Modeling the Mobile Signal Transmission Network of Earth-Moving and Construction Machines' Sensors

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Abstract. In this paper, the problem of performing distributed computations in signal transmission mobile network of earth-moving and construction machines' sensors is investigated. Distributed computing was performed within this mobile network. A new definition of distributed computing has been developed within this mobile network, which allows you to explore this sensor network in terms of sensors power consumption in the case of possibility to recharge the nodes from the environment.

The model of this mobile network was obtained. This model allows to estimate the power consumption by nodes of sensor network, depending on changing characteristics of the network.

Keywords: Mobile network · Sensors · Signal transmission
Earth-moving and construction machines

1 Introduction

As the result of research carried out by the authors [1–7], the structure of an automated control system of work of earth-moving and construction machines was developed. At the same time, authors have considered various aspects of the implementation of such system to automate digging, transportation and unloading processes. However, the issues of transmitting signals from sensors installed on earth-moving and construction machines have not been studied before. The use of wire connections between sensors and the controller of machine is unacceptable due to the constant movement of machine moving parts (bucket, boom, etc.). Work [8] is an example of moving parts in the theory of machines and mechanisms. Therefore, the use of a mobile network as the transmitting medium is the only correct solution.

Over the past few years, continuous progress in mobile communications has opened up new research areas in the field of mobile networks aimed at increasing access to data networks in environments where wired solutions are virtually impossible. For example, work [9] deals with Vehicular Ad-hoc Networks (VANET) modeling. The authors

M. Younas et al. (Eds.): MobiWIS 2018, LNCS 10995, pp. 86–98, 2018.
https://doi.org/10.1007/978-3-319-97163-6_8

presented «VanetMobiSim» , a freely available generator of realistic traffic paths for network simulators. The article [10] provides information of the computer simulation results for determining technical characteristics of fractal antennas used to transmit information in mobile networks.

The research and development of new sensor types for various devices with wireless data transmission are being actively conducted. For example, wireless sensor Vibration Energy Harvester (VEH) [11]. VEH is designed to be installed on rotating parts, for example, on train wheels, and performs several functions: measuring the temperature, transferring the measured data to the operator, generating the necessary electric energy from mechanical vibrations. According to the information from developers, VEH does not require additional maintenance, and is ideal to be installed in train wheels, as in addition to borrowing energy, the sensor instantly captures the critical temperature rise in the bearings. This helps to prevent major repairs.

And in work [12] the wireless switch "Cherry Energy Harvesting Wireless Switch" which produces the electric power, sufficient for transfer a turn on signal or short retransmission is offered. The distance to which the signal can be transmitted due to the generated energy depends on the operating frequency. For transmission at 10 m, the frequency is 2.4 GHz, for transmission at 300 m, the frequency is 868 MHz. The power generated by pressing the button can reach 0.5 mW. As an additional feature of the "Energy Harvesting Wireless Switch", one can be a work in wireless sensor networks (for this purpose, a unique identifier that eliminates erroneous operations is implemented in the switch), as well as a "pairing" function that allows several switches to be used for one receiver or vice versa.

At the same time, Energy Harvesting technology need to be given special attention, since this technology allows sensors to operate autonomously. Autonomy is achieved due to low power consumption and independent electricity generation on account of mini solar panels, vibration process or like ones. The main methods of the "Energy Harvesting" are based on converting light energy, kinetic energy and energy of the temperature difference between the environment and the heat source into electrical energy. For example, a wireless sensor network node with extremely low power consumption, which borrows and converts solar energy, thereby demonstrating that such a solution is convenient for wireless sensor network applications [13]. Borrowing the energy of the environment in a wireless network is especially important if a node battery is difficult to replace or it have a high cost. A node that borrows solar energy performs monitoring and supports wireless interface functions at levels requiring low power consumption. The presence of an additional input source makes it possible to take energy from other alternative energy sources (radio frequency radiation, vibrations, etc.) at step of energy management, in case if solar batteries are discharged or can't be accessed at the moment. The interaction of data networks is discussed in detail using the example of modeling using the NetCracker 4.1 program [14].

However, the development of mobile networks to automate the work of earth-moving and construction machines with data transfer from sensors to controllers, was not considered in the literature.

The analysis and review of the literature made it possible to simulate the mobile network for sensors signal transmission of earth-moving and construction machines.

2 Materials and Methods

Agent-based modeling is well suited to simulate the concept of such mobile network [15]. Agent-based modeling can be defined as a special case of simulation modeling, which focuses on the study of the global system state, depending on a behavior of agents which are system components. In the case of a mobile network for sensors signal transmission, a similar approach is observed, as network nodes are distributed throughout the territory, actively interact with the environment and neighboring nodes, and a behavior and technical characteristics of an individual network node affect the network performance. In the case of traditional simulation, the simulated system is considered as a linear aggregate of passive elements in the general process, and the elements' behavior is pre-established. In the case of discrete-event approach, attention is given to a particular process that is already considered nonlinearly, the stages of a particular process are analyzed.

In the case of agent-based modeling, each network component has its own behavior scenario, which affects the task quality. Thus, agent modeling is a convenient approach for describing systems consisting of components whose behavior is ambiguous and depends on many factors.

To perform the simulation, Matlab was used - a high-level programming language and the same name environment for modeling, scientific and engineering calculations, which is based on the interpreter of the native language Matlab. The algorithms implemented in Matlab, for the most part, use vectors and matrices to handle large amounts of data.

The availability of specialized tools (processing of big data, the ability to operate with neural networks) is the main reason for choosing Matlab as a tool for modeling distributed computing in mobile network for sensors signal transmission of earthmoving and construction machines.

Nodes in sensory zones are unevenly distributed. There are nodes with large number of sensors. And there are nodes with 1–2 sensors.

In this case, the simulated system is the set of nodes of mobile network, the environment in which they are located, the scenario of their behavior, the goal to be achieved by the simulated system in the course of its work.

Simulation is carried out in order to determine the advisability of organizing distributed computing in our mobile network. For this, it is necessary to simulate the system with the absence and support of distributed computing and to perform the comparative analysis of the results obtained.

The control method of the mobile network for sensors signal transmission of earthmoving and construction machines was developed on the basis of neural networks, taking into account the Energy Harvesting technology, which, through specially built-in modules for the sensor network, allows to transform various types of renewable energy into electrical one to recharge network nodes from the environment. "Energy Harvesting technology" is to collect variety of energy from the environment and converting it into electrical energy to power the autonomous miniature devices. Any natural and physical processes and phenomena - from sunlight to any mechanical vibrations can be used as energy source [16]. The developed work algorithm of our mobile network is based on the mathematical apparatus of theory of automatic control "Neural Networks" section and supplemented with the possibility of "Energy Harvesting".

In mobile network model, being developed, a node is considered as an in-dependent intellectual object that changes its state depending on changes in the parameters of the unit itself or environmental parameters. At first sight, it would be ideal to imagine a network consisting of this type of nodes, in the form of a finite automaton. But to solve the problem of controlling transitions between possible states of a node, the method of neural networks is chosen, that is, another abstraction of the description of the technical object behavior.

Subjectively, the method of neural networks is more convenient, since errors are possible during development, since the automatic design of the FSM (Finite state machine) provides the developer with more free description of the technical object behavior. While the solution of the task using neural networks is reduced to the problem of classifying an arbitrary combination of input data in accordance with a set of states similar to FSM.

Let's describe the model, compiled using the object-oriented language Java [17].

Input data:

- size of earth-moving and construction machine;
- node count in earth-moving and construction machine;
- node distribution law;
- initial energy reserve of nodes;
- Constants for calculating formulas in accordance with the protocol;
- transmitter and receiver parameters.

Output data (being measured in the network, in addition to the values of sensors themselves):

- value of energy remaining on network nodes;
- transmitted packets count;
- number of nodes whose energy was exhausted before the claimed number of work rounds was expired.

Functions:

- input data initialization;
- creation, training of a neural network;
- initialization of the mobile network;
- node parameters analysis;
- choice of state for each network node.

The network nodes independently choose one of four states: computer, receiver, transmitter, scavenger, depending on current parameter values of nodes of the mobile network. The node parameters, depending on the current state, are stored on the node as attributes of selected class. Depending on the selected state, one of the attribute blocks is activated, and the remaining blocks are blocked. The choice of the node state at the current time is made by the method of neural networks, depending on the node parameters at the current moment and the parameters of the task that requires calculations.

After completing the training, the sensor network will independently select the parameters in accordance with the possible energy from the environment and the requirements of the task at any given time.

3 Results

The class diagram of wireless network model with support for distributed computing was developed (Fig. 1).

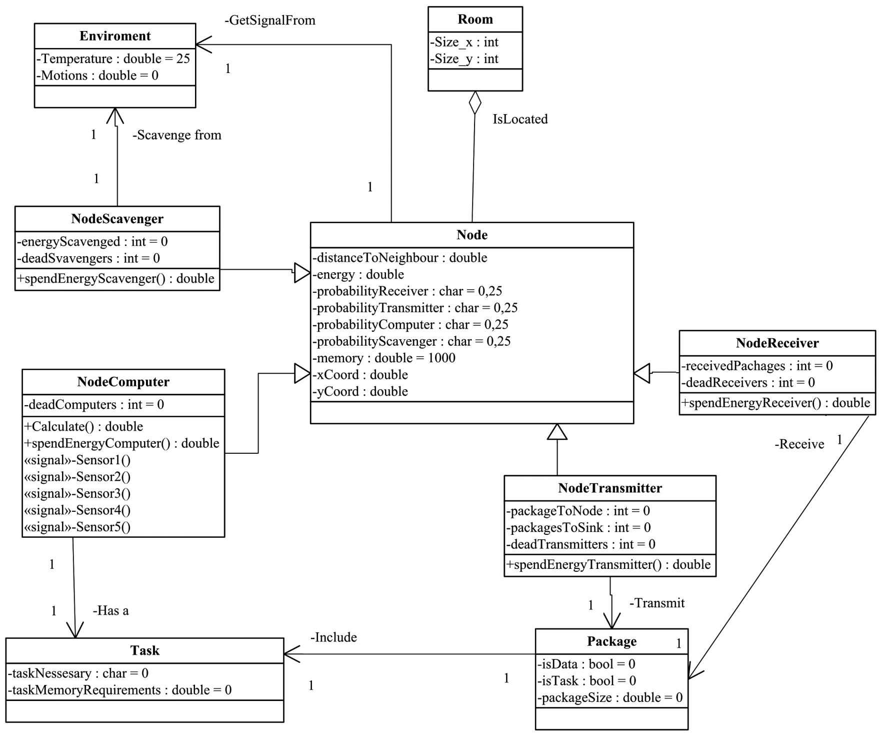

Fig. 1. Class diagram of wireless network model with support for distributed computing

According to Fig. 1, the base class is the Node class. Extended classes NodeScavenger, NodeComputer, NodeReceiver, NodeTransmitter enter into the generalization relationship with the base class Node.

The environment in which the node is located is indicated by the Room and Enviroment classes and is related with the Node class. We can say that the Room class includes several nodes and, thus, enters into the aggregation relationship with the Node class. The Enviroment class interacts with both NodeScavenger class (in the charging process) and with Node class (in the process of data collection by the node sensors).

The Task class enter into the association relationship with NodeComputer class and the Package class. The Task class is typical only for the NodeComputer state, since the calculation of the task is unacceptable when the node is in other states (it is impossible to charge the node when it is not in the NoseScavenger state). The association relationship with the Package class is explained by the fact that the task itself is transmitted over the network in the broadcast packet structure.

The Package class enters into the association relationship only with the NodeReceiver class and NodeTransmitter class, because, in one of these states, the node can receive or transmit data packets.

Mathematical modeling of the task was carried out. The parameters for calculating the power consumption are given in Table 1 and are constant. These parameters are used to calculate the energy consumption in the LEACH (Low Energy Adaptive Clustering Hierarchy) protocol [18], with which the comparison is made. The calculation of the energy consumption takes place using formula (1), according to which the current value of energy is reduced by an amount depending on the distance parameter. The distance parameter, in turn, varies depending on the nodes location according to formula (2).

$$Node(i).Energy = Node(i).Energy - ((ETX + EDA)(4000)Emp * 4000 * (distance * distance * distance * distance)) \tag{1}$$

$$distance = \sqrt{(Node(i).xd - Node(n+1).xd)^2 + (Node(i).yd) - (Node(n+1).yd)^2} \tag{2}$$

Table 1. Data for calculation of energy consumption, being inputted at the simulation

Parameter	Data
ETX	50*0.000000001;
ERX	50*0.000000001
Efs	10*0.000000000001
Emp	0.0013*0.000000000001
EDA	5*0.000000001

In the process of studying the developed model, it is planned to change the following input parameters in order to reveal the trend in energy consumption by the network:

- node density;
- node count;
- number of work rounds.

For example, the location and density of nodes can vary. In Fig. 2, there are 9 nodes, in Fig. 3 there are 40 nodes. These Figures show the distance in meters and the location of the nodes on abscissa and ordinate axes for two different types of earth-moving machines.

It is proposed to study and compare the proposed method on the basis of neural networks and the existing LEACH protocol by evaluating the following output characteristics:

- total values of energy, remaining at network nodes, depending on changing input parameters;

- number of nodes whose energy was exhausted before the claimed number of work rounds was expired.

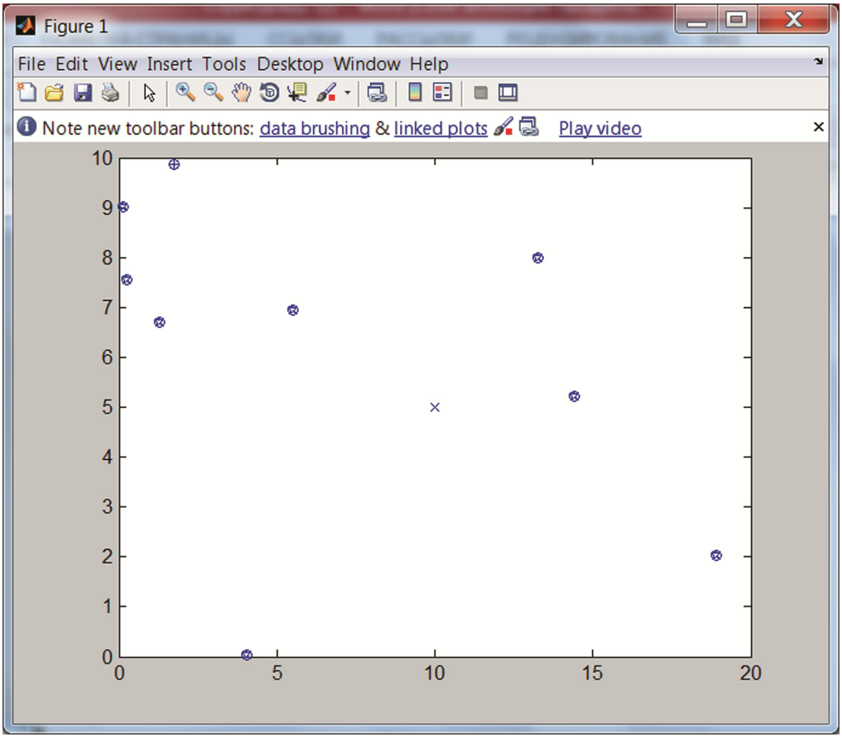

Fig. 2. The nodes location of sensor network for n = 9

After the simulation of our mobile network, the following results were obtained:

1. dependence of residual energy on the number and density of nodes;
2. dependence of residual energy on the number of work rounds.

In the first item, the variable parameter is the node count of simulated network, with the unchanged size of machine, where they are. That is, the increase in the density of the sensor network nodes is investigated. Also, depending on the number of nodes, the quantitative ratio between nodes of different types (NodeScavenger, NodeReceiver, NodeTransmitter, NodeComputer) varies, therefore the data of energy consumption is changing.

The results obtained are given in Table 2, to which the graph in Fig. 4 corresponds.

Method 1 - the method to be developed with the support of distributed computing. Method 2 - the method based on the LEACH protocol without the support of distributed computing.

Based on the results obtained in Table 2 and Fig. 4, it can be concluded that with an increase in the number of nodes of the sensor network that can be recharged from the environment, the amount of energy on the nodes of the sensor network, that remains after the expiration of the claimed number of work rounds, is increasing. That is, in terms of energy efficiency, it is advantageous to increase the density of the nodes of the sensor network.

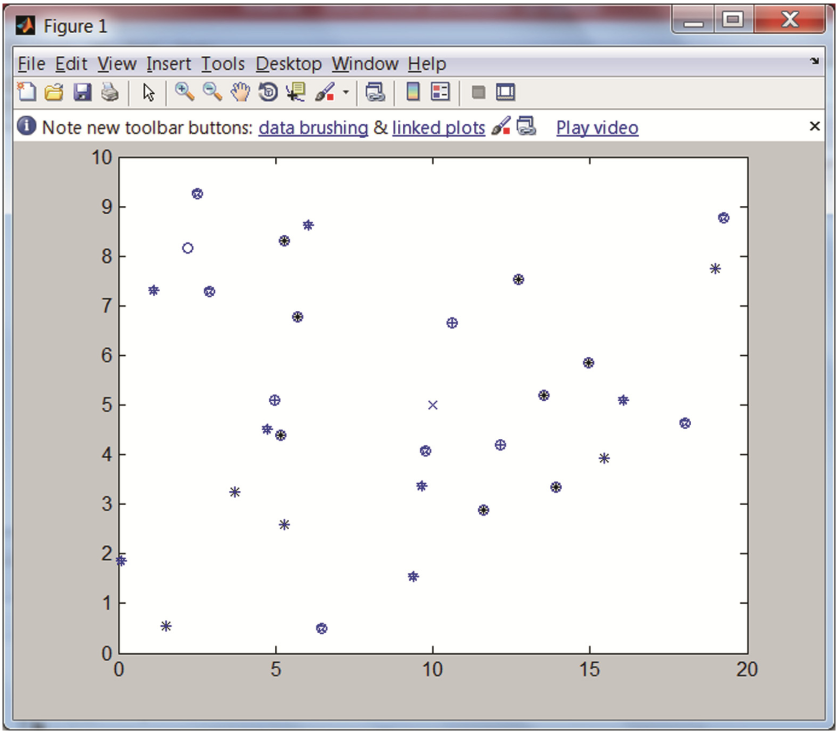

Fig. 3. The nodes location of sensor network for n = 40

In the second item, the variable parameter is the number of rounds of the simulated network with an unchanged number of nodes. That is, the energy consumption depending on its operation time is studied. It would be logical to assume that with increasing rounds, the network will expend more energy. But it is necessary to investigate how much the availability of the possibility of borrowing energy from the environment effects energy consumption, and also to compare the values of the residual energy in compared approaches.

For this, let us consider two methods. Method 1 - the method to be developed with the support of distributed computing. Method 2 - the method based on the LEACH protocol without the support of distributed computing.

The results suggest that with an increasing the number of work rounds of the sensor network and the availability of energy borrowing, energy consumption is decreases, and when this number reaches 400–500 rounds, energy consumption increases. This is evidenced by dependence graph of residual energy at the network nodes from the number of work rounds. That is, the result obtained differs from expected one.

Table 2. Results of the study on dependence of network power consumption on the density of the nodes location

	Node count	9	15	20	25	30	40	45
Method 1	Residual energy, J	29,46	46,08	62,08	79,42	98,9	130,5	148,8
	«Dead» nodes	0	0	0	0	0	0	0
Method 2	Residual energy, J	9,204	15,94	20,65	26	30,62	41,08	46,61
	«Dead» nodes	0	0	0	0	0	0	0

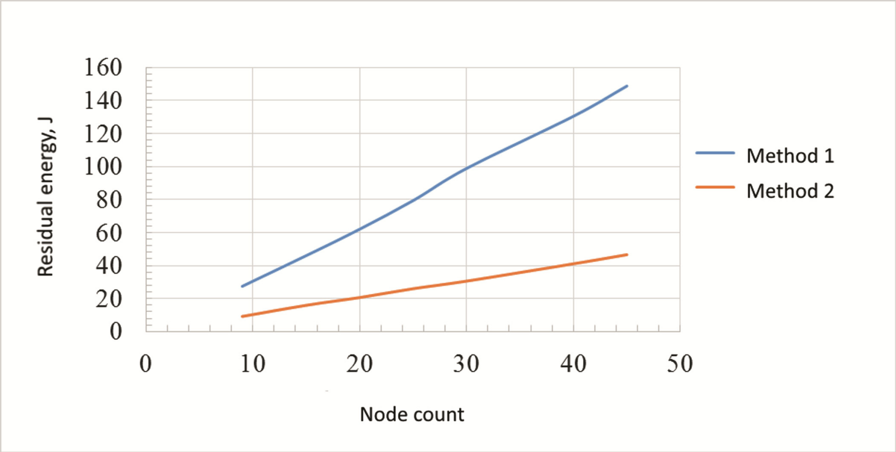

Fig. 4. The dependence of the network power consumption on the density of the nodes location.

It is interesting to note that after reaching the number of rounds of 100, the increase in the gain in energy consumption slows down (Fig. 5).

Thus, from the point of view of energy efficiency, it is advantageous to increase the number of rounds to just about 350.

The results obtained are shown in Table 3 and in Figs. 5and 6.

Table 3. The results of the study on the dependence of the network energy consumption on the number of rounds

	Number of rounds	15	25	50	100	200	300	400
Method 1	Residual energy, J	64,94	75,25	95,96	116,27	121,07	122,58	121,92
	«Dead» nodes	0	0	0	0	0	0	0
Method 2	Residual energy, J	20,06	22,75	30,84	56,72	190,65	649,48	2196
	«Dead» nodes	0	0	0	0	0	0	0

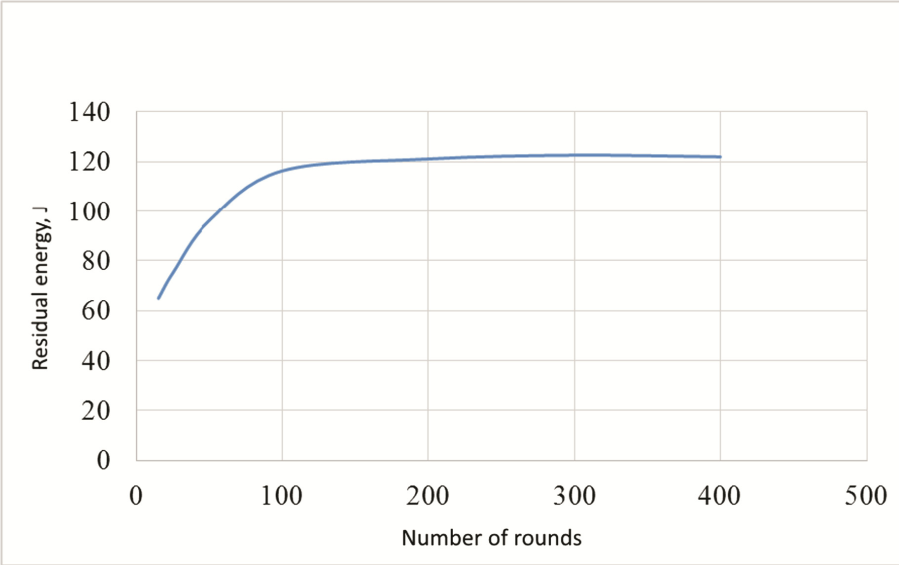

Fig. 5. The graph of the dependence of the network power consumption on the number of rounds for Method 1

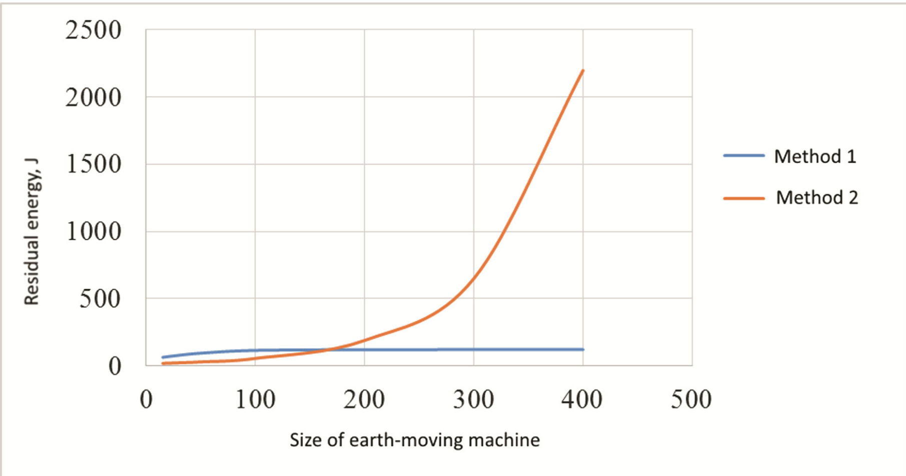

Fig. 6. The graph of the dependence of the network power consumption on the size of earth-moving machine.

The results of research, presented in Fig. 6, shows that method 2 (without the distributed computing support, based on the LEACH protocol) is not suitable for simulation the big size earth-moving machines, such as, for example, a multibucket excavator. Method 1 (with the distributed computing support) gives an adequate result for any size of earth-moving machine, allowing the data transfer without additional power consumption.

4 Conclusion

Thus, it can be concluded that the network model being developed contains data transfer nodes that interact primarily with each other, rather than with the server of the central dispatch room for control the work of earth-moving and construction machines, and send data without the participation of coordinator.

Research in this and related areas is mainly carried out to develop the most energy efficient routing protocols, which seek to solve the problem of uneven power consumption by network nodes. All energy efficient protocols use dynamic reconfiguration of network topology. The proposed method also uses dynamic reconfiguration, since the state in which each node of the sensor network is located varies over time, and this change affects the network state.

In the paper, the problem of urgency of executing distributed computations in a mobile network for sensors signal transmission of earth-moving and construction machines is investigated. The implemented model with the support of distributed computing, within the framework of the experiment simulation, has limitations that relate to the physical part of data transmission. In further studies, additional attention needs to be given to improving the model of the mobile network for signal transmission.

As a result of the research, the following conclusions can be drawn. Current energy-efficient protocols for sensor networks do not take into account the charging of the sensor network nodes from the environment. A new definition of distributed computing within the mobile network for sensors signal transmission of earth-moving and construction machines has been developed, which allows to explore this sensor network in terms of energy consumption in case if nodes can be recharged from the environment. The model of the mobile network for sensors signal transmission of earth-moving and construction machines which allows to estimate the energy consumption by the nodes of the sensor network, depending on the changing characteristics of the network was obtained.

References

1. Golubeva, T., Pokussov, V., Konshin, S., Tshukin, B., Zaytcev, E.: Research of the mobile CDMA network for the operation of an intelligent information system of earth-moving and construction machines. In: Younas, M., Awan, I., Holubova, I. (eds.) Mobile Web and Intelligent Information Systems. MobiWIS 2017. LNCS, vol. 10486, pp. 193–205. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-65515-4_17
2. Golubeva, T., Konshin, S.: Improving of positioning for measurements to control the operation and management of earth-moving and construction machinery. In: 13th International Conference on Remote Engineering and Virtual Instrumentation (REV), 24–26 February 2016, pp. 112–115. IEEE, UNED, Madrid, Spain (2016). https://doi.org/10.1109/REV.2016.7444450. 978-1-4673-8245-8/16/$31.00
3. Golubeva, T., Zaitsev, Y., Konshin, S.: Research of 3G-324 M mobile communication protocol in the management and control system of work of earth-moving machines and data transfer. In: 2016 10th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP), 20–22 July 2016, pp. 1–3. IEEE, Prague (2016). https://doi.org/10.1109/CSNDSP.2016.7573995. WOS:000386781300099

4. Golubeva, T., Zaitsev, Y., Konshin, S.: Research of electromagnetic environment for organizing the radio channel of communication of operation control system of earthmoving and construction machines. In: 19-th International Symposium on Electrical Apparatus and Technologies (SIELA 2016), 29 May–1 June 2016, pp. 1–4. IEEE, Bourgas (2016). https://doi.org/10.1109/SIELA.2016.7543006. WOS:000382936800035
5. Golubeva, T., Konshin, S.: The research of possibility of sharing use of wireless and mobile technologies for organizing the radio channels of operation control system of earthmoving and construction machines. In: 2016 International Conference on Intelligent Networking and Collaborative Systems (INCoS), 7–9 September 2016, pp. 9–14. IEEE, Ostrava (2016). https://doi.org/10.1109/INCoS.2016.24. WOS:000386596100002
6. Golubeva, T., Zaitsev, Y., Konshin, S.: Research of WiMax standard to organize the data transmission channels in the integrated control system of earth-moving machines. In: 2016 17th International Conference of Young Specialists on Micro/Nano Technologies and Electron Devices (EDM), June 30–July 4 2016, pp. 91–95. IEEE, Erlagol (2016). https://doi.org/10.1109/EDM.2016.7538701. WOS:000390301500024. Electronic ISSN: 2325-419X
7. Golubeva, T., Zaitsev, Y., Konshin, S.: Improving the smart environment for control systems of earth-moving and construction machines. In: 2016 IEEE 4th International Conference on Future Internet of Things and Cloud (FiCloud), 22–24 August 2016, pp. 240–243. IEEE, Vienna (2016). https://doi.org/10.1109/FiCloud.2016.42. WOS:000391237900034. ISBN: 978-1-5090-4053-7
8. Ivanov, K., Tultayev, B., Balbayev, G.: A single speed (CVT) transmission. In: Joint International Conference of the 12th International Conference on Mechanisms and Mechanical Transmissions, MTM 2016 and the 23rd International Conference on Robotics, Robotics 2016, Aachen, Germany, 26–27 October 2016, vol. 46, pp. 125–131. Mechanisms and Machine Science (2017). https://doi.org/10.1007/978-3-319-45450-4_13. ISSN: 2211098, ISBN: 978-331945449-8
9. Harri, J., Fiore, M., Filali, F.: Vehicular mobility simulation with VanetMobiSim. Simul. Trans. Soc. Model. Simul. Int. **87**(4), 275–300 (2011). https://doi.org/10.1177/0037549709345997. WOS:000289161600001. ISSN: 0037-5497
10. Solochshenko, A.V., Kulikov, A.A., Satimova, Y.G., Rutgayzer, O.Z.: The study of influence of changes of fractal antennas forms during using affine “compression” transformation on its characteristics. Int. J. Appl. Eng. Res. **12**(1), 7–10 (2017). ISSN: 09734562
11. Lee, O.B., Ket, T.C., Keat, Y.C., Aziz, R.A.: Applications of vibration-based energy harvesting (VEH) devices. In: Biologically-Inspired Energy Harvesting through Wireless Sensor Technologies, pp. 1–26 (2016). https://doi.org/10.4018/978-1-4666-9792-8.ch001. ISBN: 978146669792?
12. Cherry – Energy -harvesting wireless switches for industrial applications, 10 July 2015. https://www.electropages.com/2015/07/cherry-energy-harvesting-wireless-switches-industrial-applications/
13. Silicon Labs Energy Harvesting Applications // Silicon Labs Home page. www.silabs.com/energy-harvesting/
14. Yakubova, M., Serikov, T.: Development and imitating modeling in the developed network consisting of several knots removed among themselves on NetCracker 4.1. In: 2016 17th International Conference of Young Specialists on Micro/Nanotechnologies and Electron Devices (EDM), June 30–July 4 2016, pp. 210–213 (2016). https://doi.org/10.1109/EDM.2016.7538726. Electronic ISSN: 2325-419X
15. Macal, C.M., North, M.J.: Agent-based modeling and simulation. In: Proceedings of the 2009 Winter Simulation Conference, pp. 86–98. IEEE (2009). 978-1-4244-5771-7/09/$26.00 ©2009

16. Hagerty, J., Helmbrecht, F., McCalpin, W., Zane, R., Popovic, Z.: Recycling ambient microwave energy with broad-band rectenna arrays. IEEE Trans. Microw. Theory Tech. **52**(3), 1014–1024 (2004). https://doi.org/10.1109/TMTT.2004.823585
17. Hilton, A.D., Duvall, R., Rodger, S.H., Astrachan, O.: Programming Foundations with JavaScript, HTML and CSS. https://www.coursera.org/specializations/java-programming
18. Sarr, Y.M., Sarr, C., Gueye, B.: Reduction of single clusters in LEACH protocol for wireless sensor. Open Access Libr. J. **2**(e2251), 1–8 (2015). https://doi.org/10.4236/oalib.1102251