THE USING OF ZIGBEE PROTOCOL TO ORGANIZE THE "SMART HOME" SYSTEM FOR AGED PEOPLE

DOI: 10.36724/2072-8735-2021-15-10-64-70

Michael S. Stepanov,
Moscow Technical University of Communications and Informatics, Moscow, Russia, ***m.s.stepanov@mtuci.ru***

Leonid S. Poskotin,
Moscow Technical University of Communications and Informatics, Moscow, Russia, ***svp_vpl@yahoo.com***

Dmitriy V. Shishkin,
Moscow Technical University of Communications and Informatics, Moscow, Russia, ***draknem@gmail.com***

Timur Turgut,
Moscow Technical University of Communications and Informatics, Moscow, Russia, ***hinhardian@gmail.com***

Artwell Regis Muzata,
Moscow Technical University of Communications and Informatics, Moscow, Russia, ***artwero@yahoo.com***

Manuscript received 27 August 2021;
Accepted 14 September 2021

Keywords: *Internet of Things, "Smart Home", ZigBee, people with limited mobility, elderly population, automation*

The machine-to-machine communication and automation are main trends in the world of modern infocommunications. The concept of Internet of Things is widely used for these purposes. It consists of two main categories namely long-range and short-range networks. The latter includes the "Smart Office" and "Smart Home" systems, which are very popular today. Various technologies enable the automation of processes such as security management, climate control, lighting, etc. This article will focus on the development of a "Smart Home" system for people with limited mobility using ZigBee technology. Basic and additional requirements needed in this system are specified. A brief description of the latest version of the ZigBee 3.0 protocol is provided. The software part of the considered ZigBee subsystem is based on the open-source code of the Zigbee2MQTT project, which supports integration with all common home automation services through the use of the standard MQTT protocol. Hardware part is presented. It includes both server and different types of smart devices. The recommendations for the implementation of some basic and optional requirements for the Smart Home system for an elderly person are given. Among them there is movement tracking, water leaks detection, lightning automation, SOS button, climate control, reminder of important things before leaving the house, television.

Для цитирования:
Степанов М.С., Поскотин Л.С., Шишкин Д.В., Тургут Тимур, Музата А.Р. Применение протокола ZigBee для организации системы "Умный дом" для пожилых людей // T-Comm: Телекоммуникации и транспорт. 2021. Том 15. №10. С. 64-70.

For citation:
Stepanov M.S., Poskotin L.S., Shishkin D.V., Timur Turgut, Muzata A.R. (2021). The using of ZigBee protocol to organize the "Smart Home" system for aged people. *T-Comm*, vol. 15, no.10, pp. 64-70. (*in Russian*)

Introduction

Each year, technologies described by science fiction writers of the 20th century are brought to life, and "smart" things are not an exception. The Internet of things paradigm, first mentioned at the end of the 20th century, is an example of this. Lights that turn on under certain conditions, smart plugs that save energy costs, speakers with built-in voice assistants are just a small part of it. The main subject of this article is the use of Smart Home system to help aged people. Let us first describe the object and the subject of our work.

The object of our study is the Smart Home System. Its most important component is the technology whereby smart devices communicate with each other. For this purpose, we use the ZigBee protocol. It is best suited for the implementation of our project due to the following merits.

- low power consumption;
- mesh-topology support;
- no need to obtain frequency permission,

The subject of our study is the elderly population. Aged people find it increasingly difficult to cope with everyday life, so they need additional help. Those with limited mobility can't easily control the sanctification and climate control devices. Elderly people with hearing and vision impairment will find it difficult to see or hear a water leak in the bathroom. Again, any person can become a victim of scammers.

Not all aged people have the opportunity to receive immediate help from relatives or specialized workers. The project described in the article specifically targets this particular category of the population. The Smart Home system can help elderly people in everyday situations mentioned above. The use of smart devices enables lighting and climate control in automatic mode, detecting leaks, increasing safety level etc.

Basic principles of building "Smart Home" systems for the elderly

Let us consider the principles of organizing the Smart Home system for people with limited mobility using the following example. The main and optional requirements for the considered system are shown in Table 1:

Primary and secondary requirements for the system in development are specified in Table 1.

Table 1

General requirements for the "Smart Home for the elderly" system

Main requirements	Optional requirements
Movement tracking	Health monitoring
24/7 notifications of water and gas leaks	Heating, ventilation, and air conditioning (HVAC) automation
Lighting automation	CCTV monitoring and recording
Alarm button function	Bad actor deterrent system

Zigbee is the main protocol considered for building a Smart Home system. Zigbee is a WPAN protocol based on IEEE 802.15.4 for commercial and residential IoT networks that have cost, power, and space constraints. It allows you to create and manage mesh networks, discover new devices and provide security and self-healing.

The Zigbee Alliance was formed in 2002. The goal of the alliance is to develop efficient wireless networking protocols and ensure interoperability between devices from different manufacturers. Zigbee is a proprietary standard. Its use requires a license fee and agreement provided by the Zigbee Alliance, but on the other hand guarantees compatibility between devices.

Zigbee devices can switch from sleep mode to active mode in 15 *ms* or less. The response latency of the device can be very low, especially when compared to Bluetooth. The main topology of a Zigbee is a Mesh network.

Zigbee, like Bluetooth, operates primarily in the 2.4 GHz ISM band. It also operates at 868 MHz in Europe and 915 MHz in the US and Australia. Due to its lower frequency, it has better ability to penetrate walls and obstacles compared to traditional 2.4 GHz signals. Zigbee provides three security mechanisms: Access Control Lists (ACLs), 128-bit AES encryption, and message freshness timers [1].

For the implementation of the "Smart Home for the Elderly" project, the ZigBee 3.0 standard was chosen. It is included in the Zigbee Pro 2017 (R22) specification. This standard contains a number of changes:

- **Direct binding.** It doesn't depend on the manufacturer and allows end devices to interact with each other without the participation of a coordinator and a router. This helps to flexibly customize the scenarios of device behavior and increase the response speed.
- **Green Power**. A set of technologies that reduce the device power consumption and can also collect it.
- **Unification.** Zigbee 3.0 is a unified application profile that allows devices to communicate with each other regardless of their profile.
- **Backward compatibility** with all products released prior to v3.0 [2].

ZigBee protocol was selected for the project for the following reasons:

1. Mesh structure meets reliability criteria for systems that are critical to human life and health.
2. This helps to protect the network from outside attempts and not to be influenced by other transmission technologies.
3. Low power consumption, due to the "sleep mode" of Zigbee devices when inactive [3].

The premises for the deployment of this "Smart Home" system are a two-room flat and a stairwell. The plan of the premises is provided on Figure 1. One room is a master bedroom, the second room is a living room with access to the balcony. The flat also has a kitchen and separate bathroom and toilet. A part of the corridor is used as an entry hallway.

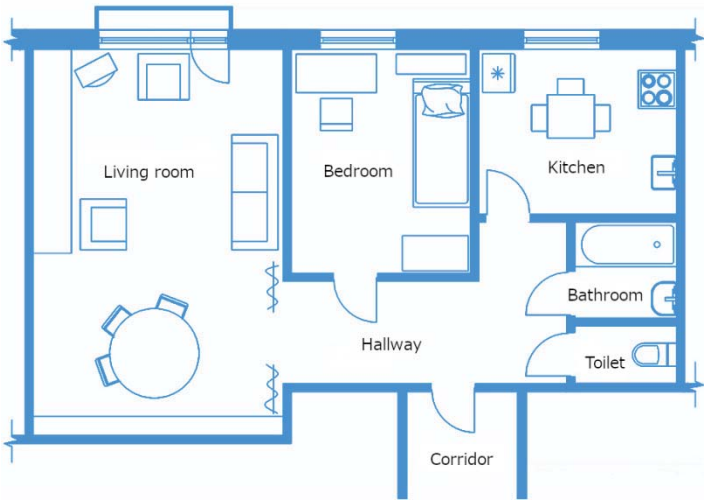

Figure 1. Flat layout

Requirements for the CCTV system

Two IP cameras are chosen for installation, one in the entry hall in view of the front door, and another – on the stairwell. The important characteristic requirements for IP cameras are as follows:

- Capable of movement detection with automatic recording after the appearance of potential bad actor in the frame.
- Good low light performance, preferably – infrared mode to enable recording at night, or when the lights are off and during power outages.
- PoE capabilities – support for IEEE 802.3af or better to simplify the centralized redundant power implementation and wiring.
- Maximum video quality desirable to increase the probability of identifying the potential perpetrator(s) on video recordings.
- High energy efficiency for longer running times on battery power and lower system running costs.
- Audio recording capabilities which enable sound recording of potential bad actor dialogue with the elderly person.
- Audio alarm and sound playback capabilities to simplify the implementation of bad actor deterrent system.

The described system is critical to human life and health, and is responsible for protection of property, so it must have high reliability. This necessitates the following requirements for the video surveillance system server:

- The necessary storage system throughput and processing power for simultaneous recording of two video streams.
- Local storage providing enough space for at least one week of 24/7 recording.
- Local storage redundancy is required to enhance system reliability.
- Cloud recording backup is desirable for enhanced system reliability and recovery of recordings in case of theft or total system failure.

Moreover, there are several things that have to be considered:

- Cloud recording backup has to be done automatically, using incremental synchronization to reduce the amount of data loss in case of local storage failure and the internet connection load.
- Remote recording and live camera feed viewing capabilities are required.
- Video surveillance server should, if possible, support PoE using IEEE 802.3af, to enable its integration with centralized camera redundant power system.

Required router capabilities

The system being designed requires regular and, if possible, continuous access to the Internet in order to back up the video recordings to a cloud data storage, and to provide remote access to information about the health of an elderly person and his property.

- The router must support connection to the Internet through wired networks of common providers in Russia, using standard access and authorization technologies, or through wireless mobile networks with the required bandwidth, in the absence of the possibility of using broadband cable connection.
- The router must have the capabilities of serving VPN endpoint to allow external connections. This enables remote configuration and management, checking the status of engineering systems, viewing video recordings and streaming video from CCTV cameras, as well as checking the health of an elderly person.

Local network

Since the system being developed will be responsible for human life and health, as well as for the safety of his property, it is necessary to ensure its reliability and resiliency. Therefore, the following parameters should exist in the local network:

- Provide sufficient bandwidth for the implementation of video surveillance systems and smart home.
- Provide centralized power delivery to IP cameras (IEEE 802.3af) in order to simplify the equipment connection diagram and provide the possibility of centralized power supply redundancy.

It is necessary to develop a solution that allows all systems to continue to function in the event of a power outage in the apartment for a period of time sufficient to notify the user, correctly stop processes, save cached data to disks and shutdown all devices.

Smart home system requirements

The system being developed should track temperature, humidity and air pressure in the apartment of an elderly person, help him save on electricity bills, simplify the acquisition of information from the meters, protect the apartment from water and gas leaks as well as intruders. The following are essential.

- Sensor for temperature, humidity, atmospheric pressure.
- Gas sensor.
- Floor-mounted water leak sensors and electrically operated water taps.
- ZigBee - compatible lighting fixtures, capable of acting as routers to improve the reliability and quality of network coverage.

- Motion and presence sensors for automated lighting control.
- ZigBee - compatible light switches, for manual lighting control.
- Implement an SOS button, integrated into the elderly person's walking stick.
- Integrate HVAC system with Smart home for automatic control of heating and air conditioning.
- ZigBee router, allowing to integrate equipment from different manufacturers into one system and create non-standard scenarios for controlling devices.

Health Tracking System requirements

It is fitted to implement the collection and logging of historical data and the health indicators of an elderly person in the described system. This requires choosing the right equipment. It is necessary to track:

- Blood pressure
- Pulse
- Blood oxygen level
- If possible - for end user convenience the device needs a capability of displaying time, date and reminders.
- Sensor data has to be collected and logged automatically.

The server

The system uses two cameras. The plan is to record live video data only when activity is detected in the field of view of cameras. Let's assume that the recording occurs 12 hours a day. The video is planned to be recorded in resolution of 1920x1080, 30 frames per second. Typical bitrate of such a video stream is 3 Mbps on average. The average input-output load for each video stream is 60 IOPS on average, assuming block size of at least 8 KB.

Thus, data storage system needs to handle archiving of data stream of 3*2/70% = 8.6 Mbps, with block size of 8 KB and up, and 60*2/70% = 171.4 IOPS. For such requirements 2 SATA HDDs in RAID-1 (mirror) are enough. To store information for at least one week, 7(days) * 12(hours) * 3600(seconds) * 2(cameras) * 3(Mbps)/8(bit) = 226 800 MB = 226.8 GB.

Currently, the production low-capacity hard drives are almost stopped. To enhance and increase the reliability, compactness and performance of the system, the use of 2 solid-state 2,5-inch SSDs, 480 GB of capacity each is proposed. This will allow archived data to be stored for either two weeks, or for a week with continuous recording.

The limit on the number of cell rewrites of a solid-state drive with TLC memory is from 1500 to 3000 cycles, which on average will allow this type of SSD to be used in the system for at least 1500*480(GB)/226.8(GB)*7/365 = 66.9 years. Besides, SSDs are vibration-resistant and can withstand higher temperature fluctuations than traditional hard drives.

Usage of SATA 3 drives is proposed. Typical throughput for these drives is 450 MB/s sequential read and 350 MB/s sequential write with an 8 KB block size. This is much more than our video surveillance system requires, and will allow us to organize additional services, such as remote viewing of recordings and synchronization with remote cloud storage without affecting the performance of the main service.

Typical power consumption of a SSD is 1.6W, 3.2W for two drives. This will allow us to meet the PoE (Power-over-Ethernet) budget and implement a centralized power supply system and its redundancy based on IEEE 802.3af standard.

In the computing module of the system, it is proposed to use a raspberry pi 4b minicomputer with 8 GB of RAM. A 32 GB microSD card will be used as the system disk, since there are no requirements for the performance of the system disk of the video surveillance server. The operating system planned for use in the device is an open source Linux Ubuntu Server 20.04.2 LTS (Long Term Support). The functionality of the video surveillance server, as well as the hub and controller of ZigBee devices, will be implemented on this device.

In order to receive power using the IEEE 802.3af protocol, it is proposed to make use of the Raspberry Pi PoE HAT – a module that allows a mini-computer to receive up to 13 W of power through the Ethernet connector. The mini-computer itself at maximum load consumes up to 9 W, usually – under to 6 W. Thus, the power provided by this module will be adequate for a mini computer and 2 solid state drives, as well as some peripherals.

To implement the ZigBee functionality, we will use the Texas Instrument CC2652R microcontroller (Figure 2), which supports the Zigbee 3.0, Bluetooth mesh, Bluetooth 5.1 and others protocols. It is planned to use development modules with a soldered chip and its support circuitry, and an antenna connector [4].

Fig. 2. CC2652R microcontroller development board with an aerial

To implement the software part of the ZigBee subsystem in this project, we will adapt the open-source code of the Zigbee2MQTT project, which supports integration with all common home automation services through the use of the standard MQTT protocol. The project already has more than 1200 verified supported ZigBee devices, and due to the open source code, it becomes possible to implement non-standard functionality, such as tracking the location of a device in the network by the time it takes the signal to pass from it to different routers [5].

Network architecture

To provide connectivity between devices in a local network, as well as to provide access to the Internet, we intend to use a Mikrotik hEX PoE router. This router has 4 Gigabit Ethernet ports with PoE power supply according to IEEE 802.3af/at standards for organizing a local network and powering connected devices. It requires a standard 48 V, 2 A power supply.

An uninterruptible power supply is required to ensure safe shutdown of all systems. Since the system has a low power consumption, any office UPS with a 15-minute battery life and a USB port to monitor battery power will do. [6]

As for interfaces connecting to the Internet, the router has a Gigabit Ethernet port, an SFP port for installing optical modules and a USB port that supports USB modems. The operating system of this router allows you to configure a VPN server on the router for incoming VPN connections.

Smart Home devices

With our ZigBee router, we will connect via a Xiaomi Gateway 3 with firmware that supports MQTT. This device serves not only as a ZR (ZigBee router), but also as a gateway, as it has support for the Bluetooth Mesh protocol. The main goal of ZR is to establish a connection with a ZC (ZigBee coordinator) and create a Mesh network with no more than 31 endpoints. It is assumed that the ZRs will be placed in all rooms, as shown in Figure 3 [7].

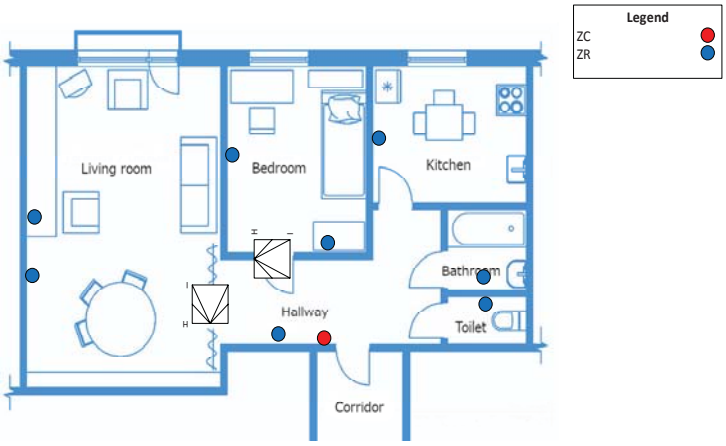

Fig. 3. ZC и ZR placement

We intend to use Aqara Temperature WSDCGQ11LM device for the role of the temperature, humidity and atmospheric pressure sensor. The data obtained from this sensor can be used to control the air conditioner and heater.

Xiaomi JTQJ-BF-01LM/BW was chosen as the gas leak detector, which can inform the user when a leak is detected with a loud sound signal, while transmitting information about the leak to the ZR to trigger the “answer” scenario (opening the vents, calling the gas service "04").

The selected floor sensor responsible for monitoring the leakage and shut-off of water is Xiaomi Aqara T1 SJCGQ12LM in conjunction with automatic valves Knycklan Valve Receiver.

Philips Hue smart lamps will be used in the lighting for all the rooms. In the ZigBee mesh network smart lamps serve as ZR by default (if provided power is sufficient) which improves connectivity and accessibility of the mesh network for the end-user devices [8].

Aqara motion sensor should be installed in the doorways to enable the automated lighting control. To increase the level of system reliability, Aqara RTCGQ13LM presence detectors will be installed in the rooms. The sensors are capable of detecting an immobile person in the room.

We plan to use Xiaomi Aqara D1 QBKG21LM ZigBee switch as a way to control the lighting manually.

ZigBee thermal sensor and control unit will be used to control the heater and air conditioner.

Health Tracking Devices

To measure health indicators, we intend to use a Fobase Air Pro smart watch connected to a smartphone via Bluetooth 5. This device provides the following functions: heart rate measurement, blood pressure measurement, body temperature and blood oxygen content, time display and taking notes. Health data from the smartphone will be synchronized every 4 hours with the server through the Xiaomi Gateway 3.

Implementation of the main functions of the "Smart Home" for an elderly person

Movement tracking. Sometimes it is necessary to know the location of an elderly person:

- In case a person develops health problems, every second will be important for doctors (or for relatives) to save human life, location information will immediately direct people to the elderly person.
- In case an elderly person has lost a certain thing in the apartment, you can, based on his location at that moment in time, indicate the approximate location of the lost thing.
- With the help of this monitoring, we can find out whether an elderly person is in the apartment or not

This can be accomplished by installing a special beacon in the elderly person's cane, which will send echo requests every 30 seconds (provided that the cane is connected to the home network on the ZR, the arrival time of the echo requests will be processed on the servers, the final result of this operation will be the coordinates of the cane's location, which can be visualized in a specialized interface in the form of an apartment map in a special mobile application.

Detecting water leaks. In old age, it is difficult to deal with problems associated with plumbing. Classic detection tools such as eyes, ears and sense of smell lose their sharpness with age, an elderly person may not hear water flowing from pipes, not see a puddle under a sink, and not smell stagnant water. Therefore, it is necessary to detect leaks in the bathroom, and report them to an elderly person or their caretaker.

The floor-mounted leak detector can be installed under the sink. When a leak is detected, the sensor will start emitting a sound signal, and will also inform ZR about it, which in turn will start the scenario of water shut-off using automatic taps.

Lighting automation. In the apartment, it is necessary to automate the lighting, since an elderly person may forget to turn off the light in the room where he is not currently located, which can lead to an increase in electricity bills. The problem can be solved by installing motion sensors at the passage to each room, on the basis of which the ZR will give commands to the actuators responsible for switching on / off the lights. Also, for greater reliability, there will be a presence sensor in each room. The system will be configured in such a way that the light will be on in the room where the person is and, in the room next to him. After a person leaves the room, the light will remain on for another 2 minutes, after which the actuator will be given a command to

turn off the light. The ability to physically turn off light sources remains.

SOS button. Sometimes trouble can happen instantly, and the only thing that can be done in time is to press the button. In this case, it is proposed to create a panic button located inside the cane of an elderly person. When activated, the lamps in all rooms are turned on with the help of actuators, relatives receive an urgent notification in the mobile application with all the necessary information: location (found using GPS on a smartphone) and health indicators (measured using smart watches).

Climate control. In each room of the apartment there are sensors for measuring temperature, humidity, atmospheric pressure. Depending on the current season and sensor readings, the server will give commands to climate devices. The scheme of climate control system is shown on Figure 4.

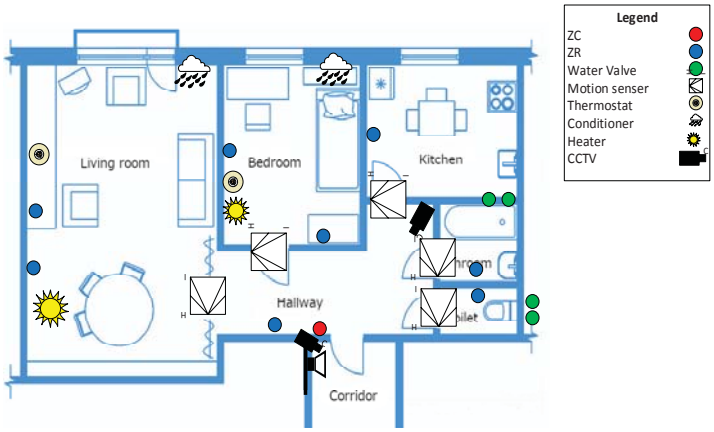

Fig. 4. Climate control system

Reminder of important things before leaving the house. When an elderly person goes out, a reminder will come to him on his smart watch about turning off electrical appliances, etc.

CCTV. Two Hikvision DS-2CD2345G0P-I are planned for use in the corridor and another one in the stairwell. The cameras are connected to ZC with wires. They turn on with the command from infra-red sensors. They are tuned to the radius of 1 meter.

Bad actor alarm

Very often, scammers try to deceive gullible elderly people who are accustomed to times when trouble was not expected from a stranger. To scare off fraudsters from the apartment, relatives can press a special button in the application (when alerting you to turn on video surveillance), which will start an audio recording from the speakers on video cameras, with information about criminal liability for fraud. This should frighten off any fraudster, and the elderly person will immediately understand that he is most likely a fraudster.

Conclusion

This article describes the creation of a smart home system for an elderly person using ZigBee technology. First, basic and additional requirements are set, which must be considered in this system. For the system realization the most recent version of the protocol ZigBee is chosen. Its fundamental principles are given. The network architecture is designed and it fulfills all the necessary requirements. The providing of the most important functions of Smart Home system for elderly person using designed network are described. The considered project can be used to automate a lot of routine processes and make the elderly person's life more comfortable and safe.

References

1. L. Perry (2018). Internet of Things for Architects. Packt Publishing. 524 p.
2. Habr web site. URL: https://habr.com/ru/post/535658/ (Last reviewed 28th of July 2021).
3. S. N. Stepanov, M. S. Stepanov (2020). Study guide for the discipline Fundamentals of the Internet of Things. MTUCI. 77 p.
4. Texas Instrument web site. URL: https://www.ti.com/product/CC2652R
5. ZigBee2MQTT Documentation. URL: https://www.zigbee2mqtt.io (Last reviewed 28th of July 2021).
6. Mikrotik official web site. https://mikrotik.com/product/RB960PGS (Last reviewed 28th of July 2021).
7. Gadget Freakz https://gadget-freakz.com/xiaomi-gateway-3-highly-hackable/
8. Github official web site. URL: https://github.com/Koenkk/zigbee2mqtt/issues/462. (Last reviewed 28th of July 2021).
9. S. N. Stepanov, M. S. Stepanov (2019). Efficient Algorithm for Evaluating the Required Volume of Resource in Wireless Communication Systems under Joint Servicing of Heterogeneous Traffic for the Internet of Things. *Autom, Remote Control*, vol.80, no.118, pp. 1970-1985.
10. S. N. Stepanov, M. S. Stepanov (2018). The model and algorithms for estimation the performance measures of access node serving the mixture of real time and elastic data. *Communications in Computer and Information Science*. Vol. 919. P. 264-275.
11. A.R. Muzata, V. A. Pershina, M. S. Stepanov, F. Ndimumahoro and J. Ndayikunda (2021). "The Modeling of Elastic Traffic Transmisson by the Mobile Network with NB-IoT Functionality,"2021 Systems of Signals Generating and Processing in the Field of on Board Communications, pp. 1-7, doi: 10.1109/IEEECONF51389.2021.9416132.

ПРИМЕНЕНИЕ ПРОТОКОЛА ZIGBEE ДЛЯ ОРГАНИЗАЦИИ СИСТЕМЫ "УМНЫЙ ДОМ" ДЛЯ ПОЖИЛЫХ ЛЮДЕЙ

Степанов Михаил Сергеевич, *Московский технический университет связи и информатики, Москва, Россия,* ***m.s.stepanov@mtuci.ru***
Поскотин Леонид Сергеевич, *Московский технический университет связи и информатики, Москва, Россия,* ***svp_vpl@yahoo.com***
Шишкин Дмитрий Витальевич, *Московский технический университет связи и информатики, Москва, Россия,* ***draknem@gmail.com***
Тургут Тимур, *Московский технический университет связи и информатики, Москва, Россия,* ***hinhardian@gmail.com***
Музата Артвелл Регис, *Московский технический университет связи и информатики, Москва, Россия,* ***artwero@yahoo.com***

Аннотация
Межмашинное взаимодействие и повсеместная автоматизация являются одними из главных тенденций современных инфокоммуникаций. Они включают в себя две основные категории, а именно сети дальнего и ближнего действия. К последним относятся системы "Умный офис" и "Умный дом", весьма популярные сегодня. Различные технологии позволяют автоматизировать такие процессы, как управление безопасностью, климат-контроль, освещение и т. Данная статья посвящена разработке системы "Умный дом" для пожилых людей с ограниченной подвижностью с использованием технологии ZigBee. Указаны основные и дополнительные требования, необходимые для данной системы. Приведено краткое описание последней версии протокола ZigBee 3.0. Приведены требования к оборудованию. Даны рекомендации по технической реализации некоторых основных и дополнительных функций системы "Умный дом" для пожилого человека.

Ключевые слова: *Интернет Вещей, "Умный дом", ZigBee, люди с ограниченными возможностями, пожилые люди, автоматизация.*

Литература

1. *Перри Л.* Архитектура интернета вещей. М.: ДМК Пресс, 2019. 454 с.
2. https://habr.com/ru/post/535658.
3. *Степанов С.Н., Степанов М. С.* Учебное пособие для выполнения практических работ по дисциплине "Основы Интернета Вещей". М.: МТУСИ, 2020. 77 с.
4. https://www.ti.com/product/CC2652R.
5. https://www.zigbee2mqtt.io.
6. https://mikrotik.com/product/RB960PGS.
7. https://gadget-freakz.com/xiaomi-gateway-3-highly-hackable.
8. https://github.com/Koenkk/zigbee2mqtt/issues/462
9. *Степанов С.Н., Степанов М.С.* Эффективный алгоритм оценки требуемого объема ресурса беспроводных систем связи при совместном обслуживании гетерогенного трафика устройств интернета вещей // Автоматика и телемеханика. 2019. № 11. С. 108-126.
10. *Stepanov S.N., Stepanov M.S.* The model and algorithms for estimation the performance measures of access node serving the mixture of real time and elastic data. Communications in Computer and Information Science. 2018. Том 919. С. 264-275.
11. *Першина В.А., Титова Н.Д., Степанов М.С.* Построение автоматизированной системы сбора данных с приборов учета на базе стандарта LoRaWAN // Телекоммуникационные устройства и системы. 2019. Том 9. №2. С. 3-9.
12. *Muzata A.R., Pershina V.A., Stepanov M.S., Ndimumahoro F. and Ndayikunda J.* "The Modeling of Elastic Traffic Transmisson by the Mobile Network with NB-IoT Functionality," 2021 Systems of Signals Generating and Processing in the Field of on Board Communications, 2021, pp. 1-7,