# ANNOTATION

of dissertation for the Philosophy Doctor (PhD) degree in specialty "6D061100 – Radioengineering, electronics and telecommunications" by

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## DEVELOPMENT AND OPTIMIZATION OF ENERGY EFFICIENT WIRELESS SELF-ORGANIZING SENSORS NETWORKS

The dissertation work is devoted to the optimization and energy efficiency of self-organizing wireless sensor networks on the example of LoRa and ZigBee technologies.

**Relevance of the study**

Wireless sensor network is a system consisting of sensors (measuring), computing and communication elements, which give the administrator the ability to measure, observe and respond to events and phenomena in a certain environment. Any civil, government, commercial or industrial organization can act as an administrator. The environment can be the physical world, a biological system, or an information technology (IT) structure. Wireless sensor networks are most commonly used in the following fields: military technology, environmental monitoring, healthcare, Smart Home use, commercial use for process monitoring, traffic flow, vehicle detection and tracking, and so on. In addition to monitoring and observation, there is often a need for control and activation under certain conditions. There are four main components in a wireless sensor network: (1) a set of distributed or localized sensors; (2) an interconnected wireless network; (3) network coordinator for data collection; and (4) computing resource for processing data correlation, events, trends and data mining. The information transmitted from the end nodes to the coordinators is of the parametric nature of text messages containing the values of the measured physical, biological or other quantities, depending on the specific application of the network. However, with the emerging of new archiving and encoding algorithms, the exchange of video and multimedia files became possible.

This work is aimed at optimizing and improving the energy efficiency of self-organizing wireless sensor networks. To this end, in this work, the parameters of wireless sensor networks and their impact on the power consumption of an individual node and the entire network were studied. Research in this direction leads to development of consumption model for sensor network nodes. This question is the main one in solving the optimization problem. However, the authors in most studies cite traditional linear models of consumption of network nodes.

**An urgent task** for improving the energy efficiency of wireless sensor networks today is to reduce the power consumption of wireless nodes by optimizing the parameters of the network nodes and the network configuration as a whole. Also reducing the power consumption of wireless nodes using directional

antennas at transmitting nodes and optimizing the location of wireless sensor network nodes when deployed indoors.

**The purpose of the research** is to increase the energy efficiency of wireless sensor networks in synchronous and asynchronous mode by studying the parameters of a wireless sensor network and creating a mathematical model of node energy consumption based on Markov's chains, taking into account directional antennas and the optimal location of sensor network nodes.

**The objects of the research**: wireless sensor networks and LoRa and ZigBee wireless data transmission technologies.

**The subject of the research** - energy efficiency of wireless sensor networks depending on its parameters, the influence of directional antennas and location of wireless nodes in space on the energy consumption of the network.

**The method of the research** is an experimental determination of the power consumption of a wireless sensor network in synchronous and asynchronous operating modes, modeling the power consumption of network nodes in asynchronous mode using Markov's chains, an experimental study of the influence of directional antennas on the power consumption of network nodes, predicting the power of the received signal strength using machine learning.

**To achieve this purpose, the following tasks were set:**

- design, assembly and debugging of wireless nodes to build a sensor network;
- study of the influence of parameters of wireless sensors network, such as transmission power, packet length, battery discharge dynamics, sleep time, probability of collisions in the communication channel, probability of errors in reception of packets on its energy consumption;
- development of a prediction model of power consumption of a wireless sensor network, taking into account the dynamics of battery discharge and sensor network parameters in deterministic and random data transmission;
- design and manufacture of directional antennas for LoRa and ZigBee technology and measurement of their characteristics;
- study of the influence of directional antennas and the location of nodes relative to the receiver in open areas and indoors on the power of the received signal;
- development of a model for predicting the optimal position of sensor network nodes in a room using machine learning methods;

**The novelty of the work**. Scientific novelty lies in the fact that for the first time in it:

- a model has been developed that predicts the power consumption and operation time of wireless sensor network nodes based on Markov's chains, taking into account the dynamics of battery discharge;
- the effect of directional antennas on reducing the power consumption of nodes, and as a result, increasing the operating time of a wireless sensor network was studied;
- a model is proposed for predicting the transmitter power in a room for a fixed position of the receiver using machine learning methods.

**The main provision for the defense**

1 Forecasting energy consumption of wireless sensors networks based Markov's chains shows, that the probability of a wireless sensor network's lifetime in asynchronous mode for more than 36 months approaches 100 percent when wireless node sends no more than 30 messages per day with a single packet length of 500 bytes using two Li-ion model 18650 batteries with capacity 3000 mAh per node;

2 The power consumption of transmitting nodes in wireless sensor networks with directional antennas is reduced by 12-25% for synchronous data transmission and by 45-60% for asynchronous data transmission comparing with power consumption using omnidirectional antennas;

3 The optimal position of transmitting node relatively to receiver indoors is determined using machine learning methods increases received signal strength by 33% on frequency 433 MHz and by 78% on frequency 2.4 GHz comparing with other nodes located at the same distance

**The theoretical and practical significance of the work**.

The results obtained in this work are important for improving energy efficiency and the optimal ratio of energy costs and network coverage area, predicting network operation and increasing node operation time. The information obtained can be used to create new sensor networks and improve existing networks in order to ensure the safety and comfort of people in homes and buildings, receive data from sensors for a longer period and optimize the use of resources.

When deploying an autonomous wireless sensor network to study slowly changing processes or random processes, it is necessary to be able to predict the network operation time. This work proposes a consumption model for wireless sensors network nodes. Research in this direction leads to development of a consumption model for wireless sensor network nodes. In particular, a power consumption model is needed to predict the operation of the network in synchronous and asynchronous modes, taking into account the non-linear nature of the node's battery discharge.

The effect of directional antennas on the power consumption of wireless sensor networks is to reduce interference, increase the signal range, and reduce the power of the transmitted signal.

Optimizing the location of sensor network nodes in space is of practical interest when deploying a wireless sensor network to improve the safety and comfort of people in large buildings.

**Reliability of results** are confirmed by the presence of publications in foreign journals with an impact factor and in publications recommended by the Committee for Quality Assurance in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, and in the proceedings of international scientific conferences of near and far abroad. The experimental data obtained during execution of the work are in good agreement with the calculations obtained on the basis of the proposed model.

**Personal contribution of the author** is that the entire volume of the dissertation work, the choice of the research method, the assembly of wireless

modules, the manufacture of directional antennas, the conduct of experiments and the analysis of the data obtained, the development of a mathematical model for the consumption of wireless sensor network nodes were performed by the author independently. The setting of tasks and discussion of the results were carried out jointly with the supervisors.

**Publications.** Based on the materials of the dissertation work, 8 printed works were published: 4 in journals from the list of Committee for Quality Assurance in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan for the publication of the main results of the dissertation for the PhD degree and 1 article in international journal with an impact factor included in the international information resources Web of Science (Clarivate Analytics , USA) and Scopus (Elsevier, the Netherlands); 3 works in the materials of International scientific conferences.

**Approbation testing of thesis.** The results obtained in the dissertation work were reported and discussed:

- at the 2018 IEEE International conference on computing and network communications (CoCoNet) (2018, Nursultan, Kazakhstan);
- at the International scientific conference of students and young scientists "Farabi Alemi" (2019 Almaty, Kazakhstan);
- at the International scientific conference of students and young scientists "Farabi Alemi" (2020 Almaty, Kazakhstan);

The results obtained in the dissertation work were published:

- **Nurgaliyev M.** Saymbetov, A., Yashchyshyn, Y., Kuttybay, N., & Tukymbekov, D. Prediction of energy consumption for LoRa based wireless sensors network //Wireless Networks. – 2020. – Vol. 26., No. 5. P. 3507-3520.
- **M.K. Nurgaliyev**, A.K. Saymbetov, B.N. Zholamanov, A.T. Yeralkhanova, G.B. Zhuman. Predicting the lifetime of LoRa based wireless sensor networks using a probabilistic model of Markov chains. // News of the National Academy of Sciences of the Republic of Kazakhstan -2021. Vol. 336., No. 2. P.157-164
- **Нұрғалиев М.К.,** Саймбетов А.К., Омарали Б.М., Құттыбай Н.Б., Тукымбеков Д.Х., Досымбетова Г.Б. Беспроводные приемопередающие устройства на основа технологии LoRa с различными оконечными устройствами. // Вестник КазНИТУ. -2020. -138, №2. -С.455-461
- **Нұрғалиев М.К.,** Саймбетов А.К., Бектұрған Ү.Қ., Шаймерденова М.Е., Құттыбай Н.Б., Тукымбеков Д.Х. Разработка беспроводных сенсорных сетей на основе технологий LoRa WAN и NRF24L01 и исследование распространения радиоволн в различных условиях // Вестник КазНИТУ. – 2019. – 134, №4. –С.279-286
- Тукымбеков Д. Х., Саймбетов А.К., Құттыбай Н.Б., **Нұрғалиев М.К.** Ажибиева А.Р., Шаймерденова М.Е., Энергоэффективная автономная интеллектуальная система уличного освещения на основе ZigBee // Вестник КазНИТУ. -2019. -134, №4. -С.262-267

**Dissertation work completed** in accordance with the plans of research work (R&D): "Development of an intelligent autonomous system for wireless control and monitoring of street lighting" 2018-2020, IRN AP05132464.

**Copyright certificate**

**Нұрғалиев М.К.,** Саймбетов А.К., Құттыбай Н.Б., Оптимизация беспроводных сенсорных сетей с помощью направленных антенн и выбора оптимального положения передающего узла в помещении // Авторское свидетельство, 2022. №25205.

**Structure and volume of the dissertation:** The dissertation work consists of an introduction, 3 sections, a conclusion and a list of references from 131 titles, contains 115 pages of the main computer text, including 86 figures, 28 formulas and 13 tables.