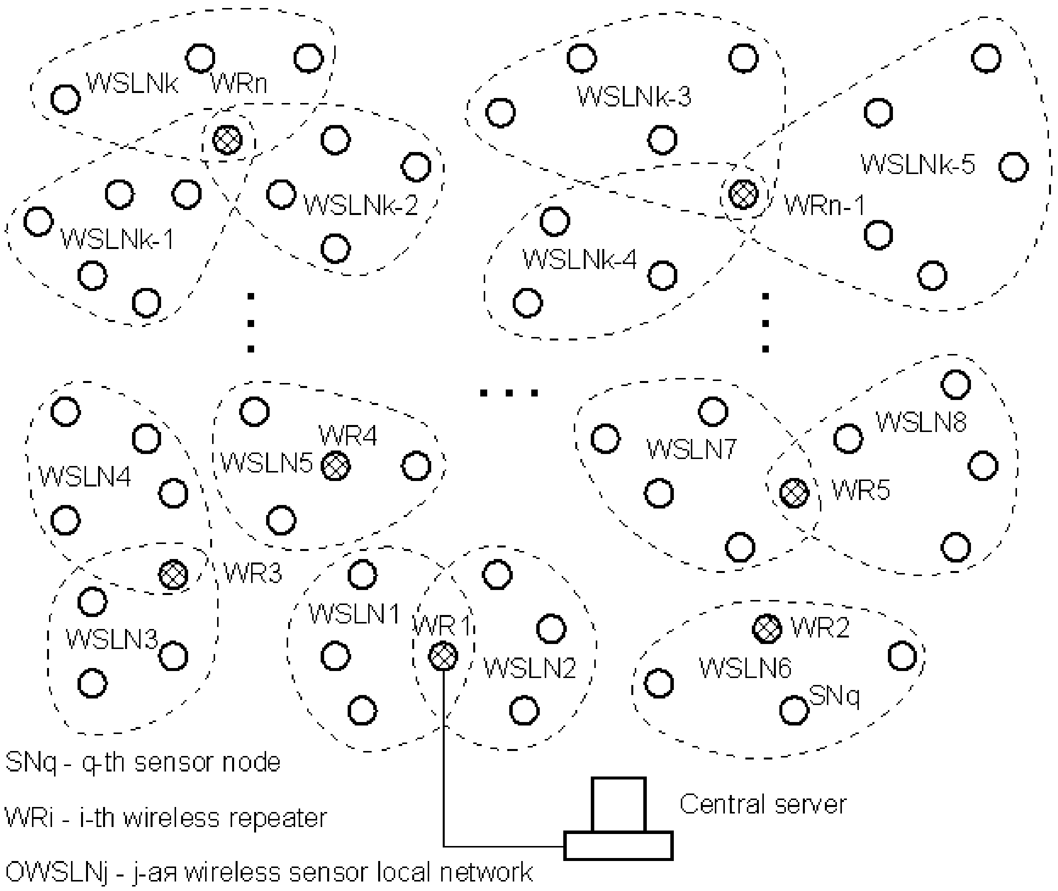

Figure 1. A variant of the topology of a wireless sensor network.

previous sensor nodes are switched to the composite awakening step e). Thus, all sensor nodes of the wireless sensor LAN are sequentially switched to the composite wake-up stage e). In this case, the sensor nodes of the wireless sensor local network relay the labels and when the wireless repeater receives a label in which the address of the sensor node coincides with the address of the message, the wireless repeater sends the message to the wireless sensor local network specified in the message. The response message from the sensor node through the wireless repeaters is relayed to the central server, from which it then performs a dialogue with the specified wireless sensor local area network and/or sends a message of the end of the communication session, after receiving which all sensor nodes are transferred to repetitive steps a) and b) and restore the local frequency channel. Thus, the sensor nodes are forced into a state of reduced power consumption. In case when sensors of the sensor node of the wireless sensor LAN detect physical interference, the sensor node is switched to the composite wake-up stage e). Then, other sensor nodes of the wireless sensor LAN that detect the beacon from the previous sensor nodes are switched to the compound awakening step e). As a result, all sensor nodes are sequentially switched to the compound awakening stage e). When a wireless repeater receives any label, a permission is sent from it to the wireless sensor LAN. Thereafter, a sensor node sends a physical impact message to the sensor node and/or central server indicated in the physical impact message. When a specified sensor node receives a physical impact message, it performs the instructions contained in the physical impact message. When the central server receives a physical impact message, it performs a dialogue with this sensor node and/or sends a session end message, after which all sensor nodes are transferred to repetitive steps a) and b) and restore the local frequency channel. Thus, the sensor nodes are forcibly returned to the state of reduced power consumption. It should be noted that the sensor nodes themselves go into a state of reduced power consumption if they do not receive any messages during the limited time interval of operation in step e). Figure 2 shows the main signals and their sequence. Since, when transmitting a beacon, wireless repeaters temporarily change the frequency channel of retransmission to the local frequency channel of the wireless sensor local network for a short time Tm, then messages transmitted by wireless repeaters in the retransmission mode on the frequency relay channel may be lost. To exclude the loss of messages by wireless repeaters, the acknowledgment mode of receiving a message with the possibility of retransmission is used. It should be noted that before transmitting messages by wireless repeaters or before sending labels and other messages by sensor nodes, they all listen for the frequency channel of retransmission and, if it is free, transmit. Moreover, the sensor nodes of a given wireless sensor local network retransmit only those messages whose wireless sensor network number coincides with their own number. In addition, wireless repeaters use a message buffering procedure while simultaneously serving more than one wireless sensor LAN, thereby eliminating the loss of packets.

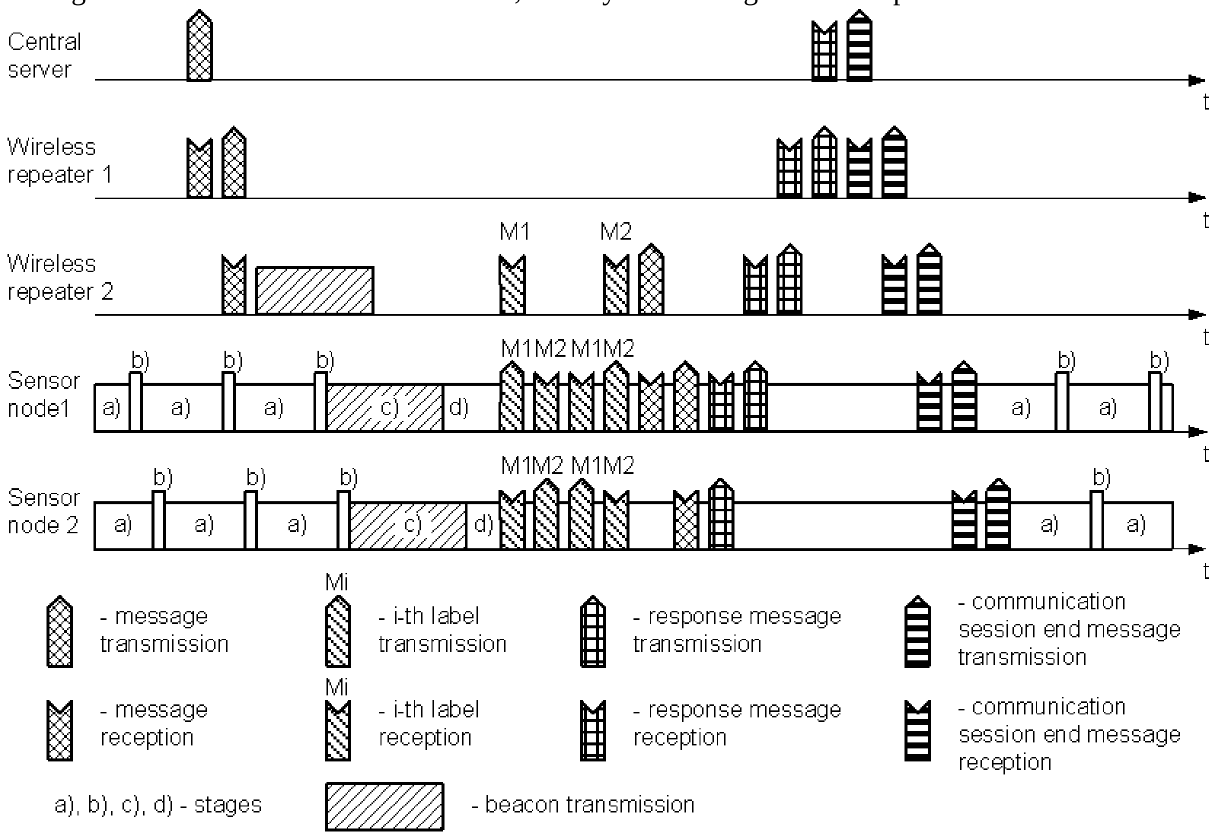

Figure 2. An example of the organization of a communication session between the central server and a given sensor node via two wireless repeaters and one sensor node.

4.2. Example of an embodiment

The proposed solution can be implemented in the technological process "the smart house" in an apartment house. For this:

- Each wireless repeater and sensor node is assigned a unique address and a number of technological parameters (frequency channel, transmitter power, modulation type, maximum length of the transmitted message, etc.) specific to the hardware implementation of these devices;
- Place the wireless repeaters on the staircases of each floor of the building;
- In designated or in all apartments locate sensor nodes that within the boundaries of a separate apartment form a wireless sensor local area network;
- In the attic or in the basement there is a central server with the ability to access the global Internet (if necessary).

4.3. Advantages of the proposed solution

Currently, the Department of Telecommunications of Ulyanovsk State Technical University, with the support of Texas Instruments and TST LLC, is implementing the described solution on the basis of radio modules TI MSP 432. The following key features of the new data transfer protocol were confirmed during the development:

- Reduction of transit traffic, due to the isolation of functionally disconnected wireless sensor local networks, which reduces the time of active operation of sensor nodes and the resource consumption of the battery;
- The ability to communicate with any sensor node at any time from both the central server and any other sensor node of the wireless sensor local area network;
- The possibility of parallel independent operation of wireless sensor local networks, including in the offline mode, i.e. without the involvement of a central server;
- The possibility of a short-term switching on of the sensor node receiver in the state of reduced power consumption, which is a significantly less power-consuming process compared to the periodic dispatch of the radio beacon in the similar protocols considered;
- The possibility of detecting a radio beacon as a fact of having a radio signal on a given frequency channel with a quality higher than the preset, which provides a minimum scan time interval, since it is not required to receive and analyze the contents of the broadcast.

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