Methods of information systems synthesis

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METHOD FOR CALCULATING THE NUMBER OF IOT SENSORS IN ENVIRONMENTAL MONITORING SYSTEMS

Abstract. Topicality. The rapid growth of environmental threats requires effective environmental monitoring systems. IoT sensors provide continuous real-time data collection. Correct calculation of the number of sensors increases the accuracy and efficiency of monitoring. Excessive number of sensors increases the cost and energy consumption of the system. Therefore, developing an approach to determining the number of sensors is critical for optimizing the IoT ecosystem. **The subject of** study in the article is methods for determining the composition of sensor networks of environmental monitoring systems. **The purpose of the article** is to develop a method for determining the required number of IoT sensors to support an environmental monitoring system. **The following results** were obtained. The general structure of the environmental monitoring system is determined. Its feature is the division of the monitoring zone into autonomous sections. Each section during the time window is served by an autonomous cluster of the system. The cluster has a certain number of channels of the same type for receiving readings from active IoT sensors. A mathematical model of the process of transmitting event messages has been devised. Based on the model, an approach to determining the average number of successfully transmitted messages about one event has been proposed.. This indicator is chosen as a criterion for the quality of the sensor network. An approximate formula for calculating the required number of sensors in the monitoring system is proven. **Conclusions.** The proposed method allows you to quickly obtain the required number of IoT sensors to support the environmental monitoring system. The deviation of the calculated number of sensors from the optimal does not exceed 3%. The direction of further research concerns the removal of the restriction on the full coverage of the monitoring area.

Keywords: Internet of Things; computer system; environmental monitoring system; cluster; IoT sensors.

Introduction

Problem relevance. In the modern world, the problems of environmental pollution, climate change and depletion of natural resources are becoming increasingly urgent [1, 2]. Therefore, there is a need to implement innovative solutions for their timely detection and control [3, 4]. One of the most promising approaches in the field of environmental monitoring is the use of Internet of Things (IoT) technologies [5]. This technology allows you to create distributed systems with a significant number of sensor devices [6]. IoT sensors are capable of measuring various environmental parameters in real time: temperature, humidity, air pollution level, content of harmful substances in water, radiation background, etc. [7]. The advantages of such systems are their scalability, autonomy, flexibility in configuration, and ability to operate in hard-to-reach or remote regions [8]. IoT sensors can operate for years on batteries [9]. They use energy-efficient communication protocols such as Long Range Wide Area Network (LoRaWAN) [10], Sigfox, Narrow Band IoT (NB-IoT) and Long Term Evolution for Machines (LTE-M) [11]. Information from IoT devices is transmitted to fog or cloud servers for further analytics [12, 13]. One of the key tasks at the design stage of such systems is to determine the optimal number of sensors [14]. The number of sensors should be sufficient to obtain representative and reliable information. It is desirable to avoid unnecessary duplication and overspending of resources [15, 16].

Insufficient number of devices can cause data gaps. Excess devices increase the costs of installation, maintenance and data transmission [17, 18]. In addition, with a significant excess of sensors, information about the event can be duplicated many times. This leads to undesirable delays in the data transmission network of the environmental monitoring system [19]. When calculating the number of IoT sensors, it is necessary to take into account the characteristics of the monitored object, environmental parameters and coverage density [20]. It is also necessary to take into account the characteristics of the devices themselves, namely, measurement accuracy, range, data transmission frequency [21, 22].

Literature review. Let's consider some scientific works on this topic. There are many scientific papers devoted to the study of the low-level architecture of IoT systems. The work [23] considers a forest fire warning system. The developed forecasting model is based on ensemble learning. However, the problem of selecting and placing sensors is not considered. The work [24] considers the IoT edge layer model. To improve performance, IoT devices are divided into clusters. However, this study does not take into account the features of environmental monitoring systems. The work [25] focuses on interaction protocols in the IoT system. This study proposes an enhanced Sensor Web, integrating IoT protocols and spatio-temporal models for unified access, collaborative management, and dynamic planning. However, the issues of covering the area with sensors are not considered. In [26], the study is aimed at accelerating the transfer of operational transactions. In this case, the number of IoT sensors is fixed. In [27], an algorithm for the optimal placement of sensors in the study area is proposed. However, it does not take into account the significant unevenness of the occurrence of critical events. In [28, 29], the main attention is paid to high-density IoT. This property is inherent in urban systems, and not environmental monitoring systems. Work [30] is focused on improving the performance of the sensor network. The issue of choosing the number of sensors is not considered in it. In [31], issues of balancing the load of the IoT system support infrastructure are considered. However, issues of determining the optimal number of sensors are not considered.

Consequently, all the considered works [23–31] do not solve the problem of selecting the optimal number of sensors for an environmental monitoring system.

The purpose of the research is to develop a method for determining the required number of sensors for an IoT environmental monitoring system. To achieve the purpose, the following tasks are solved:

1) description of the general structure of the environmental monitoring system;

2) devise a mathematical model of the process of transmitting messages about events;

3) propose a method for calculating the required number of sensors in a monitoring system.

1. General structure of the environmental monitoring system

The monitoring system collects data from IoT sensors. S is the total area of the territory where the sensors are located. IoT devices are divided into I territorial autonomous clusters. Each i-th cluster $\left(i \in \overline{1, I}\right)$ serves zone S_i, and

$$S = \bigcup_{i=1}^{I} S_i \qquad (1)$$

Each autonomous cluster of the monitoring system consists of a Cluster Central Node (CCN) and IoT sensors [32]. The IoT sensors are located within the reception area of the CCN. Data transmission between the IoT sensors and the CCN is carried out via a radio channel.

Let the i-th cluster include N_i sensors. They are distributed uniformly, randomly and independently of each other. The zones of action of the sensors of the i-th cluster completely cover the area S_i:

$$S_i = \bigcup_{j=1}^{N_i} S_{ij}, \qquad (2)$$

where S_{ij} is the area controlled by the j-th sensor of the i-th cluster.

Let t_w be the time interval during which the sensor analyzes the environment and transmits data when events are detected. Time in the monitoring system is divided into time periods of size t_w. Each such period is called a time window (Fig. 1). An event that occurs in the current window is no longer detected in the next window.

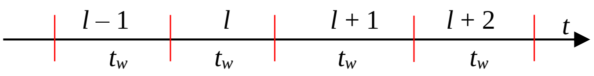

Fig. 1. Time windows of Monitoring system

The event has the shape of a circle of radius r. The center of the circle is the point with the coordinates of the event occurrence. The event will be noticed by the sensor if it is at a distance not exceeding r from the event occurrence (Fig. 2). In Fig. 2, a the SEN sensor noticed the EV event, in Fig. 2, b the SEN sensor did not notice the EV event.

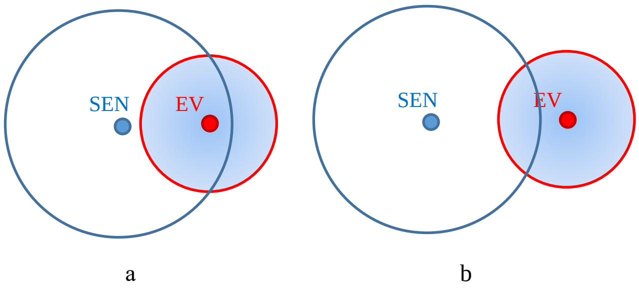

Fig. 2. Active (a) and passive (b) states of the sensor

The process of occurrence of events is given by a Poisson point process with parameter λ [33, 34]. The number of events m_i, occurring during one window per unit area has a Poisson distribution.

The points at which events occurred are distributed uniformly [35].

Let Ki be the number of frequency channels allocated for data transmission. The following situations are possible in each channel (Fig. 3):

- success (SUC) – data sent by one sensor;
- empty (EMP) – no sensor sent data;
- conflict (CON) – data was sent by several sensors.

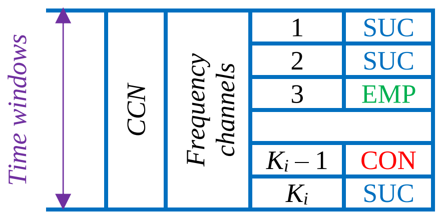

Fig. 3. Example of loading frequency channels of the central cluster node

Sensors that have noticed at least one event become active (Fig. 2, a). Each active sensor randomly selects a channel number to send data about observed events. Event data is sent in the same window in which it was seen.

2. Mathematical model of the process of transmitting messages about events

Let $M1_{aver}$ be the average number of successfully transmitted messages in a window about one event. In random event monitoring systems, $M1_{aver}$ can be considered as an indicator of the quality of such systems [36]. Let us calculate its value:

$$M1_{aver} = \frac{M_{aver}}{\Lambda}, \qquad (3)$$

where M_{aver} is the average number of successfully transmitted messages in a window; Λ is the average number of events that occurred in or near the CCN coverage area.

The area of the region where events that extend into the CCN coverage area may occur is calculated as

$$S_{ir} = S_i + \Delta S, \quad (4)$$

where ΔS is the expansion of the area of event recording by sensors of the *i*-th cluster.

Then the average number of events determined by the sensors of the *i*-th cluster is equal to

$$\Lambda = \lambda \cdot S_{ir}. \quad (5)$$

Let n_{il} be the number of active sensors of the *i*-th cluster in window *l*.

Random variables ξ_{ik} are introduced, determined by the formula

$$\xi_{ilk} = \begin{cases} 1, & \text{if } \theta_k = \text{'SUC'}, k \in \overline{1, K_i}; \\ 0, & \text{else,} \end{cases} \quad (6)$$

where θ_k is the current situation in the *k*-th channel in window *l*. Let m_{il} events occur in window l.

The probability that *j* sensors send messages in window *l* is introduced

$$p_{ijl} = \mathrm{P}(n_{il} = j / m_{il}). \quad (7)$$

Then the probability that a message will be successfully sent in the first channel, given the occurrence of m_{il} events, is equal to

$$\mathrm{P}(\xi_{il1} = 1 / m_{il}) = \\ = \sum_{j=1}^{N_i} j \cdot \mathrm{P}(n_{il} = j / m_{il}) \cdot \frac{1}{K_i} \cdot \left(1 - \frac{1}{K_i}\right)^{j-1}. \quad (8)$$

The probability that m_{il} events occurred in window *l* is

$$p_{il} = \frac{\Lambda^{m_{il}}}{m_{il}!} \cdot e^{-\Lambda}. \quad (9)$$

Then the probability that a message will be successfully sent in the first channel will be as follows:

$$\mathrm{P}(\xi_{il1} = 1) = e^{-\Lambda} \cdot \sum_{m_{il}=0}^{\infty} \frac{\Lambda^{m_{il}}}{m_{il}!} \cdot \mathrm{P}(\xi_{il1} = 1 / m_{il}). \quad (10)$$

After substituting expression (8) into formula (10), the following formula is obtained:

$$\mathrm{P}(\xi_{il1} = 1) = e^{-\Lambda} \cdot (K_i)^{-1} \times \\ \times \sum_{m_{il}=0}^{\infty} \frac{\Lambda^{m_{il}}}{m_{il}!} \cdot \sum_{j=1}^{N_i} j \cdot \mathrm{P}(n_{il} = j / m_{il}) \cdot \left(1 - \frac{1}{K_i}\right)^{j-1}. \quad (11)$$

In the current window, the probabilities of success in all channels are the same, i.e.

$$\mathrm{P}(\xi_{il1} = 1) = \mathrm{P}(\xi_{il2} = 1) = \ldots = \mathrm{P}(\xi_{ilK_i} = 1), \quad (12)$$

therefore, the average number of successfully transmitted messages in a window can be calculated as follows:

$$M_{aver} = \mathrm{M}\left[\sum_{k=1}^{K_i} \xi_{ilk}\right] = \\ = K_i \cdot \mathrm{M}[\xi_{il1}] = K_i \cdot \mathrm{P}(\xi_{il1} = 1). \quad (13)$$

From formulas (3), (11) and (13) the final expression for $M1_{aver}$ is formed:

$$M1_{aver} = \left(e^{-\Lambda} / \Lambda\right) \times \\ \times \sum_{m_{il}=0}^{\infty} \frac{\Lambda^{m_{il}}}{m_{il}!} \cdot \sum_{j=1}^{N_i} j \cdot \mathrm{P}(n_{il} = j / m_{il}) \cdot \left(1 - \frac{1}{K_i}\right)^{j-1}. \quad (14)$$

Selecting the optimal number of sensors for this indicator is equivalent to finding N_i that maximizes $M1_{aver}$. To derive the value of this indicator, expression (14) is used:

$$M1_{aver} \xrightarrow{N_i} \max. \quad (15)$$

However, the optimization problem (15) has a high computational complexity. Therefore, in practice, approximate methods for its solution are used, which allow choosing a number of sensors close to the optimal one. This method will be considered in the next section.

3. Calculation of the required number of sensors in the monitoring system

This section examines the operation of one channel *k* of the cluster S_i of the monitoring system in the window *l*. Therefore, the indices *i*, *k* and *l* are omitted in the variables to simplify the notation.

The probability value of channel availability is introduced:

$$\chi(m) = \frac{S(m)}{S}, \quad (16)$$

where *S* is the area of the channel coverage area, and *S*(*m*) is the area of the region covered by active sensors for *m* events.

Finding this probability comes down to calculating the geometric probability (Fig. 4).

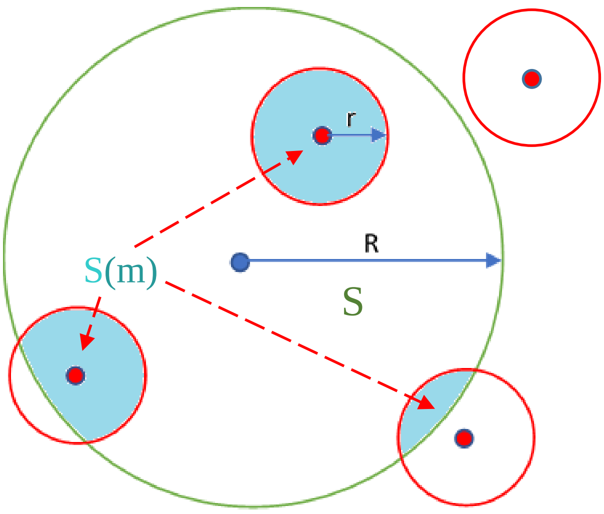

Fig. 4. Example for four active events (*m* = 4)

The following notations are introduced:

– L is the perimeter of the channel's coverage area;

– s is the area of the event's coverage area;

– η is the radius of the event's coverage area.

Then [37]:

$$\chi(m) = 1 - \left(\frac{2\pi S + \eta \cdot L}{2\pi (S + s) + \eta \cdot L} \right)^m . \quad (17)$$

The events in the model affect a circular area. Therefore, the area and perimeter of this area are equal, respectively

$$s = \pi r^2, \quad \eta = 2\pi r. \quad (18)$$

After substituting formula (18) into expression (17), the expression for calculation $\chi(m)$ is simplified:

$$\chi(m) = 1 - \left(\frac{S + r \cdot L}{\pi r^2 + S + r \cdot L} \right)^m . \quad (19)$$

An example of calculating the function $\chi(m)$ for the coverage areas of a base station, typical for LoRaWAN networks, is considered. When analyzing such systems, the most common shape of the coverage area is a circle [38].

For a circle of radius R, the area and perimeter will be calculated using the following formulas:

$$s = \pi R^2, \quad L = 2\pi R. \quad (20)$$

Taking these formulas into account, expression (19) after transformations takes the following form:

$$\chi(m) = 1 - \left(\frac{\pi R^2 + r \cdot 2\pi R}{\pi r^2 + \pi R^2 + r \cdot 2\pi R} \right)^m = 1 - \left(\frac{R^2 + 2R \cdot r}{r^2 + R^2 + r \cdot 2R} \right)^m = 1 - \left(\frac{R \cdot (R + 2r)}{(r + R)^2} \right)^m = 1 - \frac{R^m \cdot (R + 2r)^m}{(r + R)^{2m}} . \quad (21)$$

After calculating $\chi(m)$, the expected value of the number of sensors sending messages in the current window is calculated:

$$\mathrm{M}[n / m] = \xi(m) \cdot N. \quad (22)$$

The obtained expressions allow us to estimate the value $M1_{aver}$. For this, formula (8) is transformed:

$$\mathrm{P}(\xi_1 = 1/m) = M\left[n \cdot \frac{1}{K} \cdot \left(1 - \frac{1}{K}\right)^{n-1} \Big/ m \right]. \quad (23)$$

The probability estimate for success in the first channel, given that m events have occurred, is

$$\mathrm{P}(\xi_1 = 1/m) = \chi(m) \cdot N \cdot \frac{1}{K} \cdot \left(1 - \frac{1}{K}\right)^{\chi(m) \cdot N - 1} . \quad (24)$$

Next, the probability in formula (10) is replaced by its estimate (24):

$$\mathrm{P}(\xi_{il1} = 1) = e^{-\Lambda} \times \sum_{m=0}^{\infty} \frac{\Lambda^m}{m!} \cdot \chi(m) \cdot N \cdot \frac{1}{K} \cdot \left(1 - \frac{1}{K}\right)^{\chi(m) \cdot N - 1} . \quad (25)$$

Formula (25) is used to obtain an estimate of the expected value of successfully transmitted messages in the window (formula (13)). The result is substituted into formula (3) to obtain an estimate of $M1_{aver}$:

$$M1_{aver} = \left(K e^{-\Lambda} / \Lambda \right) \times \sum_{m=0}^{\infty} \frac{\Lambda^m}{m!} \cdot \chi(m) \cdot N \cdot \frac{1}{K} \cdot \left(1 - \frac{1}{K}\right)^{\chi(m) \cdot N - 1} . \quad (26)$$

After accepting the approximate equality

$$\mathrm{M}[m] \approx \Lambda. \quad (27)$$

the expression for evaluation (26) takes a simpler form:

$$M1_{aver} = (K / \Lambda) \times \chi(\Lambda) N \cdot \frac{1}{K} \cdot \left(1 - \frac{1}{K}\right)^{\chi(\Lambda) \cdot N - 1} . \quad (28)$$

Based on the constraints of the problem, the maximum value of function (28) is achieved when condition

$$\chi(\Lambda) N \cdot \frac{1}{K} = 1, \quad (29)$$

is met, therefore the required number of sensors is

$$N = \frac{K}{\chi(\Lambda)}. \quad (30)$$

4. Discussion of results

Simulation modeling of functions (14) and (28) for different values of the number of events showed that the deviation of the calculated number of sensors from the optimal one does not exceed 3%.

Fig. 5 shows graphs of the average number of successfully transmitted messages in a window about one event for several values of Λ. The same parameters of the monitoring system were considered for all values of the average number of events.

It can be noted that the lower the average number of events Λ, the higher the value of criterion (3). The values of the criterion are very large for low values of Λ. Therefore, it is advisable to calculate the number of required sensors for the maximum possible value of Λ in the system. In this case, there will be enough sensors to detect events for smaller values of Λ.

The formula for calculating the number of sensors (30) is valid under the following restrictions:

– the entire coverage area of the base station is under the control of sensors;

– all channels of each cluster are characterized by the same parameters.

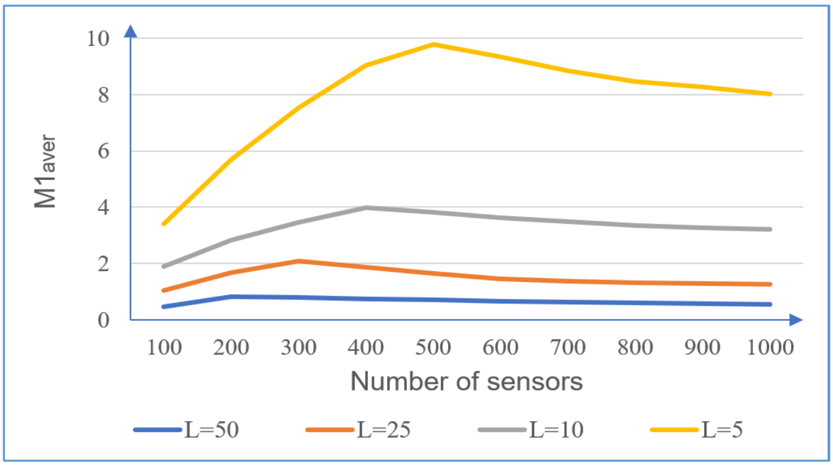

Fig. 5. The value of the quality indicator for different event intensities (L ≡ Λ)

Conclusions

The article proposes a method for determining the required number of sensors for an IoT environmental monitoring system.

The following tasks were considered when developing the method:

1. The general structure of the environmental monitoring system is determined. Its feature is the division of the monitoring zone into autonomous sections. Each section during the time window is served by an autonomous cluster of the system. The cluster has a certain number of channels of the same type for receiving readings from active IoT sensors.

2. A mathematical model of the process of transmitting event messages is developed. Based on the model, an approach is proposed to determine the average number of successfully transmitted messages about one event. This indicator is chosen as a criterion for the quality of the sensor network.

3. An approximate formula for calculating the required number of sensors in the monitoring system is proven. Simulation modeling showed that the deviation of the calculated number of sensors from the optimal one does not exceed 3%.

The direction of further research concerns the removal of the restriction on the full coverage of the monitoring zone.

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References

1. Liu, X., Lu, D., Zhang, A., Liu, Q. and Jiang, G. (2022), “Data-Driven Machine Learning in Environmental Pollution: Gains and Problems”, *Environmental Science and Technology*, vol. 56(4), pp. 2124–2133, doi: https://doi.org/10.1021/acs.est.1c06157
2. Abdullayeva, M.Y., Aghayev, B.S. and Yaqubov, R.V. (2024), “Problems of environmental pollution with microplastic waste and ways to solve them”, *Bio Web of Conferences*, 95, 02002, doi: https://doi.org/10.1051/bioconf/20249502002
3. Hamza, Y.I., Bream, A.S., Mahmoud, M.A. and El-Tabakh, M.A.M. (2025), “Tracing industrial pollution: unveiling environmental health via insects’ biomarkers”, *Sustainable Environment Research*, vol. 35(1), 9, doi: https://doi.org/10.1186/s42834-025-00246-0
4. Yaloveha, V., Hlavcheva, D., Podorozhniak, A. and Kuchuk, H. (2019), “Fire hazard research of forest areas based on the use of convolutional and capsule neural networks”, *2019 IEEE 2nd Ukraine Conference on Electrical and Computer Engineering, UKRCON 2019 – Proceedings*, DOI: http://dx.doi.org/10.1109/UKRCON.2019.8879867
5. Alam, M., Islam, M.M., Nayan, N.M. and Uddin, J. (2025), “An IoT Based Real-Time Environmental Monitoring System for Developing Areas”, Journal of Advanced Research in Applied Sciences and Engineering Technology, vol. 52(1), pp. 106–121, doi: https://doi.org/10.37934/araset.52.1.106121
6. Lee, B.M. (2025), “Efficient Resource Management for Massive MIMO in High-Density Massive IoT Networks”, *IEEE Transactions on Mobile Computing*, vol. 24(3), pp. 1963–1980, doi: https://doi.org/10.1109/TMC.2024.3486712
7. Mani Kiran, C.V.N.S., Jagadeesh Babu, B. and Singh, M.K. (2023), “Study of Different Types of Smart Sensors for IoT Application Sensors”, S*mart Innovation, Systems and Technologies*, vol. 290, pp. 101–107, doi: https://doi.org/10.1007/978-981-19-0108-9_11
8. Zhang, Y., Jing, R., Zou, Y. and Cao, Z. (2025), “Optimizing power allocation in contemporary IoT systems: A deep reinforcement learning approach. Sustainable Computing: Informatics and Systems”, vol. 46, number 10114, doi: https://doi.org/10.1016/j.suscom.2025.101114
9. Singh, C., Khilari, S. and Taware, R. (2024), “Active Machine-to-Machine (M2M) and IoT Communication Architecture for Mobile Devices and Sensor Nodes”, L*ecture Notes in Networks and Systems*, 1072 LNNS, pp. 25–38, doi: https://doi.org/10.1007/978-981-97-5786-2_3
10. Lodhi, M.A., Wang, L., Farhad, A., Qureshi K.I., Chen J., Mahmood, K. and Das, A.K. (2025), “A Contextual Aware Enhanced LoRaWAN Adaptive Data Rate for mobile IoT applications”, *Computer Communications*, vol. 232, 108042, doi: https://doi.org/10.1016/j.comcom.2024.108042

11. Trendov, S., Sariiev, E., Mukhtar, K.B.S., Kachan, D. and Siemens, E. (2025), "Comparison of Performance and Power Consumption in Sigfox, NB-IoT, and LTE-M", *Lecture Notes in Networks and Systems*, vol. 1338 LNNS, pp. 127–158, doi: https://doi.org/10.1007/978-3-031-89296-7_8
12. Alsadie, D. (2024), "Advancements in heuristic task scheduling for IoT applications in fog-cloud computing: challenges and prospects", *PeerJ Computer Science*, 10, e2128, doi: https://doi.org/10.7717/PEERJ-CS.2128
13. Petrovska, I., Kuchuk, H., Kuchuk, N., Mozhaiev, O., Pochebut, M. and Onishchenko, Yu. (2023), "Sequential Series-Based Prediction Model in Adaptive Cloud Resource Allocation for Data Processing and Security", *2023 13th International Conference on Dependable Systems, Services and Technologies*, DESSERT 2023, 13–15 October, Athens, Greece, code 197136, doi: https://doi.org/10.1109/DESSERT61349.2023.10416496
14. Zhu, Y., He, Z. and Zhang, X. (2023), "Optimal number and locations of automatic vehicle identification sensors considering link travel time estimation", *Iet Intelligent Transport Systems*, vol. 17(9), pp. 1846–1859, doi: https://doi.org/10.1049/itr2.12379
15. Taneja, M. and Davy, A. (2017), "Resource aware placement of IoT application modules in fog-cloud computing paradigm", *Proc. 2017 IFIP/IEEE Symposium on Integrated Network and Service Management* (IM), pp. 1222–1228, doi: https://doi.org/10.23919/INM.2017.7987464
16. Kuchuk, G.A., Akimova, Yu.A. and Klimenko, L.A. (2000), "Method of optimal allocation of relational tables", *Engineering Simulation*, vol. 17(5), pp. 681–689, available at: https://www.scopus.com/record/display.uri?eid=2-s2.0-0034512103&origin=resultslist
17. Wing Lo, Y., Ho Tsoi, M., Chow, C.F. and Mung, S.W.Y. (2025), "An NB-IoT Monitoring System for Digital Mobile Radio With Industrial IoT Performance and Reliability Evaluation", *IEEE Sensors Journal*, vol. 25(3), pp. 5337–5348, doi: https://doi.org/10.1109/JSEN.2024.3512859
18. Kuchuk, N., Mozhaiev, O., Mozhaiev, M. and Kuchuk, H. (2017), "Method for calculating of R-learning traffic peakedness", *2017 4th International Scientific-Practical Conference Problems of Infocommunications Science and Technology*, PIC S and T 2017 – Proceedings, pp. 359–362, doi: https://doi.org/10.1109/INFOCOMMST.2017.8246416
19. Jiang, F., Zhou, Y. and Chen, Y. (2023), "MaMED: ML-Assisted Minimum End-to-End Delay Routing in SDN-IoT Networks for IoT Monitoring", *IEEE Wireless Communications and Networking Conference Wcnc*, 2023-March, doi: https://doi.org/10.1109/WCNC55385.2023.10118741
20. Narayana, T.L., Venkatesh, C., Kiran, A., J C.B., Kumar A., Khan S.B., Almusharraf, A. and Quasim, M.T. (2024), "Advances in real time smart monitoring of environmental parameters using IoT and sensors", *Heliyon*, vol. 10(7), e28195, doi: https://doi.org/10.1016/j.heliyon.2024.e28195
21. Mittal, U., Singh, A., Bharati, S.P., Singh, P., Arya, A. and Yadav, S. (2023), "Smart Sensor Network for Environment Parameter Monitoring using IoT", *2023 7th International Conference on Computing Communication Control and Automation Iccubea 2023*, doi: https://doi.org/10.1109/ICCUBEA58933.2023.10392152
22. Mozhaev, O., Kuchuk, H., Kuchuk, N., Mykhailo, M. and Lohvynenko, M. (2017), "Multiservice network security metric", *2nd International Conference on Advanced Information and Communication Technologies*, AICT 2017 – Proceedings, pp. 133–136, doi**:** https://doi.org/10.1109/AIACT.2017.8020083
23. Grari, M., Idrissi, I., Boukabous, M., Azizi, M. and Moussaoui, M. (2022), "Early wildfire detection using machine learning model deployed in the fog/edge layers of IoT", *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 27(2), pp. 1062–1073, doi: https://doi.org/10.11591/ijeecs.v27.i2.pp1062-1073
24. Kuchuk, H., Mozhaiev, O., Kuchuk, N., Tiulieniev, S., Mozhaiev, M., Gnusov, Y., Tsuranov, M., Bykova, T., Klivets, S., and Kuleshov, A. (2024), "Devising a method for the virtual clustering of the Internet of Things edge environment", *Eastern-European Journal of Enterprise Technologies*, vol. 1, no. 9 (127), pp. 60–71, doi: https://doi.org/10.15587/1729-4061.2024.298431
25. Chen, D., Wang, S., Wang, C., Zhang, X. and Chen, N. (2025), "Enhanced sensor web services by incorporating IoT interface protocols and spatio-temporal data streams for edge computing-based sensing", *Geo Spatial Information Science*, https://doi.org/10.1080/10095020.2025.2450510
26. Kuchuk, N., Kashkevich, S., Radchenko, V., Andrusenko, Y. and Kuchuk, H. (2024), "Applying edge computing in the execution IoT operative transactions", *Advanced Information Systems*, vol. 8, no. 4, pp. 49–59, doi: https://doi.org/10.20998/2522-9052.2024.4.07
27. Dohare, I., Singh, K., Khan, T., Mohan, Y. and Alam, I. (2025), "Coati optimization algorithm for node localization in sensor enabled-IoT", Cluster Computing, 28(4), 221, doi: https://doi.org/10.1007/s10586-024-04914-5
28. Kuchuk, H., Kalinin, Y., Dotsenko, N., Chumachenko, I. and Pakhomov, Y. (2024), "Decomposition of integrated high-density IoT data flow", *Advanced Information Systems*, vol. 8, no. 3, pp. 77–84, doi: https://doi.org/10.20998/2522-9052.2024.3.09
29. Kuchuk, H., Mozhaiev, O., Tiulieniev, S., Mozhaiev, M., Kuchuk, N., Tymoshchyk, L., Lubentsov, A., Onishchenko, Y., Gnusov, Y. and Tsuranov, M. (2025), "Devising a method for increasing data transmission speed in monitoring systems based on the mobile high-density Internet of Things", *Eastern-European Journal of Enterprise Technologies*, *3*(4 (135)), pp. 52–61, doi: https://doi.org/10.15587/1729-4061.2025.330644
30. Raj, S.P., Kalpana, D., Arun, M., Manthena, K. V., Krishna, K.S. and Krishnan, V.G. (2025), "Performance Optimization in Wireless Sensor Networks using REAMR Protocol for IoT Applications", 2025 International Conference on Emerging Smart Computing and Informatics Esci 2025, doi: https://doi.org/10.1109/ESCI63694.2025.10988270
31. Kuchuk, H., Husieva, Y., Novoselov, S., Lysytsia, D., Krykhovetskyi, H. (2025), "Load Balancing of the layers Iot Fog-Cloud support network", *Advanced Information Systems*, vol. 9, no. 1, pp. 91–98, doi: https://doi.org/10.20998/2522-9052.2025.1.11
32. Al-Sadoon, M.E., Jedidi, A. and Al-Raweshidy, H. (2023), "Dual-Tier Cluster-Based Routing in Mobile Wireless Sensor Network for IoT Application", *IEEE Access*, 11, pp. 4079–4094, doi: https://doi.org/10.1109/ACCESS.2023.3235200
33. Abdi, H., Shiri, M. and Shahrokhzadeh, B. (2024), "Proposing a Reliable and Fault-Tolerant Routing Algorithm for IoT Sensor Networks Using Poisson Distribution", *11th International Symposium on Telecommunication Communication in the Age of Artificial Intelligence Ist 2024*, pp. 608–614, doi: https://doi.org/10.1109/IST64061.2024.10843568
34. Kuchuk, G., Kharchenko, V., Kovalenko, A. and Ruchkov, E. (2016), "Approaches to selection of combinatorial algorithm for optimization in network traffic control of safety-critical systems", *Proceedings of 2016 IEEE East-West Design and Test Symposium*, EWDTS 2016, 7807655, doi: https://doi.org/10.1109/EWDTS.2016.7807655

35. Petrovska, I., Kuchuk, H. and Mozhaiev, M. (2022), “Features of the distribution of computing resources in cloud systems”, *2022 IEEE 4th KhPI Week on Advanced Technology*, KhPI Week 2022 – Conference Proceedings, 03-07 October 2022, Code 183771, doi: https://doi.org/10.1109/KhPIWeek57572.2022.9916459
36. Okafor, N., Ingle, R., Okwudili Matthew, U., Saunders, M. and Delaney, D.T. (2024), “Assessing and Improving IoT Sensor Data Quality in Environmental Monitoring Networks: A Focus on Peatlands”, IEEE Internet of Things Journal, vol. 11(24), pp. 40727–40742, doi: https://doi.org/10.1109/JIOT.2024.3454241
37. Aharonyan, N.G. and Ohanyan, V.K. (2018), “Calculation of Geometric Probabilities Using Covariogram of Convex Bodies”, *Journal of Contemporary Mathematical Analysis*, vol. 53(2), pp. 113–120, doi: https://doi.org/10.3103/S1068362318020061
38. Peniak, P., Bubeníková, E. and Holečko, P. (2024), “Generic model of IoT Edge device for object monitoring via LoRaWAN”, *IFAC Papersonline*, vol. 58(9), pp. 160–165, doi: https://doi.org/10.1016/j.ifacol.2024.07.389

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Метод розрахунку кількості сенсорів IoT в системах моніторингу довкілля

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Анотація. Актуальність. Швидке зростання екологічних загроз вимагає ефективних систем моніторингу довкілля. IoT-сенсори забезпечують безперервний збір даних у реальному часі. Правильний розрахунок кількості сенсорів підвищує точність та ефективність моніторингу. Надмірна кількість сенсорів збільшує витрати та енергоспоживання системи. Тому розробка підходу до визначення кількості сенсорів є критично важливою для оптимізації екосистеми IoT. **Предметом вивчення** в статті є методи визначення складу сенсорних мереж систем моніторингу довкілля. **Метою статті** є розробка методу визначення необхідної кількості сенсорів IoT підтримки системи моніторингу довкілля. Отримано **такі результати**. Визначена загальна структура системи моніторингу довкілля. Її особливістю є розбиття зони моніторингу на автономні ділянки. Кожна ділянка на протязі дії часового вікна обслуговується автономним кластером системи. Кластер має певну кількість однотипних каналів для прийому показань активних сенсорів IoT. Розроблена математична модель процесу передачі повідомлень про події. На базі моделі запропонований підхід до визначення середньої кількості успішно переданих повідомлень про одну подію. Даний показник обраний у якості критерія якості сенсорної мережі. Доведена приблизна формула для розрахунку необхідної кількості сенсорів у системі моніторингу. **Висновки.** Запропонований метод дозволяє швидко отримати необхідну кількість сенсорів IoT підтримки системи моніторингу довкілля. Відхилення розрахованого числа сенсорів від оптимального не перевищує 3%. Напрям подальших досліджень стосується зняття обмеження щодо повного охоплення зони моніторингу.

Ключові слова: Інтернет речей; комп’ютерна система; система моніторингу довкілля; кластер; сенсори IoT.