ANNOTATION

to the dissertation work submitted for the degree of Doctor of Philosophy (PhD) in the educational program «8D06201–Radioengineering, electronics and telecommunications»

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SYSTEM FOR PREDICTING THE POSITION OF MOBILE NODES OF WIRELESS SENSOR NETWORKS IN OPEN AND INDOOR AREAS

General characteristics of the work

The dissertation work is aimed at increasing the accuracy of predicting the location of mobile nodes in wireless sensor networks (WSN) in open and indoor areas. In the course of the study, machine learning based on sectorization of RSSI fingerprint data inside buildings, radio map reconstruction based on Locally Weighted Regression (LWR), as well as hybrid localization methods for Long Range Wide Area Network (LoRaWAN) networks in open space, complemented by machine learning using Weighted Centroid Localization (WCL), were proposed.

Relevance of the topic

Currently, due to the development of the Internet of Things, smart buildings, smart city systems, industrial monitoring, and mobile robotics, the problem of accurately determining the location of nodes in wireless sensor networks is of particular importance. Since the value of sensor data largely depends on their exact spatial location, the quality of localization directly affects the efficiency of monitoring, navigation, safety, and resource management. Therefore, increasing the accuracy of predicting the location of wireless nodes in open and indoor areas is an urgent scientific and applied task.

In indoor areas, this problem is complicated due to the signal propagation, the influence of obstacles, and the instability of received signal strength indicator (RSSI). Although localization methods based on received signal strength are widely used, they require a large amount of measurement data collection and radio map construction, which demands significant time and effort. In addition, the adaptation of trained models to new trajectories and changing environmental conditions is not always high. Moreover, the development of methods that reduce the volume of measurements, allow radio map reconstruction from limited data, and take into account spatial features is also an important issue. In this regard, the development of new methods for efficient data processing, radio map reconstruction from limited measurements, and improving localization accuracy is important.

Similar challenges are also observed in LoRaWAN networks in open areas. This technology provides wide coverage and low energy consumption. However, Non Line Of Sight (NLoS) conditions in urban environments and uneven gateway placement limit the accuracy of predicting the location of WSN nodes. In addition, in real network infrastructure, the reception of messages by different gateways and the dependence of RSSI on environmental conditions affect the accuracy of node

positioning methods. For this reason, hybrid methods combined with machine learning are of particular interest. Such integration allows refining the initial coordinate estimation, reducing errors under complex propagation conditions, and improving the generalization capability of the model.

Thus, the methods proposed in this dissertation aimed at improving localization accuracy in open and indoor areas represent a research direction with scientific novelty and high practical significance.

The purpose of the research. Improving the accuracy of localization of mobile nodes in wireless sensor networks in open and indoor environments and reducing the average RSSI error during radio map reconstruction inside buildings based on limited measurements.

To achieve the stated purpose, the following tasks must be accomplished:

• to improve the accuracy of localization of mobile nodes in indoor LoRaWAN environments using methods of RSSI data preprocessing, sectorization, and machine learning models;

• to reduce the average RSSI reconstruction error in radio map construction in indoor area using limited measurements and the locally weighted regression method, as well as to compare its effectiveness with alternative radio map reconstruction algorithms;

• to reduce the localization error of LoRaWAN nodes in outdoor areas using the weighted centroid localization method and machine learning models.

Research methods:

• RSSI data preprocessing, sectorization, and development of machine learning models kNN, SVR, GRU, RF, and MLP in the Python environment for localization of mobile nodes in indoor environments;

• methods for radio map reconstruction in indoor areas based on limited RSSI measurements, including interpolation, locally weighted regression, and alternative methods, followed by comparative analysis;

• methods for localization of LoRaWAN nodes in outdoor areas, including weighted centroid localization and machine learning models MLP, XGBoost, LightGBM, and kNN in the Python environment.

Object of the research. Wireless sensor networks based on LoRa and ZigBee technologies.

Subject of the research. Methods of radio map reconstruction, methods for predicting the location of mobile nodes based on machine learning, as well as hybrid models designed to improve localization accuracy in LoRaWAN networks in open areas.

The scientific novelty of the work lies in the fact that, for the first time:

• the sectorization method was used for RSSI data preprocessing together with machine learning models to improve the accuracy of predicting the location of mobile nodes in indoor LoRaWAN wireless sensor networks;

• the use of the Locally Weighted Regression (LWR) method for radio map reconstruction based on limited measurements in indoor space was shown to reduce the average RSSI error compared with the traditional interpolation method;

• the use of the Weighted Centroid Localization (WCL) method for predicting

the location of LoRaWAN network nodes in open space was shown to reduce the average localization error compared with direct prediction methods based only on machine learning.

Provisions for the defense:

1. The sectorization method in LoRaWAN wireless sensor networks increases the accuracy of predicting the location of mobile nodes in indoor areas by up to 19% depending on the complexity of the movement trajectory.
2. The application of locally weighted regression (LWR) for radio map reconstruction in indoor areas reduces the average received signal strength indicator (RSSI) reconstruction error by 32% compared with the traditional interpolation method.
3. The application of the Weighted Centroid Localization (WCL) method reduces the average error of predicting the location of nodes in LoRaWAN networks in open areas by 29%.

Theoretical significance of the work. Processing of RSSI data, application of locally weighted regression, and construction of hybrid models expand scientific approaches to improving localization accuracy. In addition, the obtained results establish new approaches for integrating machine learning methods with physical models and allow a deeper understanding of radio signal propagation patterns. The results of the study provide a theoretical basis for the development of localization algorithms that ensure high accuracy under limited data conditions.

Practical significance of the work. The results of the study can be applied in the design and implementation of localization systems in wireless sensor networks in both indoor and outdoor environments. The proposed methods not only improve localization accuracy but also reduce the amount of measurements required for radio map construction and ensure model robustness in complex environments. Indoor localization systems, mobile robotics, smart buildings, warehouse and industrial logistics, as well as monitoring systems based on urban LoRaWAN infrastructure can be developed using the obtained results.

Reliability and validity of the obtained results. The validity of the results of the dissertation work is confirmed by the presence of publications in foreign journals with an impact factor above zero.

Author's personal contribution. The theoretical analysis, development of the research structure, organization of the experimental system in indoor areas, data collection and preprocessing, development of localization and radio map reconstruction algorithms, training and tuning of machine learning models, analysis and comparison of results, as well as preparation of the main text of the work were carried out with the direct personal participation of the author. The formulation of research tasks and discussion of results were conducted jointly with the scientific supervisors..

Approbation of the work. The results of the dissertation work were published in the following sources:

Articles published in journals indexed in international scientific databases such as Thomson Reuters and Scopus:

1. Nurgaliyev M., **Bolatbek A.,** Zholamanov B., Saymbetov A., Kopbay K., Yershov E., Orynbassar S., Dosymbetova G., Kapparova A., Kuttybay N., Koshkarbay N. Machine learning based localization of lora mobile wireless nodes using a novel sectorization method //Future Internet. – 2024. – Vol. 16. – No. 12. – P. 450. **Web of Science: Impact Factor 3.6, Q2. Scopus: CiteScore 9.6, Percentile 84%**

2. **Bolatbek A.,** Beyca Ö. F., Zholamanov B., Nurgaliyev M., Dosymbetova G., Almen D., Saymbetov A., Yertaikyzy B., Orynbassar S., Kapparova A. A Physically-Aware Residual Learning Framework for Outdoor Localization in LoRaWAN Networks //Future Internet. – 2026. – Vol. 18. – No. 4. – P. 216. **Web of Science: Impact Factor 3.6, Q2. Scopus: CiteScore 9.6, Percentile 84%**

Scientific articles published in journals recommended by the Science and Higher Education Quality Assurance Committee of the Ministry of Science and Higher Education:

1. Nurgaliyev M., **Bolatbek A.**, Dosymbetova., Kapparova A., Yertaikyzy B. LoRaWAN – Based Indoor Localization for Mobile Nodes Using Machine Learning Technique // "Universitet Enbekteri – University Proceedings". - 2025. - Vol. 100 – No. 3. - P. 449-455.

2. **Bolatbek A.B.,** Zholamanov B.N., Nurgaliyev M.K., Saymbetov A.K., Abzhanova G.M. Energy efficient algorithm for transmission parameter selection in LoRa wireless networks // Bulletin of D. Serikbayev EKTU. – 2025. – Vol.. 1. – No. 3. – P. 157.

Publications in proceedings of international conferences:

1. **Bolatbek A.**, Orynbassar S., Saymbetov A., Nurgaliyev M., Zholamanov B., Dosymbetova G., Kuttybay N., Kapparova A. ZigBee Based Indoor Localization via RSSI-Based Fingerprinting with Adaptive Path Loss Estimation //2025 10th International Conference on Computer Science and Engineering (UBMK). – IEEE, 2025. – P. 1449-1454.

2. **Bolatbek A.,** Zholamanov B., Seitzhanova A. // Fingerprint-based localization in lorawan using machine learning «FARABI ALEMI», 2025. – P.152

Certificate of Copyright:

Bolatbek A.B., Saymbetov A.K., Nurgaliyev M.K., Zholamanov B.N. Restoration of a radio map indoors based on a locally weighted method. Republic of Kazakhstan, “National Institute of Intellectual Property”, 2026, Certificate of Copyright No. 69347 dated March 31, 2026.

The volume and structure of the dissertation. The dissertation work consists of an introduction, four chapters, a conclusion and a bibliography of 107 references. The work is 102 pages long, including 68 figures and 18 tables.

In the first chapter of the dissertation, the current state of the problem of determining the location of mobile nodes in wireless sensor networks is considered, and an overview of the used technologies and methods is presented.

In the second chapter of the dissertation, the results of determining the location of mobile nodes in an indoor environment based on preliminary data processing by the sectorization method and the application of machine learning models are considered.

The third chapter of the dissertation is devoted to the problem of radio map reconstruction, in which methods based on static and mobile measurements are studied.

The fourth chapter of the dissertation is devoted to the proposed hybrid method for determining the location of LoRaWAN nodes in an outdoor environment, the stages of data processing and the configuration of machine learning models.

Relation of the dissertation topic to research program plans

The dissertation work was partially carried out in accordance with the research plan of the scientific project"Improving the energy efficiency of mobile and static wireless sensor nodes in indoors and outdoors" for the years 2023–2025, individual registration number (IRN) AP19678552.