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Developing the Reconfiguration Method to Increase Life Expectancy of Dynamic Wireless Sensor Network in Container Terminal

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Abstract **– Nowadays control and management logistics solutions that are used in terminals apply sensor based technologies to identify and localize containers in the yard. Nevertheless, because of the limits in the existing sensor technical specification, the position of nodes is still affected by some errors or sometimes it cannot be determined in real-time systems due to battery fall.**

The sensor nodes pertaining to information storage and processing are mainly equipped with an uninterrupted power supply, independent distribution network connectivity and low performance computing system. The capacity of data traffic near a coordinator node is much higher than in the distant points; as a result, the existing elements close to processing nodes faster than others stop operating due to a lack of electricity and, as a result, the network ceases its overall work.

The article describes the modification of network routing protocols for energy balancing in nodes, using the mobility of the coordinator node, which provides dynamic network reconfiguration possibilities.

Keywords **– Industry 4.0, life expectancy, sensor network.**

I. Introduction

The traffic flow in ports and terminals is increasing continuously and this pushes the use of automated systems and advanced solutions in the area of logistics. Recurring needs include identification and tracking of containers, and their localization in the yard. Existing solutions for localization increase daily. Recently the number of systems that do not require human intervention in the system process (Industry 4.0) has increased.

According to the concept of the Internet of Things, by 2019 there will be more than a few trillion telecommunications devices connected in the World Wide Web [5], the majority of which will form the “thing” systems in accordance with the recommendation of the International Telecommunications Union Y.2069. For the telecommunications devices to be able to interact with each other or to operate following the user instructions, various sensor nodes, which are able not only to read information about the environment, but also to communicate with one another via network protocols, have been integrated into them.

Today’s technology allows anyone to reduce the size of the existing computing systems by creating an inexpensive, low-power autonomous system that makes it possible to use both physical and wireless networks in order to transmit information. This type of technology gained most of its popularity by receiving information from sensors as well as in the area of control systems. Networks that use low-power computing systems and also transmit data via wireless connection are known as wireless sensor networks whose main task is to obtain information from the sensors and transmit it within the network.

The differentiated energy consumption in hubs [11], [14] always appears in the operating sensor network; as a result, the existing elements close to processing nodes faster than others stop operating due to a lack of electricity and, as a result, the network ceases its overall work.

II. Related Research

Nowadays the topical research of a wireless sensor network based container monitoring systems use new network transmission protocol improvement [16], routing of transmission [11], and formation of the network structure [12], which makes it possible to increase the overall life expectancy of a wireless sensor network.

Modern technologies allow creating processors with low power consumption; as a result, the operation of the processor does not significantly influence the life cycle of the system. Mainly electricity is consumed through data transmission using both physical and wireless networks.

To level the energy consumed in all network nodes, a variety of energy balancing methods are used. Let us analyse some basic energy balancing techniques and approaches.

The structure of a heterogeneous network requires the use of various techniques in order to improve energy efficiency:

- The adjustment of battery capacity based on the location of the element in the network [7].
- Differentiated density of network node depending on the intended density of transmission in a particular area [8].
- Mainly routing protocols are used on the software level and they are based on the remaining power units in the nodes [4], the use of virtual coordinates [15], the alternation of long-range and short-range transmission [6], the positioning of nodes as well as the use of sets.

The use of mobility of network components is considered to be a prospective balancing method. In various studies [3], [13], authors have shown that the use of mobility is good for increasing the autonomous actions of a sensor network.

III. The Methods for Reconfiguring the Wireless Sensor Network

The primary task of the network reconfiguration method is to increase the time interval of the network topology change. In the particular case, it will be determined by the conditions, which will promote the creation of new network reorganisation at the beginning of each operating cycle.

The interaction process of the network topology changes methods and the algorithm consists of:

1. Network coordinator node management method. In a functioning system, there are some restrictions that do not allow preparing all the information required for assessing the life expectancy of a network.
2. In the phase of detecting the network configuration, the system determines the location of the coordinator.
3. In the case the coordinator is a dynamic algorithm of the network management operating module which will examine the need to modify the network configuration of the current iteration time, it will contribute to changing the network topology.
4. In case the coordinator is static or it is not possible to identify the location of the coordinator in the network, in order to increase the life expectancy of a network a virtual coordinator node has been introduced, which is managed through the heuristic method proposed in the paper.

A. The Management Method of the Dynamic Coordinator Node

The local area network module has been introduced which controls the conditions that promote the sensor network reconfiguration in the nodes:

1. The location of the coordinator changes.
2. A large difference of the remaining power in the network elements has been discovered.

The software module has two main tasks in the system:

- To ensure the collection and storage of the remaining amount of power in the nodes according to the specified step.
- To determine the period when it is necessary to carry out the reorganisation of the routing path.

The management part of the node module is multifunctional unlike the network sensor elements. Some module tasks can be executed simultaneously. Each executable cycle or condition is carried out as an independent operation. An action scheduler is cyclically operating in the node control module which regardless of the situation performs the set tasks in the network. This approach allows managing the operations of the control module as well as managing every executable process.

In the particular model, each of the network coordinator nodes has a local node management module that provides the interaction between the node and the network.

The initialization phase of the node management module is defined by the overall network node communication model Mi in accordance with (1).

$$Mi = \{Sa, Se, Sp, L, Sra\}, \quad (1)$$

where

Sa is a number of nodes;

$Sa = \{a_1, a_2, ..., a_n\}$ participating in the communication process;

Se is a number of sectors in the communication environment, in which certain operations are conducted;

Sp is a number of congested sectors in the network where the nodes consume the largest amount of energy;

L is the length of the path from the place of the coordinator to the node in the network;

Sra is a number of routing nodes in the path that the node control module will use in order to transmit information to the management node.

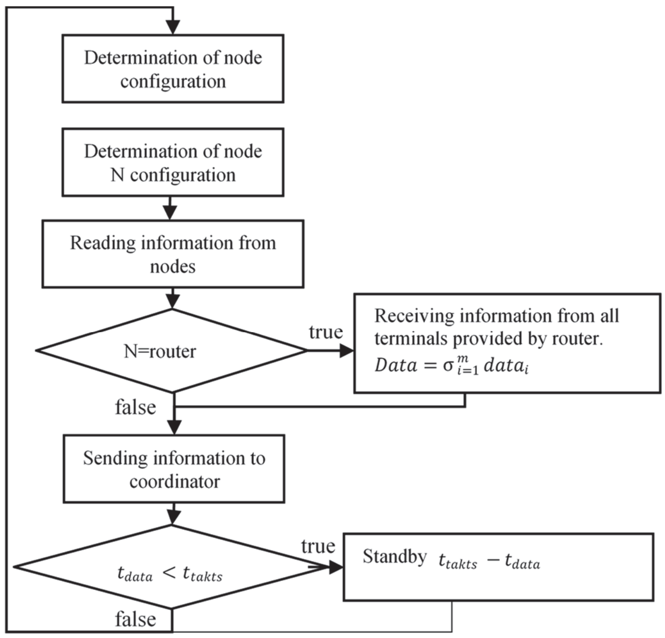

Fig. 1. The alternative operating algorithm of the network nodes.

When the node module is operating cyclically, the dependence on the node operational status has been determined in the intensity of the information between the nodes Mi.

Figure 1 shows that as a result of the use of the current algorithm it is possible to reduce the overall life expectancy of WSN because in a situation when the coordinator remains unchanged in the network $V(x, y) = V(x + 1, y + 1)$ or is located in the position $V(x,y)$ where there is only one possible network configuration $k \to \max(RiN)$ [9], the energy will be wasted on creating configuration; thus, the original topology will be created.

The introduction of the node management module in the network will improve network performance by reducing the load of the node during information processing; similarly, it will allow responding to the current changes in real time because the module operates independently of the state of node and the amount of energy.

B. Data Flow Control Method

An efficiently operating system is unable to obtain all the necessary information in order to determine the life expectancy of a wireless sensor network. Some network model base values, such as the capacity of the transponder may vary depending on the time which takes the system to remain active as well as the external environment which the system works in. Let us look at some examples where it is not possible to precisely define the required parameters for the network life expectancy assessment:

- There are technical difficulties that reduce the quality of the transmitted information in some network segments. This may be due to another network in the same region with similar or adjacent frequency. In this case, the need for a repeated transition of information is increased resulting in a significant increase in energy consumption in the sensitive area.
- The influence of the external climatic factors on the autonomous power supply can result in an increase of the power consumption in the standby mode.

For example, wireless sensor networks can be represented with the help of a directed graph. Based on the structure of the graph, each route (v, u) can be used for transmitting information from node v node u. Each of the v nodes has a defined amount of adjacent objects $N(v) \in V$ that may communicate with the node v. Whilst generating a route, the broadband data retransmission is used in the network [9], the information is transmitted from the node $N(v)$ to the entire network simultaneously.

The data flow handling algorithm in the network is described in this paper. After receiving the transmitted information from node S, which is designed to receive node D, node V uses the following sequence of actions:

1. The potential transponder set $R(v, d) \in Nv$ is selected and sorted by priority from the set $N(v)$.
2. The potential transponder set of nodes belongs to the set $R(v, d) \in Nv$ and determines the operating strategy of node v.
3. Information on the functionality of the node is recorded in the service of the transmission packet and distributed to the network management agent.

To determine the retransmission priority, it is important to take into account the remaining amount of energy in each individual node. The node control module selects a transponder with the greatest amount of remaining energy E_0 in the node. The route building algorithm completely concludes its operations once it has reached the recipient node d.

The paper states that each network element can operate in two modes (terminal or router). In order to split the task into the early stage of network reconfiguration, each node has to remain in listening mode. During the listening mode, the remaining amount of energy E_0n is assessed in the node.

The route of the wireless sensor network from the terminal S to the coordinator D – $S(s, d)$ takes the dendriform structure, which is built using the recursive approach from terminal to the coordinator. The first stage is defined by the possible network router set $R(s, d) \in N(s)$. This will allow describing the path $S(s, d)$ as the sorted sub-route list:

$$S(s, d) = [S(v_1, d), \dots, S(v_n, d)],\ vj \in R(s, d). \quad (2)$$

The next step is to set up the local action strategy $R(vj, d)$ for each router. As a result, each list of sub-routes can be improved:

$$S(vj, d) = [S(vj,1, d), \dots, S(vj, m, d)],\ vj,i \in R(vj, d). \quad (3)$$

The path from the terminal to the coordinator can be displayed as the dendriform list placed on the second level:

$$S(s, d) = [[S(v_1,1, d), \dots, S(v_1,m_1, d)], \dots, [S(v_n,1, d), \dots, S(v_n,m_n, d)]]. \quad (4)$$

When creating a route, the level is extended up until the router list contains only one coordinator D node. In this case, the segment of the sensor network is equipped with the only remaining coordinator node. Henceforth, it is to be assumed that the recipient node D (the coordinator) is fixed and will not be used in any formulas.

Let us introduce a way to combine paths. Let us suppose that $S(v)$ is the path from node V to the coordinator in the router list $R(v) = (v_1, v_2, \dots, v_n)$ where the node U does not exist. Also, supposedly, $S(u)$ is a path consisting of nodes $R(v)$ that have been excluded from the list.

Let us define the path that uses the combined list of $S(v) \in S(u)$ where nodes U are used with low levels of a factor, like this: $R(v) = (v_1, v_2, \dots, v_n, u)$.

In an operating system, the management module of a node has two functions:

- to provide the collection and storage of the remaining amount of energy in the nodes in the particular step tcn.
- to determine the period tcn when it is necessary to carry out the reorganisation of the routing path.

The node control module part is multifunctional unlike the network sensor elements. Some module tasks can be done simultaneously. Each executable cycle or condition is fulfilled as an independent operation. An action scheduler is cyclically operating in the node control module, which executes the set tasks within the network regardless of any situation. This approach allows coordinating the actions of the control module as well as managing every executable process.

In the proposed model, each network coordinator node has a local node management module that provides the interaction between the network and the node.

IV. The Use of the Dynamic Coordinator within a Network

Using actual wireless sensor network systems, there are some restrictions that do not allow collecting all the necessary information to identify model of a system:

- it is impossible to find out the precise actions of the network coordinator – whether it will stagnate or use the expected movement trajectory or location.
- The power pki consumed in the nodes can change over time.

It can be concluded that whilst a network is working there are situations when the physical coordinator node cannot be reached or it is not possible to establish a communication route between the sensor node and the coordinator. As a result, the energy consumption increases providing inefficient communication between terminal nodes and the coordinator. To increase the life expectancy of the network, a virtual coordinator node is introduced which moves in the network cyclically using the familiar motion trajectory.

Additional labels have been introduced for the controlling management of virtual coordinator:

$S(k)$ – a set of vertices containing the vertices k and their adjacent vertices:

$$S(k) = \{k\} \cup \{j: (k, j) \in Es\}. \quad (5)$$

$S(k)$ – the number of nodes, which are physically connected to the virtual coordinator node k and located in its vicinity:

$$D(k) = i \in Vn:(u, i) \in En(k), where\ u \in Vn - coordinator\ node. \quad (6)$$

In each step n, if the coordinator is located in any locationp_n, the next step is chosen from the list $S(p_n)$ based on the remaining amount of energy in the nodes p_{n+1}. If the network management module facilitates network topology change, according to the conditions described in the article, the coordinator changes its location. Being in a new location the virtual coordinator processes the information that the node contains by spending the amount of time t_s which is defined by the user. The key step of the algorithm is the selection of the next position p_{n+1}.

The sources have offered a variety of heuristic [1], [2], [10]. A random position choice of the possible list of positions is considered to be the simplest method: $p_{n+1} = random(S(p_n))$. Based on the modeling results performed by the authors [2], it can be seen that within most of the research scenarios the WSN life expectancy is increased compared to the fixed location of the coordinator. Despite the positive research results, this method is not recommended for use, since the transfer of the network coordinator by randomly determining the position does not guarantee any results and in some situations when the coordinator is located in the nodes where there is a low amount of remaining energy, the life expectancy will decrease.

The proposed method (placing the coordinator node on the network perimeter) allows loading the nodes where the remaining amount of energy is higher.

One of the authors [10] offers ensuring the relocation of the coordinator along the visible perimeter of a network. This approach is based on the fact that generally with an active network, the elements that are located in the network center have a lower amount of the remaining energy in the nodes.

The proposed method allows loading the nodes with a higher amount of the remaining energy by placing the coordinator node in the network perimeter.

In his works, Basagni proposes the usage of MRE (Maximum Residual Energy) [1] coordinator motion algorithm. The coordinator node determines the remaining energy in the adjacent nodes through the GMRE algorithm and selects a single node with the largest remaining amount of energy in it. In this case, the planning of the coordinator movements is linked to searching maximum remaining amount of energy in the nodes.

The article offers an alternative method. With each step a location p_n for the virtual coordinator should be selected in a way that the network can be active as long as possible provided that the network topology is not changed. By using an analogue, a new method (Maximum Residual Energy Maximal Lifetime) is defined.

$$Ek(t) = \arg\ (max k \in S(pn) min\ En(t), \quad (7)$$

where pkn is the total power consumed in an operating cycle of the node k.

The common energy consumption of a network node can be calculated or modified dynamically based on information received from sensor nodes. If the amount of time the coordinator spends in each of the positions of node k is equal to t_k and the remaining amount of energy in the nodes is known before the coordinator is in the certain position – $E_0^n(t)$, as well as the amount of energy in the node when the coordinator leaves its position $E_0^n(t + t_k)$, then the energy consumed by each of the nodes can be expressed by using the following formula:

$$pkn = E_0n(t) - tEk_0n(t+tk). \quad (8)$$

The method that is proposed in the article uses a management module of a network node and the dynamic coordinator node for storing information. In the case of network topology change, this approach allows receiving a global overview on the entire network configuration and for the virtual coordinator node to occupy the best position in order to gather information from the nodes.

V. The Simulation Modelling of Methods for Increasing the Life Expectancy of a Wireless Sensor Network

In order to perform the experimental approbation of methods for increasing the life expectancy of a wireless sensor network, the author proposes the following actions:

- Setting up the network topology in the wireless sensor network simulation software and dividing the constant values of the network.
- Experimentally comparing the effectiveness of methods for increasing the life expectancy of a wireless sensor network.

A. The Proposed Determination of Effectiveness of Methods for Increasing the Life Expectancy of Wireless Sensor Networks within Networks of Various Sizes

Table I shows the dependence of the network life time coefficient on the modelled network size. From the data obtained in the experiment, it can be concluded that by using the proposed method of increasing life expectancy, the increase of the life time coefficient depends on network size. This is based on the fact that by increasing the number of network nodes the difference between the energy consumed in the nodes increases. Using a network reconfiguration method, it is possible to increase the overall life expectancy of the network with the largest amount of energy difference between the nodes.

TABLE I
THE DEPENDENCE OF COEFFICIENT ΔT ON THE MODELLED NETWORK SIZE USING A VARIETY OF HEURISTIC METHODS

Number of nodes	MRE	RANDOM	MREML
10	20.1408	−30.5998	−16.0439
30	43.5082	−5.4268	−11.4561
50	62.6674	−0.4599	1.4793
70	88.7197	15.4599	23.4793
90	112.335	31.9885	40.2624
110	115.114	46.2421	54.7148
130	122.283	42.2984	62.8865

Using small-scale networks where the number of nodes is m < 50, there is a risk that the applied network methods for increasing life expectancy will lead to a reduction in life expectancy; the coordinator location will be created due to an inefficient network topology.

B. Modeling of Network Performance Routing Protocol Simulation

Figure 2 shows the remaining amount of energy of a network in three ways: static operation with constant coordinator location (Fig. 2a), casual activity, when the network topology is formed using randomly created network topology (Fig. 2b) and the method algorithm proposed in this paper (Fig. 2c) that is modelled using a number of network nodes $m = 150$.

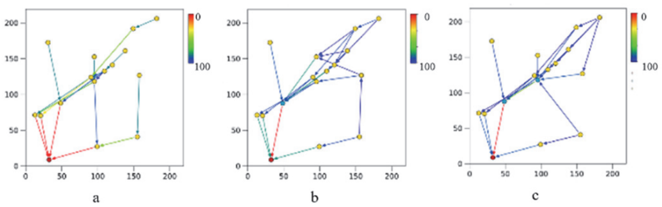

Fig. 2. The distribution of the remaining energy in network nodes.

Using a static coordinator location, there are locations in the network where the nodes barely use their energy and the network stops working; the remaining amount of energy in the nodes comprises 90 % of the initial amount of energy. While using the new network route generating possibility in each transmission cycle (RANDOM), it will be understandable that there is a balance in energy consumption. With the proposed methods of increasing the life expectancy of the network by using the moving coordinator it is possible to see that the amount of energy consumed is in disbalance except for the locations that are physically located in distant points throughout the network and during the operating time of a network have only sensor functions.

C. The Summary of Results Obtained during Simulation Modelling

Using the simulation modelling tool, the following results have been achieved:

1. With the dynamic coordinator node, the life expectancy is 27 % in relation to the standard model value of the fixed network topology.
2. Using small-scale networks where the number of nodes is $m < 50$, the proposed methods for increasing life expectancy of a network reduce the overall network life expectancy wasting energy for the network topology change.

VI. CONCLUSION

The aim of this paper has been to design methods for enhancing the planning stage of flow monitoring wireless sensor network in container terminals, for providing the necessary components of the appropriate network scenario and for increasing the overall life expectancy of a wireless sensor network.

In the network scenarios with the ability to modify the routing protocol, the use of modified Bellman-Ford and Dijkstra's algorithms is proposed for maintaining an optimal data flow route based on the increase of the criteria of a network life expectancy. The remaining amount of energy is defined as the most significant criteria for the choice of a path within a certain network node at the stage of iteration.

To avoid unnecessary network topology changes, particular conditions that determine the moment of the network structural changes are pointed out in the article.

As a result, the article proposes the methods for a wireless sensor network topology change that use the coordinator node of the network as the primary factor for the topology change in the network.

To reduce the amount of energy consumed in the nodes, the article proposes a method that anticipates the implementation of an independent software module of the network, which will control the state of each network node and promote the change of the network topology regardless of the form of action of the node. Accordingly, a low-power wireless set will be used as a means of communication, which will transmit technical information to the network agent manager.

In some cases, there might be situations when the physical coordinator node could not be reached or communication route could not be established between the sensor node and the coordinator; the alternative would be to use the virtual coordinator operated on the basis of adaptive heuristic algorithms.

REFERENCES

[1] S. Basagni, A. Carosi and C. Petrioli, "Controlled vs. uncontrolled mobility in wireless sensor networks: Some performance insights," in *IEEE 66th Vehicular Technology Conference*, Baltimore, MD, 2007, pp. 269–273. https://doi.org/10.1109/VETECF.2007.70

[2] D. M. Blough and P. Santi, "Investigating upper bounds on network lifetime extension for cell-based energy conservation techniques in stationary ad hoc networks," in *Proceedings of the 8th annual international conference on Mobile computing and networking. (MobiCom '02),* New York, NY, 2002, pp. 183–192. https://doi.org/10.1145/570645.570668

[3] C. A. Chestek, V. Gilja, P. Nuyujukian, R. J. Kier, F. Solzbacher, S. I. Ryu, R. R. Harrison and K. V. Shenoy, "HermesC: Low-Power wireless neural recording system for freely moving primates," *EEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 17, no. 4, pp. 330–338, Aug. 2009. https://doi.org/10.1109/TNSRE.2009.2023293

[4] Y. Chen and Q. Zhao, "On the lifetime of wireless sensor networks," *Communications Letters, IEEE*. vol. 9, no. 11, pp. 976–978, Nov. 2015. https://doi.org/10.1109/LCOMM.2005.11010

[5] S. E. Collier, "The Emerging Enernet: convergence of the smart grid with the Internet of Things," in *2015 IEEE Rural Electric Power Conference (REPC)*, Asheville, NC, 2015, pp. 65–68. https://doi.org/10.1109/repc.2015.24

[6] H. Miranda, V. Gilja, C. A. Chestek, K. V. Shenoy and T. Meng, "A high-rate long-range wireless transmission system for multichannel neural recording applications," in *2009 IEEE International Symposium on Circuits and Systems*, Taipei, Taiwan, 2009, pp. 1265–1268. https://doi.org/10.1109/iscas.2009.5117993

[7] S. Halder, A. Ghosal, A. Chaudhuri and S. DasBit, "A probability density function for energy-balanced lifetime-enhancing node deployment in WSN," in *Proceedings of the 2011 International Conference on Computational Science and Its Applications, ICCSA'11* (Lecture Notes in Computer Science), Berlin, Heidelberg: Springer-Verlag, 2011, pp. 472–487. https://doi.org/10.1007/978-3-642-21898-9_40

[8] I. S. Hammoodi, B. Stewart, A. Kocian, S. McMeekin, "A comprehensive performance study of OPNET modeler for ZigBee wireless sensor networks," in *2009 3rd International Conference on Next Generation Mobile Applications, Services and Technologies, NGMAST '09*, Cardiff, Wales, 2009, pp. 357–362. https://doi.org/10.1109/ngmast.2009.12

[9] A. Jurenoks and L. Novickis, "Wireless sensor network live circle simulation tools to balance energy consumption in the network nodes," in *Proceedings of 29th European Simulation and Modelling Conference (ESM 2015)*, Leicester, UK, 2015, pp. 245–249. ISBN 978-9077381-908.

[10] R. Mautz and S. Tilch, "Survey of optical indoor positioning systems," in *2011 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, Guimaraes, 2011, pp. 1–7. https://doi.org/10.1109/ipin.2011.6071925

[11] G. Miezītis, V. Zagurskis and R. Taranovs, "Multiple mobile gateways in wireless sensor networks," *Technologies of Computer Control*, vol. 13, pp. 38–42, 2012.

[12] P. Munz, I. Hudea, J. Imad R. Smith, "Mathematical modelling of network structure," in *Proceeding in the Infectious Disease Modelling Research Progress*, 2009, pp. 133–150. ISBN 978-1-60741-347-9.

[13] R. Harrison, R. Kier, C. Chestek, V. Gilja, P. Nuyujukian, S. Ryu, B. Greger, F. Solzbacher and K. Shenoy, "Wireless neural recording with single low-power integrated circuit," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 17, no. 4, pp. 322–329, Aug. 2009. https://doi.org/10.1109/TNSRE.2009.2023298

[14] R. Taranovs, V. Jesilevskis, G. Miezītis, D. Bļizņuks, Ē. Kļaviņš, A. Kalniņš and V. Zagurskis, "An approach for meeting room activity monitoring and analysis," *Technologies of Computer Control,* vol. 15, pp. 63–68, 2014. https://doi.org/10.7250/tcc.2014.009

[15] S. S. Baskakov, "Issledovanie sposobov povyšenija èffektivnosti maršrutizacii po virtualnym koordinatam v besprovodnyh sensornyh setjah," *Vestnik MGTU im. N. È. Baumana. Ser. Priborostroenie*, no. 2, pp. 112–124, 2009.

[16] M. M. Komarov and L. S. Voskov, "Pozicionirovanie datčikov besprovodnoj seti kak sposob ènergosbereženija," *Datčiki i sistemy*, no. 1, pp. 34–38, 2012.

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