ИНФОРМАЦИОННО-КОММУНИКАЦИОННЫЕ ТЕХНОЛОГИИ

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DEVELOPMENT AND RESEARCH OF RELIABILITY ASSESSMENT OF LINEAR WIRELESS SENSOR NETWORKS

The article is devoted to the issue of estimating the reliability of linear wireless sensor networks. Scientific research in the field of forecasting is given. This article discusses the Internet of Things (IoT) technology, which is growing by 15-20%, actively developing in all directions and its principles of operation. The area with the greatest potential for the application of the Internet of Things in Kazakhstan is smart control of resource consumption, including in the sphere of housing and communal services. Использованы методы построения и управления смарт-систем. Also describes the increase in comfort, thanks to IoT technology. User-friendly interface is used. Mainly considered the system of automation of business structures depending on the scale. All currently available methods have been suggested, which are key factors in optimizing all processes. Also considered options for modeling and system development, taking into account all the relevant problems of technology automation. The importance of the scientific topic affects the high potential for the development of IoT technology and the lack of uniform standards for devices included in these systems. The system is scalable, allowing it to be used for almost any purpose. This paper proposes an approach to solving a number of problems arising in the monitoring of long pipelines using wireless sensor networks. In order to take full advantage of the potential of IoT technologies, the architectural basis of which is formed by wireless sensor networks, it is necessary to develop tools to assess and ensure the reliability of these networks. Thus, the focus of the study is on the application-specific formalized reliability criteria for wireless sensor networks.

***Key words**: IoT sensors, internet of things technology, wireless sensor network, network evaluation and reliability.*

Introduction. Internet of Things (IoT) technologies are in the focus of not only leading commercial companies, research centers, but also the governments of many countries. IoT-sensors can already effectively analyze water, heat, electricity, gas consumption, monitor emergency situations in real time, remotely control a huge number of city functions - from streetlights

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and skylights to security cameras with face recognition function. With the development of IoT, ensuring the safety and comfort of urban residents is becoming much easier. It is safe to say that the digitalization of urban services and infrastructure is of strategic importance for the development of a civilized society. Many IoT architecture solutions are based on the results of wireless sensor network research, in particular the proposals within the Internet of Things-Architecture (IoT-A) project of the European Union's 7th Framework Programme for the Development of Research and Technology [1-2]. Vital infrastructure monitoring systems based on wireless sensor networks (WSNs) are one of the most popular IoT technologies, since proper monitoring will reduce damage from natural and man-made disasters, timely respond to the consequences of infrastructure deterioration, reduce environmental and economic risks.

Corporations and government agencies, especially in the U.S., Europe and the Middle East, are currently making major efforts to research, develop and patent wireless sensor network-based technologies for monitoring long pipelines of various applications. Specifically, research on the use of WSNs for pipeline monitoring was conducted as part of joint research projects between Stanford University, the University of Southern California, and Chevron Corporation. The competition for pipeline monitoring solutions was run by a U.S. federal government agency (Bureau of Reclamation) on the crowdsourcing platform Innocentive. According to a GlobeNewswire analysis report, even for a private task such as monitoring water pipes for leak detection, the solution market reaches a billion dollars and is growing at 5% per year. WSNs can continuously monitor critical infrastructure, detect and report any anomalies, but there are a number of challenges to overcome, such as node placement, energy optimization, efficient data flow, etc., which require reliability and life-time assessment techniques for WSNs.

It should be noted that experts in the field of information put forward reasonable doubts about the reliability of IoT technologies, in general, and the ultimate benefit to society from their implementation. It is noted that companies specializing in IoT technologies, seeking to occupy as much of the market as possible and prioritize the earliest release of products, without paying enough attention to issues of reliability and safety. In order to fully exploit the potential of IoT technologies, it is necessary to develop appropriate tools to assess and ensure their reliability. Particularly applicable to pipeline monitoring systems using WSNs, since these networks may operate in harsh climatic conditions and network nodes may be located in places that are not readily accessible for routine inspections. The main role of sensor nodes in WSNs used for monitoring is to periodically collect and transmit data to an intelligent central base station (sink), where the collected data is processed to detect a variety of anomalous events. In large-scale WSNs used to monitor long sites, such as pipelines, most sensor nodes are geographically remote from the base station and are usually equipped with relatively low-capacity, low-cost self-contained batteries. This fact largely determines the main disadvantages of long-haul WSNs, since the periodic transmission of raw data over long distances through several transitions to the base station leads to a rapid drain on the battery of sensor nodes and reduces the service life of the network. Other disadvantages include low reliability of wireless channels, high cost of bandwidth, low level of data security [3-4]. Thus, there is a need to solve the optimization problems of extended WSNs, where the target function or constraints include the reliability indicator.

Experimental. A typical scenario used in a number of recent publications on the subject is discussed [6-8]. A WSNs consists of several (*n*) sensor nodes placed on the surface of the pipe, the topology is a simple chain at the end of which is a base station. Sensors are responsible for collecting data, periodically sending packets to the base station. All nodes play an important role in data forwarding, the node closest to the base station transmits data to the stock directly, intermediate nodes are used to transmit packets from other nodes, i.e., the data sent by the sender to the stock is retransmitted by nodes located between the sender and the stock. The main power consumption is caused by transmitting traffic. Obviously, this leads to excessive waste of energy of sensor nodes located closer to the base station because of the high asymmetric load on these nodes. Each sensor node performs periodic monitoring within its sensitivity range. All sensor nodes are initially in the same environment, have similar communication capabilities, power consumption, and their behavior is described by the same conceptual models. Each node transmits its packet to its neighbor node in the direction of the base station. Distances between neighboring nodes differ slightly. The appropriate software module deployed in the base station receives data from all sensor nodes, decides whether or not there is a problem on its own, or transmits the data via a highly reliable IP network to a decision-making center.

Results and Discussion. The load generated by the sensor node will be modeled by a Poisson process, which is also not only a commonly used assumption, but has also been repeatedly verified experimentally. We denote the intensity of the flow given from sensor *j* by *Aj*. For homogeneous nodes: *Aj = A Vj* = 1 *...n*. The current node battery capacity (*C*) is conveniently measured in the number of potentially possible packet transmissions. Thus, the lifetime of a node is modeled by a Markov chain with continuous time:

$$C(t),\ t > 0.$$

Initial battery capacity is sufficient to transmit C_0 packets. Let us introduce the probabilities of states,

$$P_k(f) < P[C(f) < k], \quad k = 0,1 \ldots C_0.$$

Then the Kolmogorov equations for this system:

$$\frac{dC_k(t)}{dt} = -\lambda C_k(t) + \lambda C_{k+1}(t), \quad 0 < k < C_0,$$

$$\frac{dC_{C_0}(t)}{dt} = -\lambda P_{C_0}(t),$$

$$P_k(0) = \begin{cases} 1, k = C_0 \\ 0, k < C_0 \end{cases}$$

The normalization condition must also be met:

$$\sum_k P_k(t) = 1.$$

This process is a variation of the process of death and reproduction, contains an absorptive state, transitions from state to state are possible only in the direction of population decrease. The solution of the system of Kolmogorov equations in this case takes the form:

$$P_k(t) = \frac{(\lambda t)^{C_0 - k}}{(C_0 - k)!} e^{-\lambda t}, \quad 0 < k < C_0.$$

Hence,

$$P_k(t) = 1 - e^{-\lambda t} \sum_{k=0}^{C_0 - 1} \frac{(\lambda t)^k}{k!}.$$

The obtained function describes the probability that the sensor battery will be discharged by time t, i.e. $P_0(t)$ allows to calculate the sensor lifetime and formalize various criteria of network reliability.

Using the results of the previous section for the sensor with energy reserve C we obtain the average lifetime of the sensor: $^C/2$; Taking into account the properties of the Poisson process we obtain that for a homogeneous WSNs the average lifetime of the sensors (from the far sensor to the near sensor to the drain) will be:

$$\frac{C}{\lambda}, \frac{C}{2\lambda}, \ldots, \frac{C}{n\lambda},$$

because the intermediate sensor needs to transmit packets of all sensors that are further away from the rack. The network will become unconnected for a time n times shorter than the lifetime of the far node. To balance the lifetime of the nodes it is necessary to abandon the use of nodes that are homogeneous in energy reserve, i.e. for a node that is separated from the drain by j hops the battery capacity should be: $(n - j + 1)C$.

Also, based on the criterion of average node lifetime, it can be concluded that the approach to optimization and balancing of power consumption of linear WSNs proposed in the article [5], according to which nodes are divided into clusters of 3 nodes, one of the nodes aggregates traffic and forwards it to a symmetric node in the next cluster. If the middle node is taken as the cluster head, indeed, the average lifetime of the other two nodes in the cluster will be $\frac{C}{\lambda}$. However, the head node must transmit data over a distance increased threefold. Taking into account the fact that the growth of power consumption for data transmission increases in proportion to the square of the distance, the capacity of this node will no longer be C, but $\frac{C}{9}$, respectively, the average lifetime of the head node without regard to retransmission of cross-traffic will decrease to $\frac{C}{27\lambda}$.

Even if we take total energy cost as a criterion rather than reliability in some way, the clustering from [5] is still of limited use. Let e_1 be the energy cost of transmitting a packet at 1-hop distance, and e_2 be the energy cost of transmitting a packet between cluster head nodes, and

$$e_2 = a e_1, \quad a < 1.$$

Then we get the following condition of benefit of the considered method of clustering:

$$a < \frac{7}{3} - \frac{6}{n+3}.$$

As noted above, in many applications $a \leq 9$, i.e., degradation of signal-to-noise ratio is inevitable.

The formula $P_0(f)$ can be applied to formalize other reliability criteria, for example, the probability of failure-free operation during the prescribed time. Also, using sub-models for λ and *C*, one can evaluate different approaches to traffic aggregation [9-11].

Conclusions. An approach to the formalization of the reliability criterion of extended wireless sensor networks is proposed. It is shown that homogeneous wireless sensor networks are structurally imbalanced in the energy consumption of nodes. The recently proposed approach to energy conservation of linear wireless sensor networks using clustering [5], generally speaking, is not tenable and entails degradation of network reliability. To ensure the required level of reliability of linear wireless sensor networks, it seems promising to use base stations on an unmanned aerial vehicle, and it is predicted that the total system energy costs will increase. Also, good prospects are seen in the application of traffic aggregation schemes using noise coding.

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СЫЗЫҚТЫ СЫМСЫЗ СЕНСОРЛЫҚ ЖЕЛІЛЕРДІҢ СЕНІМДІЛІГІН БАҒАЛАУДЫ ӘЗІРЛЕУ ЖӘНЕ ЗЕРТТЕУ

Мақала сызықты сымсыз сенсорлық желілердің сенімділігін бағалау мәселесіне арналған. Мұнда болжау саласындағы ғылыми зерттеулер келтірілген. Бұл мақалада заттардың интернеті (IoT) технологиясы қарастырылады, оның жұмыс принциптері де барлық бағыттарда белсенді дамиды әрі ол 15-20%-ға дейін өсе алады. Қазақстанда заттар интернетін қолданудың ең үлкен әлеуеті бар сала тұрғын үй-коммуналдық шаруашылық саласында қолданылатын ресурстарды тұтынуды мұқият бақылау болып табылады. Ғылыми жұмыста смарт жүйелерді құру және басқару әдістері қолданылды. IoT технологиясының арқасында жайлылықтың артуы да сипатталған. Пайдаланушыға ыңғайлы интерфейс қолданылды. Негізінен масштабқа байланысты бизнес-құрылымдарды автоматтандыру жүйесі қарастырылады. Қазіргі уақытта барлық процестерді оңтайландырудың негізгі факторлары болып табылатын барлық қол жетімді әдістер ұсынылды. Технологиялық процестерді автоматтандырудың барлық өзекті мәселелерін ескере отырып, жүйені модельдеу және әзірлеу нұсқалары да қарастырылады. Ғылыми тақырыптың маңыздылығы IoT технологиясының жоғары даму әлеуетіне және осы жүйелерге енгізілген құрылғылардың бірыңғай стандарттарының болмауына әсер етеді. Жалпы жүйе масштабталады, бұл оны кез-келген мақсатта пайдалануға мүмкіндік береді. Жұмыста сымсыз сенсорлық желілерді қолдана отырып, кеңейтілген құбырларды бақылау кезінде туындайтын бірқатар мәселелерді шешуге оң көзқарас ұсынылады. Архитектуралық негізін сымсыз сенсорлық желілер қалыптастыратын Заттар интернеті технологияларының әлеуетін толық пайдалану үшін аталған желілердің сенімділігін бағалау және қамтамасыз ету құралдарын әзірлеу қажет. Осылайша зерттеудің фокусы қолданбаның ерекшелігін ескере отырып рәсімделген сымсыз сенсорлық желілердің сенімділік критерийлері болып табылады.

Түйін сөздер: *IoT сенсорлары, интернет заттары технологиясы, сымсыз сенсорлық желі, желіні бағалау және сенімділік.*

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РАЗРАБОТКА И ИССЛЕДОВАНИЕ ОЦЕНКИ НАДЕЖНОСТИ ЛИНЕЙНЫХ БЕСПРОВОДНЫХ СЕНСОРНЫХ СЕТЕЙ

Статья посвящена вопросу оценки надёжности линейных беспроводных сенсорных сетей. Приведены научные исследования в области прогнозирования. В данной статье рассматривается технология Интернета вещей (IoT), которая растет на 15-20%, активно развиваясь во всех направлениях и её принципы работы. Сферой с наибольшим потенциалом применения Интернета ве-

щей в Казахстане является умный контроль потребления ресурсов, применяемый в том числе и в сфере жилищно-коммунального хозяйства. Использованы методы построения и управления смарт-систем. Также описывается повышение комфортности, благодаря технологии IoT. Использован удобный интерфейс для пользователя. Главным образом рассматривается система автоматизации бизнес-структур в зависимости от масштаба. Были предложены все доступные методы на данный момент, которые являются ключевыми факторами в оптимизации всех процессов. Также рассмотрены варианты моделирования и разработки системы, учитывая все актуальные проблемы автоматизации технологии. Важность научной темы влияет на высокий потенциал развития технологии IoT и на отсутствие единых стандартов устройств, включенных в эти системы. Система является масштабируемой, что позволяет использовать её практически для любых целей. В работе предлагается подход к решению ряда задач, возникающих при мониторинге протяженных трубопроводов с использованием беспроводных сенсорных сетей. Для того чтобы в полной мере воспользоваться потенциалом технологий Интернета вещей, архитектурную основу которого формируют беспроводные сенсорные сети, необходимо разработать средства оценки и обеспечения надежности указанных сетей. Таким образом, в фокусе исследования находятся формализованные с учетом специфики приложения критерии надежности беспроводных сенсорных сетей.

Ключевые слова: *IoT-датчики, технология Интернета вещей, беспроводная сенсорная сеть, оценка и надежность сети.*