Представлена нова концепція функціонування протоколу LEACH, використаного для самоорганізації вузлів в мобільній мережі. Великим недоліком функціональності вузлів бездротової сенсорної мережі при використанні LEACH протоколу є високе споживання енергії в процесі самоорганізації. Концепція нової функціональності знижує витрату заряду акумулятора, що передбачає більш тривале збереження енергії

Ключові слова: бездротова сенсорна мережа, LEACH, протоколи самоорганізації, вузол, кластерне дерево

Представлена новая концепция функционирования протокола LEACH, использованного для самоорганизации узлов в мобильной сети. Большим недостатком функциональности узлов беспроводной сенсорной сети при использовании LEACH протокола является высокое потребление энергии в процессе самоорганизации. Концепция новой функциональности снижает расход заряда аккумулятора, что предусматривает более длительное сохранение энергии

Ключевые слова: беспроводная сенсорная сеть, LEACH, протоколы самоорганизации, узел, кластерное дерево

UDK 004.72
DOI: 10.15587/1729-4061.2015.51202

ANALYSIS OF A NEW MODEL OF LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY PROTOCOL IN THE WIRELESS SENSOR NETWORK

V. Mosorov
Doctor of Technical Science*
E-mail: volodymyr.mosorov@p.lodz.pl
S. Biedron
Postgraduate student*
E-mail: SBiedron@wpia.uni.lodz.pl
T. Panskyi
Postgraduate student*
E-mail: panskyy@gmail.com
*Institute of Applied Computer Science
Lodz University of Technology
Stefanowskiego str., 18/22, Lodz, Poland, 90-924

1. Introduction

Wireless sensor networks are mostly built from a large number of nodes. A typical node within a wireless sensor network is comprised of a radio transmitter/receiver, memory module, microprocessor and battery or another source of energy. Sensor network nodes can be equipped with various types of sensors, which cause them to play different roles. This type of network can be used to monitor changes in the weather, patient condition, or even observe deformations or vibrations in the construction industry, where such a network may become an early warning system [1]. This would provide the potential to prevent disasters and accidents, as well as to improve the design and technology. One significant limitation on the use of large-scale wireless data transmission is the still relatively high cost of wireless measurement modules and the fear of interferences, signal fading, and interferences from other wireless networks. Nevertheless, the increasing range of wireless modules and transmission technologies already enable their application for the purpose of controlling machinery and technological devices both on an industrial shop floor and in the field.

In this article the modified model of low energy adaptive clustering hierarchy protocol in sensor network is presented. Modified LEACH protocol allows reducing the battery charging time and increases the nodes operating time, which in turn improves the reliability and availability of wireless sensor network.

2. Analysis of published data and problem statement

Nowadays the technological development of wireless sensors in sensor networks occurs very rapidly. These networks are a special group of distributed measurement systems that are increasingly used to observe environmental factors for civilian or military [2]. These observations are made possible by the cooperation of all nodes. Functionality of such a network, you could observe in the exchange of information between the nodes. This type of network can be used to observe weather changes, measure the health of the patient, and above all in the administration of deviations from the norm or administration vibration in industrial buildings where the network can find its use as an early warning system before the disaster or an accident [3, 4]. Development of the network would improve the design and increase the safety of the construction industry [5].

Since the introduction of the LEACH protocol [6, 7] a lot of its modifications had been created. There are some LEACH modifications which had been created for increasing the influence on a larger energy efficiency and speed of self-organizing nodes. It was created among others LEACH Protocol with Two Levels Cluster Head where a solution with the two-level node connection into clusters had been presented. In publication regarding the Secure Low Energy Adaptive Clustering Hierarchy Protocol (sLEACH) [8] is illustrated how to ensure the safety in protocols. The developers of a Multi-Hop Low Energy Adaptive Clustering Hierarchy Protocol (MH-LEACH) [9] presented a method for

jumping information transmitting from the nodes to the center of data collection. In publication regarding the Advanced Low Energy Adaptive Clustering Hierarchy Protocol (AD-LEACH) [10] more complicated variant of the protocol LEACH, taking into account the functionality previously not implemented in other methods has been presented.

The most of the research focuses on collecting data from a test environment rather than on the method of analysis and communication between nodes [11]. The concept of the new functionality of LEACH protocol used for self-organization nodes in mobile networks is a new idea proposed only by the authors of this article. The big problem with the functioning of wireless sensor network nodes that the usage of standard LEACH results in high energy consumption during self-organization process. This problem is persistent when nodes have portable limited sources of energy in the batteries. The concept of the new functionality reduces battery consumption which implies a longer nodes lifecycle.

3. Purpose and objectives of the study

The main goal of this publication is to present a new method of self-organizing nodes in sensor networks.

In accordance with the set goal the following research objectives are identified:

– increase the public interest in wireless sensor networks;

– analysis of self-organizing sensor networks protocols;

– presentation the new concept of operation of LEACH protocol.

4. Sensor node within a wireless sensor network

The idea of the sensor network functionality is shown in Fig. 1. The gateway functions as a transmitter/receiver. Special attention should be given to the lines showing the ability to exchange information without having to connect to the gateway on each attempt to make contact. This application helps to reduce the costs and avoid excessive traffic within the network.

The algorithms used by sensor networks to self-organize must be able to function locally, because most often the size of the network exceeds the range of a single node, and their distribution is random and irregular. Each node within a sensor network is, therefore, a standalone device. As a rule, sensor networks are homogeneous networks. Apart from the base stations, all nodes are identical and perform the same role. The nodes are deployed within a so-called sensor field. Their number depends on the intended use of the network and can range from several to tens of thousands. Nodes can be distributed in two ways. Firstly, they can be deployed in keeping with a certain specific design within which each node has a precisely defined position. This configuration can be used in networks monitoring the status of machines, warehouse stocks or, as mentioned above, functioning as early warning systems in the construction industry. Secondly, the nodes can be randomly deployed in hardly accessible terrain. Such random distribution requires the use of protocols enabling the development of a dynamic network infrastructure and data transmission from the source to the base station. The data collected by node sensors are transmitted to the base station on a multi-hop path. Each node within a sensor network functions as a terminal station and a router, too. The base station is a network component that collects information from the nodes and then transmits it via links to the end user.

A sensor node within a wireless sensor network is comprised with the transmitter/receiver, calculation module, gauging module and a power supply [12].

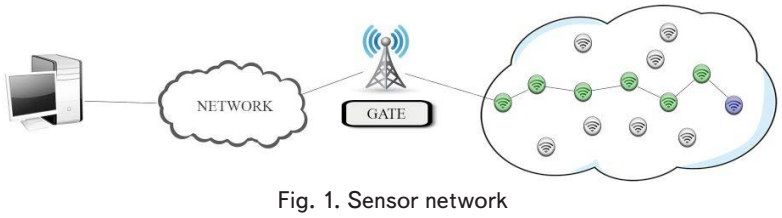

Fig. 1. Sensor network

Depending on the requirements, a variety of sensor network topologies can be used. The simplest one is a star network in which all nodes communicate with one central point (base station). These are so-called single-hop networks, where the data packet goes directly from sender to receiver (Fig. 2). If the monitored area is larger than the transmission range of a single node, it is necessary to use a multi-hop network, where data packets are transmitted between several nodes before they reach the recipient. Hence, the next issue that comes up is that of seeking the optimum packet transmission route (routing). In this case, the network is no longer stellar and can be a very complex structure that can change with the passage of time.

In the case of large and vast networks nodes are grouped into subnets, thus creating a hierarchical topology which in this case is called a “cluster tree” (Fig. 3).

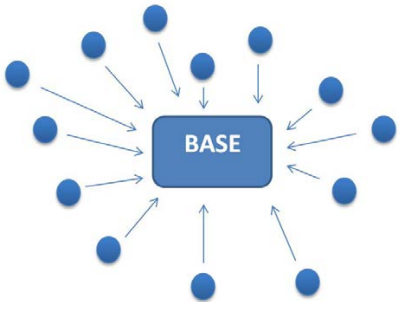

Fig. 2. Single-hop networks

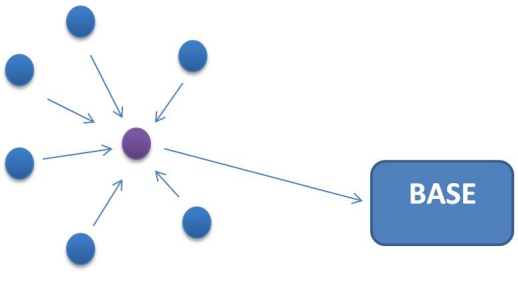

Fig. 3. Cluster tree

Within the given subnet, or so-called cluster, a single central node is selected that can communicate with other central nodes within an adjacent cluster [13]. This reduces the number of nodes that may communicate with each other, which results in that the path for data packets is better controlled. This has a considerable impact on energy

consumption. One problem is the increased activity of the central node which must be passed through by all the packets exchanged between clusters. It automatically consumes more energy than the other network nodes.

5. Access to the communication channel

Wireless sensor networks boast two types of access to the communication channel:

– synchronized access – the communication device transmits at a strictly preset moment in time previously agreed with the other nodes. This is then the so-called time division multiple access (TDMA). Such multiple access allows for better use of energy supply and better compensation of energy losses between the nodes. The transmitter and receiver nodes only wake up for the time of measurement and data transmission. Nevertheless, to keep them synchronized some energy is required. It is for the nodes' synchronization that there exists no collision within the network – and the use of the power supply becomes more efficient.

– free access – the devices can transmit at any moment in time, competing for access to the channel. Here, frequently applied is the principle "listen before you transmit" in combination with the so-called "back-off" algorithm, or the popular carrier sense multiple access with collision avoidance (CSMA/CA). This type of multiple access, in conjunction with the appropriate network topology, in practice makes it possible to build the most energy-efficient network nodes. The gauging node only wakes up for the time of measurement and data transmission. In the case of reaction to stimuli from the sensor, the deep sleep mode does not require power supply.

Comparing these two methods it is possible to conclude that the CSMA/CA will be a better solution for the star/cluster architecture with a relatively small load on the network, where energy efficiency is affected by the number of collisions – e. g. events detection. This type of multiple access does not disturb mobility, since access to the channel does not require prior agreement with the other nodes – a node can simply appear in proximity to other devices and try to transmit its packet. The TDMA method is much more successfully applied in mesh networks, homogeneous networks powered by a portable source of energy, for the purpose of continuous measurements, and in cases of heavy traffic within the network. Mobility is a hindrance, because a change of the environment requires calibration and synchronization.

Sensory nodes communicate with each other wirelessly. This purpose is served by radio or optical communication techniques, e.g. infrared radiation. An optical medium is very safe, but its directional transmission and short range restrict its suitability only to simple applications when the devices can "see" each other. Usually, a radio medium is applied, i. e. wireless calls are made using electromagnetic waves, mostly within the range of generally accessible ISM (Industrial, Scientific, and Medical) bands. The ISM is used free of charge and is not licensed, but is regulated by law in terms of the maximum transmission power and impact on other bands.

Wherever the most important thing is the range, the wireless communication standard used is the IEEE 802.11. This standard is commonly known under the more popular name Wi-Fi. However, it was not developed to solve the problems with sensor networks and works to improve its performance are still underway.

The standards applied in and designed specifically for sensor networks include:

– ZigBee IEEE 802.15.4 [14] – ZigBee-based networks are characterised by low energy consumption, maximum capacity up to 250 kb/sec, low memory requirement between 4 kb – 32 kb, and internodal range of 100 m. It utilises the CSMA/CA mechanism. It supports networks with the tree topology (cluster tree) which distinguishes between end nodes and relay nodes. In addition to those already mentioned, the most important properties of the ZigBee network include the frequency band in which it can work and the range of the IEEE 802.15.4 configuration. The working frequencies available to the network concurrently determine the maximum transmission rate are shown in Table 1.

Table 1

Working available frequencies

Frequency	Accessibility	Transmission	Channels
2,4 GHz	World	250 kb/s	16
868 MHz	Europe	29 kb/s	1
915 Mhz	Usa	40 kb/s	10

– IEEE 802.15.4 WirelessHart – a standard that is being ushered in now and is a radio extension of the wired HART communication standard. It utilises the TDMA mechanisms and supports homogeneous mesh topologies. It has a number of improvements in relation to the ZigBee. A WirelessHART network can contain three types of devices: WirelessHART devices, adapters and gateways. WirelessHART devices are battery powered, so they are completely wireless. Their task is to transmit information within a WirelessHART network. WirelessHART adapters help connect wired HART devices to WirelessHART networks. The signal of 4–20 mA remains available to the DCS system. WirelessHART gateways ensure communication between all devices within the network. They manage the network, define the pathways, take care of security, and offer the option of replacing common communication standards, such as MODBUS, with the HART standard.

6. Mobility in sensor networks

The architecture the authors would like to deal with in this publication is the use of mobile nodes in a sensor network. This type of network has a higher topology dynamics. Mobility of network elements is associated with significant complications in the functioning of the routing protocols, which largely affects the choice of the protocols' operating parameters and hardware layer. For this reason, most solutions used in static sensor networks are not suitable for direct use, because of low efficiency in the event of dynamic topology changes that take place in mobile networks. Another disadvantage that is fairly difficult to accept is the relationship between the dynamics of mobile wireless sensor networks and the quality of the service offered. The higher is the dynamics among the nodes, the lower is the quality of the communication services. In this type of networks the exchange of information between the nodes is mostly limited to the minimum. Wireless or partially wireless sensory networks utilize two architectures. One of them has a structure that is similar to that used in mobile networks. A node transmits radio signals to the base station device. The base station is a network device that is the interface between a mobile node and the rest of the nodes within the network [15].

With its built-in transmitters a functional node constantly sends signals about its accessibility in all directions. Whenever it is within the range of the base station, the base station receives these signals and transmits them to the next central control network which controls groups of base stations.

The second type of architecture is an ad-hoc network where all the nodes (network elements) can move freely [16] and at the same time have the potential to self-organize themselves and establish radio communications in an arbitrary manner.

In sensor networks we can meet more complex routing than that used in TCP/IP networks. The network structure consists mostly of a very large number of nodes what causes impossible to give each node a global address ID. This state of affairs would introduce huge amounts of traffic on the network only for organization, not to mention the collection and transmission of information from the test environment. If the network should work properly sensors must organize themselves in an automatic way, because they are very often arranged in a random and uncontrolled manner. Another significant problem is the limit in terms of energy resources, data processing and storage capacity operating is why we need efficient management of nodes.

Parameters that must be taken into account when selecting routing protocol and network sensor self-organization [16]:

– position, density, and distribution of nodes in the test environment;
– energy;
– adaptability;
– distance between the nodes;
– communication;
– Quality of Service.

7. The concept of modified LEACH protocol

Low Energy Adaptive Clustering Hierarchy is a protocol that operates based on hierarchical routing protocols. The protocol creates a so-called "cluster" comprised of a group of sensors which communicate with one and the same root node. Clusters formation is the preliminary process that initiates root nodes selection. Root nodes aggregate the data from all the sensors within the cluster and then send them to the base station. This causes a reduction in the amount of data transmitted directly to the base station.

The functioning of LEACH protocol [17]:

– The first phase comprises clusters formation and root nodes selection. Each node generates a random number between 0 and 1. If the number turns out to be less than the threshold value T(n) the node becomes the root node of the cluster. The T(n) value is calculated as follows:

$$T(n)=\frac{p}{1-p\left(r\cdot \mathrm{mod}\left(\frac{1}{p}\right)\right)},\quad p\in G,$$

where p – expected number of nodes to become root nodes; G – set of nodes participating in the selection process.

The newly selected root nodes transmit a message/communication to all the nodes within the network. The nodes join those root nodes from which they receive the most powerful signal, where the root node calculates the schedule for all members of the cluster so formed.

– The second phase consists in collecting and transferring data to the root nodes that aggregate and transmit them to the base station. After a specified time, the network once again passes through the first phase.

One disadvantage of this solution is quite a serious issue of excessive traffic in the course of root nodes selection and greater energy consumption among the root nodes relative to the other nodes within the cluster.

The proposed concept introduces an additional datum that affects the selection of the given node for the root node of the cluster. This datum is the status of the mobile and limited energy source of each node, the value of which would have a key role in selecting the function to be fulfilled. By the operation of a sensor network based on the LEACH protocol we know that the root node, for its increased activity in relation to the other nodes within the cluster, consumes more energy. It collects information from nearby nodes, and then transmits them to the base station. The presented concept is shown at Fig. 4.

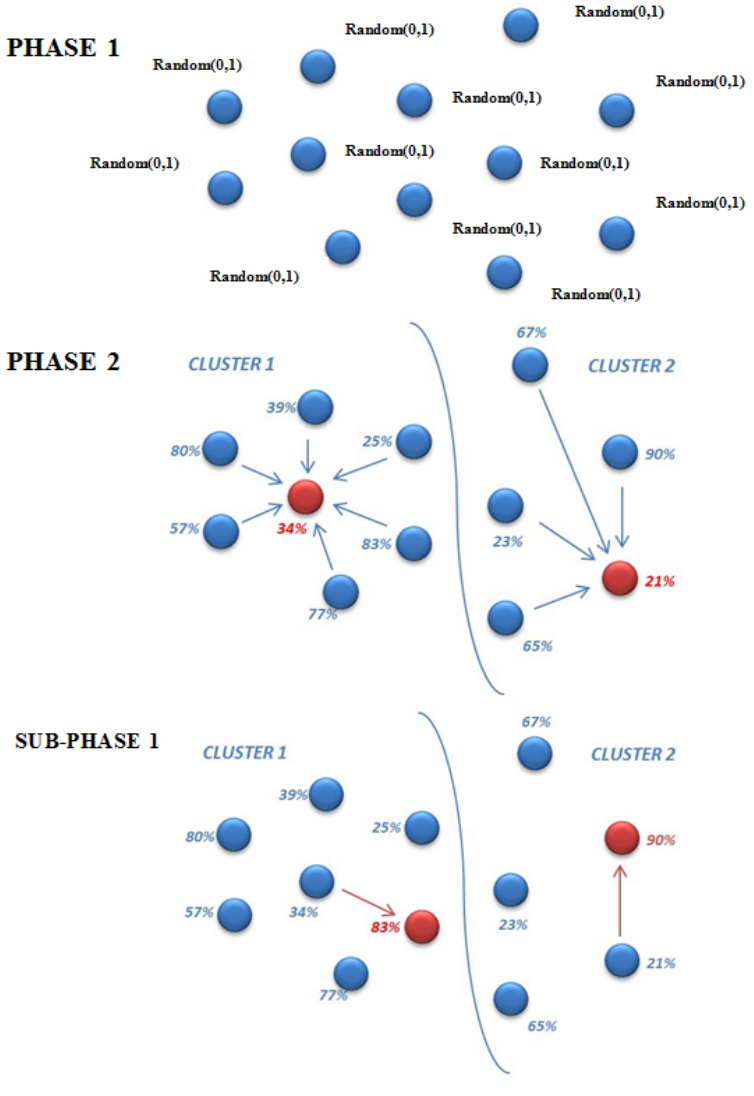

Fig. 4. Modified LEACH protocol

The concept of the modification takes into account the root nodes selection in the first phase as per the status of their power supply.

In the second phase data are transmitted to the root nodes which further transmit them to the base station.

In contrast to the LEACH protocol, this concept allows for sub-phase being a calculation within the given cluster of the statuses of the power supply of each node. The node with the strongest source of power supply becomes the root node, and the previous root node becomes an ordinary cluster node. After the preset time the process begins with the first stage, as is the case with the LEACH protocol.

8. Conclusion

To sum up the concept of the new functionality LEACH proposed in the publication is the next step in creating a network of mobile phones that do not require operator. This idea was proposed in the publication [18].

The aim of this publication was to present a new kind of protocol, which, in contrast to the usual protocol LEACH consume less energy, and at the same time increasing the public interest to a new self-organizing node protocols in a WSN network. The new proposed modification woke up an interest among scientific staff of Technical University of Lodz which led to creating an environment designed to physically tests of the presented concept functionality.

Hierarchical routing protocols are currently the best solution for sensor networks, whether they consist of a small or large number of nodes. The algorithms based on the hierarchy of the nodes increase the efficiency of the network through data processing and aggregation in clusters of sensors. These protocols usually involve two phases – in the first one clusters are formed, in the other the recorded data are routed. However, in contrast to other protocols used in sensor networks, they are found to demonstrate considerable computing power consumption and frequently excessive traffic within the network itself. The computing time and resources for the LEACH protocol are several times higher than is the case with direct protocols. The proposed concept under development reduces the incidence of excessive traffic in the course of the root nodes selection in the first phase and increases the life of each node by assigning the function of the root node to each node within the cluster.

References

1. Bogumił, P. Bezprzewodowe sieci sensorowe w przemyśle – problemy funkcjonowania i stosowalności [Electronic resource] / P. Bogumił. – Available at: http://www.wsn.agh.edu.pl/?q=pl/node/164
2. Fu, C. An Energy Balanced Algorithm of LEACH Protocol in WSN [Text] / C. Fu, Z. Jiang, W.Wei, A. Wei // International Journal of Computer Science Issues. – 2013. – Vol. 10, Issue 1, No. 1. – P. 354–359.
3. Roseline, R. A. Energy Efficient Routing Protocol and Algorithms for Wireless Sensor Networks- A Survey [Text] / R. A. Roseline, Dr. P. Sumathi // Global Journal of Computer Science and Technology. – 2011. – Vol. 11.
4. Jin-wei, W. Research on the Number of Optimal Cluster Heads of Wireless Sensor Networks Based on Energy Consumption [Text] / W. Jin-wei, S. Hua-zhi, S. De-bing // Journal of Computer Research and Development. – 2008. – Vol. 03.
5. Dhawan, H. A Comparative Study on LEACH Routing Protocol and its Variants in Wireless Sensor Networks: A Survey [Text] / H. Dhawan, S. Waraich. International Journal of Computer Applications. – 2014. – Vol. 95, Issue 8. – P. 21–27. doi: 10.5120/16614-6454
6. Yadav, L. Low Energy Adaptive Clustering Hierarchy in Wireless Sensor Network (LEACH) [Text] / L. Yadav, Ch. Sunitha // International Journal of Computer Science and Information Technologies. – 2014. – Vol. 5, Issue 3. – P. 4661–4664.
7. Aslam, M. Survey of Extended LEACH-Based Clustering Routing Protocols for Wireless Sensor Networks [Text] / M. Aslam, N. Javaid, A. Rahim, U. Nazir, A. Bibi, Z.A. Khan // EEE 14th International Conference on High Performance Computing and Communication & 2012 IEEE 9th International Conference on Embedded Software and Systems, 2012. – P. 1232–1238. doi: 10.1109/hpcc.2012.181
8. Xiao-yun, W. SLEACH: Secure Low Energy Adaptive Clustering Hierarchy Protocol for Wireless Sensor Networks [Text] / W. Xiao-yun, Y. Li-zhen, C. Ke-fei // Wuhan University Journal of Natural Sciences. – 2005. – Vol. 10, Issue 1. – P. 127–131. doi: 10.1007/bf02828633
9. Neto, J. H. B. MH-LEACH: A Distributed Algorithm for Multi-Hop Communication in Wireless Sensor Networks [Text] / J. H. B. Neto, A. da S. Rego, A. R. Cardoso, J. Jr. Celestino // ICN 2014: The Thirteenth International Conference on Networks, 2014. – P. 55–61.
10. Iqbal, A. Advanced LEACH: A Static Clustering-based Heteroneous Routing Protocolfor WSNs [Text] / A. Iqbal, M. Akbar, N. Javaid, S.H. Bouk, M. Ilahi, R. D. Khan // J. Basic. Appl. Sci. Res. – 2013. – Vol. 3, Issue 5. – P. 864–872.
11. Faludi, R. Building Wireless Sensor Networks [Text] / R. Faludi. – O'Reilly Media, 2010. – 322 p.
12. Jankowski, M. Sieci Sensorowe – wybrane zagadnienia [Text] / M. Jankowski. – Praca magisterska, 2009.
13. Lewis, F. L. Wireless Sensor Networks. Smart Environments: Technologies, Protocols, and Applications [Text] / F. L. Lewis. – John Wiley & Sons, Inc., 2004. doi: 10.1002/047168659X.ch2
14. Jeznach, J. Analiza protokołów rutingu w sieciach sensorowych [Text] / J Jeznach, P. Niepsuj. – Praca magisterska, 2007
15. Deb, B. A Topology Discovery Algorithm for Sensor Networks with Applications to Network Management [Text] / B. Deb, S. Bhatnagar, B. Nath. – DCS Technical Report DCS-TR-441, 2002.
16. Zdunek, R. Bezprzewodowa sieć sensorowa [Text] / R.Zdunek. – Praca magisterska, 2010. – 51 p.
17. Zhong, J. Variable Threats Based Self-Organization Scheme for Wireless Sensor Networks [Text] / J. Zhong, A. Berlok // Proceedings of the 2009 Third International Conference on Sensor Technologies and Applications, 2009. – P. 327–332. doi: 10.1109/sensorcomm.2009.57
18. Mosorov, V. The application of sensor networks within mobile cell networks [Text] / V. Mosorov, S. Biedron, T. Panskyi // Eastern-European Journal of Enterprise Technologies. – 2015. – Vol. 4, Issue 9 (76). – P. 48–52. doi: 10.15587/1729-4061.2015.47697