DOI: 10.5604/01.3001.0010.8643

ORGANIZATION OF IMPLEMENTATION OF UBIQUITOUS SENSOR NETWORKS

Sergey Toliupa[1], Yuriy Kravchenko[2], Aleksander Trush[2]
[1]Kyiv National Taras Shevchenko University, Department of Cybersecurity and Information Protection, [2]Kyiv National Taras Shevchenko University, Department of Network and Internet Technologies

Abstract. *The article deals with the implementation of one of the most promising technologies of the 21st century – the permeable sensor networks of the USN. The features, architecture, organization and routing algorithms of sensory networks are described. It is determined that further improvement of the work of such networks requires standardization of the development process and implementation process. USN's Vertical Sensor Networks is one of the most promising technologies of the 21st century. Cheap and "smart" sensors, in large quantities combined into a wireless network connected to the public communications network, today provide an unprecedentedly wide range of control and management services for buildings, businesses, cars, and so forth. USN networks, depending on the type of sensors, can be deployed on the ground, in the air, under and over water, in buildings and, finally, on the skin and inside living organisms, including humans. They are also widely used in such important areas as military affairs, crisis and emergency management, and the fight against terrorism.*

Keywords: ubiquitous sensor networks USN, network architecture, touch-route routing algorithms

ORGANIZACJA IMPLEMENTACJI WSZECHOBECNYCH SIECI SENSOROWYCH

Streszczenie. *Artykuł dotyczy implementacji jednej z najbardziej obiecujących technologii XXI wieku – wszechobecnej sieci sensorowej USN. Opisano funkcje, architekturę, organizację i algorytmy routingu sieci sensorowych. Ustalono, że dalsza poprawa takich sieci wymaga standaryzacji procesu rozwoju i procesu wdrażania. Pionowe sieci sensorowe USN to jedna z najbardziej obiecujących technologii XXI wieku. Tanie i "inteligentne" czujniki w dużych ilościach w połączeniu z siecią bezprzewodową podłączoną do publicznej sieci komunikacyjnej zapewniają obecnie niespotykany dotąd szeroki zakres usług zarządzania budynkami, przedsiębiorstwami, samochodami i tak dalej. Sieci USN, w zależności od rodzaju czujników, mogą być rozmieszczone na ziemi, w powietrzu, pod wodą i nad wodą, w budynkach, a wreszcie na skórze i wewnątrz organizmów żywych, w tym ludzi. Są również szeroko stosowane w tak ważnych obszarach, jak sprawy wojskowe, w sytuacjach kryzysowych i zarządzania kryzysowego oraz w walce z terroryzmem.*

Słowa kluczowe: wszechobecne sieci sensorowe USN, architektura sieci, algorytmy routingu sieci sensorowych

Introduction

USN's Vertical Sensor Networks (Ubiquitous Sensor Networks) is one of the most promising technologies of the 21st century. Cheap and "smart" sensors, in large quantities combined into a wireless network connected to the public communications network, today provide an unprecedentedly wide range of control and management services for buildings, businesses, cars, and so forth. USN networks, depending on the type of sensors, can be deployed on the ground, in the air, under and over water, in buildings and, finally, on the skin and inside living organisms, including humans. They are also widely used in such important areas as military affairs, crisis and emergency management, and the fight against terrorism. To support the specified characteristics, each sensor must correspond to a specific architecture in which the main elements are: directly the touch device, memory, antenna, power supply.

1. Vertical Sensor Networks USN

An important aspect of the efficient functioning of the network is its scalability. However, today it is impossible to ignore the mobile all-pervading sensory networks, the use of which also covers all aspects of human activity and society. Other important features of the networks are:

- Low energy consumption. Due to the fact that quite a large part of the USN deployment scenarios involves the presence of sensors in hard-to-reach places, their maintenance may become an unrealistic task. That is why the life cycle of the sensor is often limited by the time the power source is operating.
- Self-organization of the network. Deployment of the sensor network is significantly different from the deployment of traditional networks. Often, sensors are distributed randomly in a given area, and further such a "set" of sensors should be self-organized into the network. Then it will not be possible to control them from the outside. Self-organization should be dynamic - the failure of the components of the network due to, for example, their physical destruction, or the discharge of power sources, should be determined operatively [4]. Otherwise, the effective functioning of the USN will be under threat.

Standardization of such networks is dealt with by the IEEE 802.15.6 working group. Taking into account the all-pervading nature of sensor networks and their use in various spheres of life, it is advisable to name the society that uses them - ubiquitous. This corresponds to the previous name of the WSN (Wireless Sensor Networks) network. The urgency of the network and its viscidity, as reflected by standards and draft standards of the International Telecommunication Union, allowed the use of the USN abbreviation.

Wireless sensor networks are just such examples of special networks that do not have a common infrastructure other than gateways to other networks. Each of the nodes of the sensor network must be able to function as both a terminal and a transit node. Transmission of data in sensory networks is carried out by means of their redirection to the nearest node step by step.

Such networks are called multi-step (with repeaters). It should be noted that more sophisticated routing algorithms may exist when the next node is selected based on an analysis of its characteristics, such as energy costs, reliability, etc. In the presence of mobile sensor nodes, the architecture of the sensor network becomes more and more dynamic.

Sensor networks are defined as "distributed networks consisting of small wireless nodes of narrow specialization in a large number distributed on a certain surface (Fig. 1). Thus, the sensor network is a large number of wireless sensors, distributed in some area with a high density. In the area of signal, coverage of each of the sensors must be at least another sensor; in this case, the sensor will be called neighboring. The more "neighbors" of each of the sensors, the higher the accuracy and reliability of the sensor network [1].

A cluster organization is considered efficient and scalable for solving similar problems (Figure 2), but only if the cluster network's main site is rational and at the appropriate time.

Indeed, at the time of the T1 time, the sensor node does not necessarily have to be at another time, since the existing main node can already spend a fairly large amount of energy for transmitting messages from all sensory cluster nodes to the time T2. Therefore, at the moment of time T2, the main node in the cluster can be assigned another sensor node, which has by this time retained the largest energy supply.

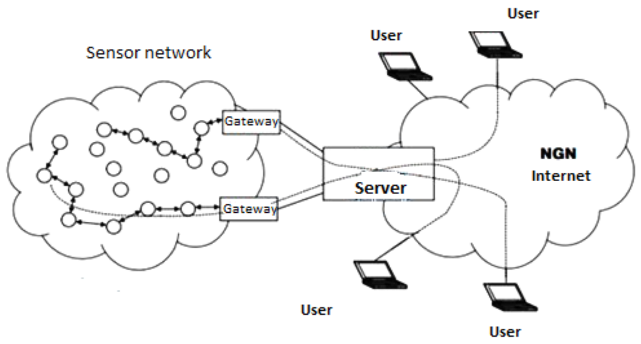

Fig. 1. An example of connecting the sensor network to the public communications network

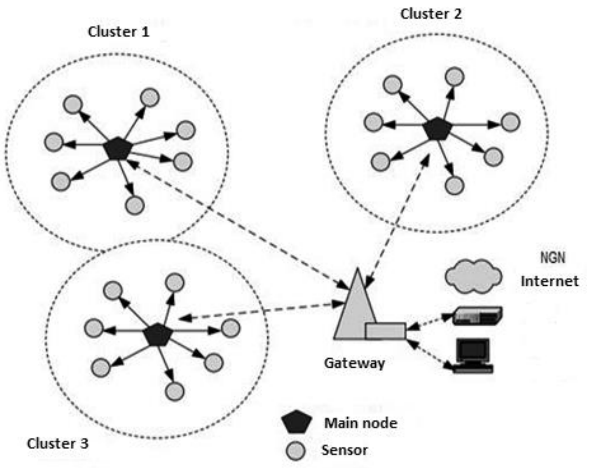

Fig. 2. USN Cluster Architecture

One of the most well-known mechanisms that provide the functioning of sensor networks and the selection of main nodes is the Low Energy Adaptive Cluster Hierarchy (LEACH) algorithm.

The LEACH algorithm involves the probable selection of the sensor node for the role of the main at the beginning of the functioning of the sensor network, and subsequently rotation of the main energy characteristics of other sensor nodes. Such a solution increases the duration of the functioning of sensor nodes and the network as a whole, but does not solve the problem of providing better coverage for a sufficiently long time. And this is natural, since when creating a LEACH such a task was not raised. There are quite a few algorithms that are one way or another trying to improve LEACH. These are algorithms used as a criterion for the amount of residual energy; the location of the candidate node for the main cluster node in relation to other nodes; information about the topology of the network at the current time. For example, the HEED (Hybrid Energy – Efficient Distribution) algorithm uses a mixed criterion for choosing a host based on the analysis of residual energy and the location of adjacent nodes. All these algorithms are used to maximize the duration of the functioning of sensor nodes and the network as a whole. However, with the development of sensor networks, there were additional tasks that require close attention. For example, the problem of quality of service, which is the most important metric for any network, including the sensory one [6].

The problem of extending the life of the sensor network is very important. However, if this network does not perform its functions to the extent necessary, then the task itself to increase the life of the sensor network does not meet the requirements for quality of service. In monitoring systems, one of the most important requirements is the continuity, that is, the monitoring of parameters throughout the space or throughout the process. Proceeding from the above, it is necessary to develop such an algorithm for selecting the main node of the cluster, which would provide better coverage of the area of two-dimensional area (area) for monitoring over a sufficiently long period of time. This approach means optimizing the life of the sensor network, as well as optimizing the performance of the sensory network of its functional tasks with a given quality of service over a sufficiently long period of time.

2. Sensor architecture

The sensor, like any telecommunication node or terminal, consists of hardware and software. In general, the sensor consists of the following subsystems: monitoring and perception, data processing, as well as communication subsystem and power supply. The subsystem of monitoring and perception allows the sensor to collect such data on the environment as temperature, light intensity, vibration, acceleration, magnetic field, chemical composition of air, acoustics, etc. It is this subsystem that defines the area or implementation in which the sensor can be used. The sensor can optionally be supplemented by other subsystems, such as positioning, power generator, etc. (Figure 3)

The monitoring and perception subsystem contains an analogue device that directly removes certain statistics, and an analog-to-digital converter that converts analog data into digital for further processing. The data processing subsystem includes memory and a central processing unit, allows you to store and process both sensor-generated data and the service data necessary for the correct and efficient operation of the communication subsystem.

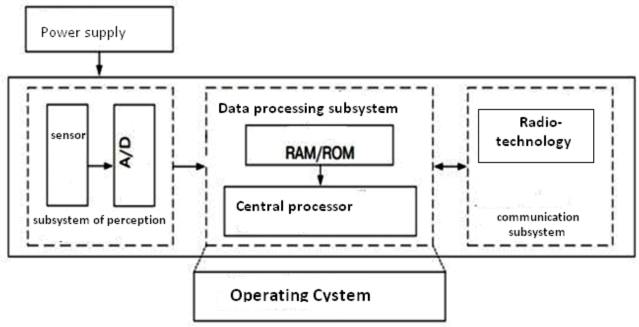

Fig. 3. Sensor architecture

The most important technical aspects of the sensor implementation are the small size of a telecommunication device with complex functions. Today, the minimum requirements for the hardware part of the sensor can be as follows: the frequency of the central processor is 20 MHz, the amount of RAM is 4 KB, the transmission rate is 20 kbit/s. Hardware optimization allows you to reduce the size of the sensor, however, as a rule, it causes an increase in its price. Optimization of the operating system (OS), taking into account the architecture of the used CPU is necessary. Today's most popular is the open source Tiny OS, which allows you to flexibly handle the sensors of various developers. Power requirements impose significant limitations on radio technologies that can be effectively applied in sensor networks. Moreover, the limited performance of the CPU does not allow the use of standard routing protocols for IP networks, but the high complexity calculation of the algorithm of the optimal path overload the central processor of the sensor. A large number of special routing protocols for sensor networks have been developed. In addition to the classical architecture of the sensor node, others are possible, due to the need not only to monitor or control the measured characteristics, but also to influence the objects of measurements. Such an element that has the ability to influence the object is called an actor.

One of the most important parameters when constructing sensory networks is energy consumption. Given that the sensor node can serve as both a terminal and a transit node, increasing the life of the power supply is one of the priority tasks, which is solved not only by increasing the life of the power source, but also through its efficient use.

Taking into account the known classical energy consumption ratio by the mobile node, which indicates that the ratio of energy consumption in the "transmission; receptions; standby mode; sleeping mode "is given in the ratio" 13:9:7:1", intensified attention is paid to reducing the time of transmission and reception of information and increasing the proportion of time when the sensor is in standby or hibernation mode. This should be taken into account when designing routing algorithms.

3. Sensor architecture

Since the sensor network may not have a permanent infrastructure, it is hardly possible to use classic routing algorithms for sensor networks. In addition, in USN, data traffic can be generated so that the same information is obtained from different sensor nodes operating in any zone. In addition, sensor sizes and costs are limited in the same way as their resources: energy, memory, computing capabilities. Therefore, it's impractical to transmit the same information across the network from many sensor nodes. Proceeding from the above, when developing routing algorithms in wireless sensor networks, the following factors should be taken into account:

Self-organization. Sensory networks should be able to self-organize. Proceeding from this, computing capabilities, communication and management capabilities should be sufficient to ensure autonomous existence.

Energy efficiency. Sensor nodes are designed, as a rule, with the provision of battery power and, accordingly, the term of their operation is primarily determined by the power supply system. Minimization of power consumption is one of the most important research tasks in the field of wireless sensory networks.

Flexibility. Sensory network algorithms should be flexible enough to allow them to adapt to different USN implementations. The operating environment, the environment and the capabilities of the sensor node itself vary widely, although some conditions may be pre-predicted or even identified before the network is created.

Scalability. In wireless sensor networks, the number of sensor nodes depending on the task being solved can vary from a few hundred to thousands. It is no coincidence that in the Zig-Bee specifications, the number of sensor nodes located in the same zone can reach 64,000. The large-scale and high-bandwidth networks with a bandwidth limit should, moreover, provide services with a certain level of service quality.

Tolerance to failures. Unlike traditional networks, wireless sensor networks are organized randomly, and the interconnections of sensory nodes in them are also random in time. Sensory nodes may fail due to insufficient power supply, the emergence of critical conditions in the environment, the failure of the hardware, etc.

Accuracy and quality. Ensuring sufficient accuracy and actualization of information in real time is one of the most important tasks for a large number of USN implementations. The algorithms must ensure that the data is transmitted in the wireless sensor network at the right time and with a given probability. The ideal algorithm should ensure the timely transmission of information with a given accuracy and minimum power consumption.

4. Classification of routing algorithms in USN

At the development stages of the USN, various solutions were proposed for constructing network routing algorithms, taking into account the necessary features outlined above. The proposed USN routing algorithms can be grouped into different groups according to the criteria. In tabl. 1 shows a simple classification of routing algorithms in USN using a typical approach.

In a one-level network, all nodes play the same role and have the same functionality. The collected data is transmitted to the network using multi-directional routing. The algorithms in the one-level network should ensure the transfer of large amounts of transit information through the network and, of course, they are application-oriented. Basically, the algorithms for a one-level network are centralized, since their main task is to ensure the transit of data through a homogeneous touch network. In many cases, the algorithms for a one-level network are quite complex, since there is both a scaling and a dynamic change in the USN topology.

Table 1. Simple classification of routing algorithms

Criterion	Category	Examples
Network structure	One-level	SPAN
	hierarchical	ILEACH
Knowledge about resources	Based on residual energy	HEED
	On the basis of accuracy Location	Directed Diffusion
Management protocols	Centralized	SPAN
	Geographic	GFG
	Based on QoS	SAR
	Based on the theory of queues	COUGAR

The SPIN (Sensor Protocols for Information viaNegotiation) and DD (Direct Diffusion) algorithms are basic for a one-level wireless sensor network, and all the subsequent one-level algorithms are developed on their basis.

In hierarchical networks, sensor nodes play different roles, and there are two categories of sensor nodes: the main cluster node CH (Cluster Head) and members of the cluster. A higher level of sensory nodes collects information from cluster members and controls a lower level. After aggregation of data, nodes of a higher level, if necessary, direct it to the next level. The main nodes of the clusters interact with the nodes of the public communications network. Each main node collects data from the nodes of its cluster, aggregates them and passes on. All hierarchical routing algorithms should provide the choice of the best CH. Since the cluster's main nodes are responsible for gathering, aggregation, and transmitting data over quite long distances, they should be more energy independent than just cluster members. The algorithms for selecting the master cluster node assume rotation and redistribution of the cluster main node periodically depending on the distribution of the load as a whole through the wireless sensor network and other factors such as power consumption, coverage, etc.

At the development stages of the USN, various solutions were proposed for constructing network routing algorithms, taking into account the necessary features outlined above. The proposed USN routing algorithms can be grouped into different groups according to the criteria. In a one-level network, all nodes play the same role and have the same functionality. The collected data is transmitted to the network using multi-directional routing. The algorithms in the one-level network should ensure the transfer of large amounts of transit information through the network and, of course, they are application-oriented. Basically, the algorithms for a one-level network are centralized, since their main task is to ensure the transit of data through a homogeneous touch network. In many cases, the algorithms for a one-level network are quite complex, since there is both a scaling and a dynamic change in the USN topology. The SPIN (Sensor Protocols for Information viaNegotiation) and DD (Direct Diffusion) algorithms are basic for a one-level wireless sensor network, and all the subsequent one-level algorithms are developed on their basis [4, 7].

Consider algorithms for hierarchical wireless sensor networks. The main problem in creating algorithms for such networks is the choice of the main node of the cluster. There are two approaches to choosing the main cluster node: random choice and preference choice.

Let's consider the algorithm of random selection of the main node, using which the rotation of the main nodes can be performed among all members of the cluster, taking into account their characteristics at the current time. The LEACH (Low-Energy Adaptive Clustering Hierarchy) hierarchical low-energy clustering algorithm involves ensuring the balance of energy consumption of the wireless sensor network. The LEACH algorithm is basic. There are many algorithms based on it. The basic idea behind LEACH is to: touch nodes can be randomly selected as the main ones based on information about their functioning at a pre-emptive point in time. In this case, in the cluster, each sensor node generates a random number from the interval [0, 1]. Each sensor node has a threshold Th (LEACH) corresponding to a predetermined number of main sensor nodes in the network. If the integer random number is less than Th (LEACH), then the touch node may become the main one; otherwise this node remains only a member of the cluster. The Th (LEACH) calculation is a key task in implementing the LEACH algorithm.

LEACH is a very effective algorithm. It reduces power consumption by 7 and more times compared with the direct interaction of sensor nodes and 4 to 8 times in comparison with other routing algorithms.

In hierarchical networks, sensor nodes play different roles, and there are two categories of sensor nodes: the main cluster node CH (Cluster Head) and members of the cluster. A higher level of sensory nodes collects information from cluster members and controls a lower level. After aggregation of data, nodes of a higher level, if necessary, direct it to the next level. The main nodes of the clusters interact with the nodes of the public communications network. Each main node collects data from the nodes of its cluster, aggregates them and passes on. All hierarchical routing algorithms should provide the choice of the best CH. Since the cluster's main nodes are responsible for gathering, aggregation, and transmitting data over quite long distances, they should be more energy independent than just cluster members. The algorithms for selecting the master cluster node assume rotation and redistribution of the cluster main node periodically depending on the distribution of the load as a whole through the wireless sensor network and other factors such as power consumption, coverage, etc.

Comparing the one-level and hierarchical routing algorithms, it can be noted that hierarchical algorithms provide more possibilities for the introduction of USN. The research noted the following characteristics of hierarchical algorithms:

- hierarchical network routing is an effective way of reducing energy costs;
- hierarchical routing allows you to flexibly solve various tasks based on the capabilities of sensor nodes. Hierarchical routing allows you to balance network load;
- hierarchical routing allows you to simply implement a schedule and avoid collisions;
- hierarchical routing is easy to implement.

Although one-level routing can use optimal routes, its implementation is usually quite complicated. The limited capabilities of sensor nodes can be a problem for the implementation of complex algorithms and schemes. Hierarchical routing involves the division of compounds into the internal cluster and external ones. Only the main node of the cluster is responsible for the external connections, while the cluster members interact only on the internal cluster level. This simple routing reduces the number of messages in the cluster [5].

5. Conclusion

The article deals with the architecture and routing algorithms of sensor networks. It is determined that further improvement of the work of such networks requires standardization of the development process and implementation process.

References

[1] Akyildiz I.F.: Key Wireless Networks Technological in the Next Decade. NEW2AN 2006, St. Petersburg, Russia June 2006.
[2] Berkman L.N., Tolupa S.V.: The architectural concept of construction, the principle of implementation, the efficiency of the application of intelligent telecommunication network. Problematic sciences works of VITI NTUU-KPI 3/2007, 9–17.
[3] Burov E.: Computer networks. Baku, Lviv 1999.
[4] Golishko A.: IMS: useful recommendations. CONNECT 5/2009, 2–6.
[5] Retana A., Slice D., Ras U.: Principles of Designing Corporate IP Networks. Williams Publishing House 2002.
[6] Steklov V.K, Kilchytsky Ye.V.: Fundamentals of management of networks and telecommunication services. Technique, Kiev 2002.
[7] Tikhvin O.V., Terentyev S.V.: SV LTE mobile communication networks and architecture. Moscow, Eco-Trend Publishing House 2010.
[8] Ujukha T.: Prospects of SDN on a telecom. Market. Technologies and media 2(107)/2015, 52–54.

Prof. Sergey Toliupa
e-mail: tolupa@i.ua

Scientific and practical interests are related to such areas as intelligent control systems, the direction of improving the efficiency of information technology, information security systems, cybersecurity and cyber defense. He is the author of 5 monographs and over 150 scientific and methodological works, 16 textbooks and manuals.

Prof. Yuriy Kravchenko
e-mail: kr34@ukr.net

The branch of scientific interests is the functional stability of computer and other complex technical systems. The author of more than 100 scientific works and inventions.

Ph.D. Aleksander Trush
e-mail: trush.viti@gmail.com

Scientific and practical interests are related to such areas as information and communication systems and networks, systems of technical protection of information, cyber defense. He is the author of over 35 scientific and methodological works, 2 textbooks.

otrzymano/received: 10.10.2017 *przyjęto do druku/accepted: 15.02.2018*