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Developing the idea of clustering networks of the Internet of things

E.V. Gorina [1], *Ph.D. (Engineering), elena_rez@mail.ru*
F. Bimbetov [2], *Postgraduate Student, fbimbetov@gmail.com*
T.M. Tatarnikova [2,3], *Dr.Sc. (Engineering), Professor, tm-tatarn@yandex.ru*

[1] *Saint-Petersburg State University of Industrial Technologies and Design, St. Petersburg, 191186, Russian Federation*
[2] *Saint Petersburg Electrotechnical University, St. Petersburg, 197376, Russian Federation*
[3] *Saint Petersburg State University of Aerospace Instrumentation, St. Petersburg, 190000, Russian Federation*

The development of new algorithms, methods and technologies that help reduce energy consumption in Internet of Things networks is a relevant task. Sensor nodes of the Internet of things consume limited energy resources when performing computing operations, receiving and transmitting data. One of the well-known approaches to reduce the energy consumption of sensor nodes is network clustering. The head node of the cluster assumes the functions of a relay of data from sensor nodes.

The paper proposes an algorithm that develops the idea of clustering networks of the Internet of things. The algorithm is based on bee swarm intelligence that assumes determining the current round cluster head and potential heads of clusters for subsequent rounds of the cycle immediately at the be-ginning of the cycle. Thus, the phase of choosing the cluster head node becomes redundant starting from the second round of the cycle, and sensor nodes do not need to perform energy-intensive calcula-tions associated with choosing the cluster head.

The simulation results show the superiority of the bee swarm algorithm in comparison with the well-known LEACH adaptive clustering algorithm with low energy consumption in terms of the duration of a wireless sensor network.

Keywords: *sensor networks, clustering, Internet of things, bee swarm algorithm, power consumption, simulation modeling.*

The fifth-generation (5G) communication networks and new service types are a particularly relevant topic of research over the past 5–7 years [1]. Moreover, the achieved results that manifested themselves in a wide variety of new types of services based on the concept of the Internet of things made it possible to think about a smooth transition to the concept of communication networks in 2030 [2].

It should be noted that the direction of using artificial intelligence in communication networks is developing in parallel with infocommunication technologies. The topic of using artificial intelligence in information and communication technologies has appeared relatively recently and is of increasing interest, the reason for which is in the need to process and analyze big data generated by smart devices of the Internet of things [3, 4].

The physical basis of the Internet of things is *wireless sensor networks* (WSN), one of the most important limitations of which is the requirement for low power consumption by sensor nodes. Sensor nodes implement the smart functions of the Internet of things.

It turns out that energy consumption determines the WSN service life that can be measured by the following metrics [5]:

- the number of nodes that continue to function (have the energy to work);
- the duration of the WSN operation until the moment of "death" of the first WSN node;
- packet delivery ratio – the ratio of the number of packets delivered to the recipient to the number of sent packets.

Thus, if the traditional network protocols are aimed at achieving high quality of service (QoS), then the protocols of the Internet of things should be primarily focused on energy saving [6].

Problem statement

The energy of sensory devices is spent on receiving and transmitting data, processing them, calculating the route, etc. Thus, choosing a method for organizing information interaction is one of the urgent scientific tasks when creating WSN. Most modern research is devoted to developing schemes that meet the requirements for reducing the number of operations when organizing the interaction of sensor nodes. For example, such mechanism that allows reducing energy consumption is WSN clustering due to the transfer of sume functions to the cluster head nodes [7]. WSN is constructed as a set of clusters into which the sensory field it creates is divided. In each WSN cluster, the head of the cluster (head node) acts as a relay of data received from the sensor nodes belonging to this cluster. Further, the cluster head transmits the collected data to the base station, which in turn delivers them to the global cloud [8].

The timing diagram of the clustered WSN functioning is shown in Figure 1.

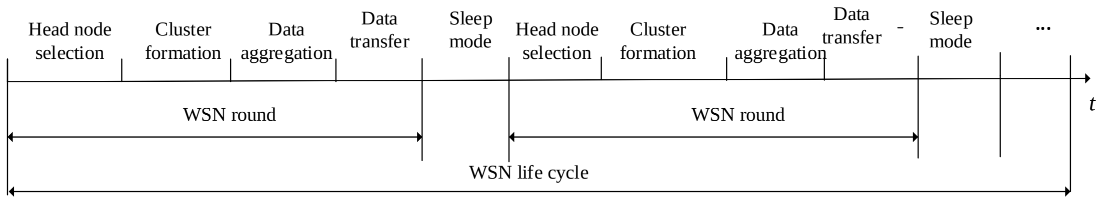


Fig. 1. Time diagram of the clustered WSN life cycle

Each round of WSN functioning involves sequential performing of the following actions:

– choosing the head of the cluster that implements the functions of a data relay, from sensor nodes to the base station based on the Euclidean distance and the residual energy level metrics [9];

– forming a cluster based on the metric of the Euclidean distance from the sensor node to the head node;

– data transmission: first, data sending schedule from the cluster head to all its sensor nodes and, second, the actual data itself from sensory devices to the cluster head using the TDMA method (Time Division Multiple Access), which guarantees the absence of data transmission collisions [10];

– data aggregation at the cluster head - combining data received from sensor nodes including screening out incorrect and duplicate data [11];

– transition to sleep mode that involves sensory devices going into a reduced power consumption mode.

Thus, the WSN functioning duration is made up of *r* rounds.

Despite the presence of a clustering mechanism, researchers are still looking for ways to reduce the WSN energy consumption. The paper proposes one of the algorithms that develops the idea of WSN clustering in order to reduce the power consumption of sensor nodes.

Proposed algorithm

We propose to immediately determine the cluster head of the current round and potential cluster heads for the remaining (r–1) cycle rounds not in each round but only at the beginning of the cycle. Potential cluster heads are sensory nodes that are close to the current cluster head in terms of the Euclidean distance metric and the residual energy level. Thus, the phase of choosing the cluster head node becomes superfluous starting from the second round of the cycle, and sensor nodes get rid of some calculations associated with choosing the cluster head.

The proposed algorithm is based on swarm intelligence. Swarm intelligence is a set of algorithms aimed at studying and describing the collective behavior of a decentralized self-organizing system that include WSN. System elements are simple agents with a small set of performed operations, which together create a single swarm intelligence capable of solving search engine optimization problems. Each movement of an agent is characterized by a certain position in the study area, its objective function value is calculated and it is the basis for making a decision to explore the nearby area.

In the proposed algorithm, the agents are scout bees and forager bees who randomly move with a constant step in the selected area of the objective function. The main goal of a bee colony is to search for nectar - the optimal value of the objective function.

First, several scout bees go to explore the area and to identify the most honey-bearing areas in search of the largest accumulation of nectar. Then the scout bees return to the hive and tell forager bees where to collect the nectar. Forager bees follow the scout bee and arrive not at one point but spread over a certain area located not far from the initial place of nectar accumulation. Thus, forager bees can find and remember both the most promising and less promising places. Table 1 shows the adaptation of the terms of the bee swarm algorithm to the optimization problem.

The algorithm consists of the following steps.

1. Initial data input:
   – the number of sensor nodes N;
   – the number of scout bees X;
   – the number of best areas B;
   – the number of promising areas P;
   – the radius of the neighborhood R, in which a bee performs a search;
   – the length a and width b of the area under study;
   – the movement step value for studying the plane Δ.

2. Sending scout bees – a random selection of X points on the investigated plane: X = random.uniform(a, b).
3. Evaluating the obtained values of the objective function X points and selecting the best B and promising P areas.
4. Random selection of l points in the best areas and p points in promising areas ($l > p$), the neighborhood of each point is given by coordinates with R radius.
5. Checking for the intersection of areas and the occurrence of the selected points of each type in each other's neighborhood. For this purpose we use the Euclidean distance metric: $d(x, y) = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$, $d > R$.
6. Studying the neighborhoods of each of the l and p selected points in search of the best and most promising areas.
7. Repeating steps 2-6 until the stop condition is met.

Table 1

Adaptation of the bee swarm algorithm terms to the optimization problem

The term of the bee swarm algorithm	The optimization problem term
Nectar	Objective function extremum
Swarm of bees	Array of all coordinates of the investigated plane
Nectar search neighborhood	Neighborhood of the selected point
Scout bees	Randomly selected points of the investigated plane
Best areas	Points at which the objective function value reaches an extremum
Promising areas	Points where the objective function value is close to the value of the best areas
Forager bees	Number of points in the vicinity of the best and promising areas

Result analysis

We tested the performance of the bee swarm algorithm and the assessment of the accuracy of finding the best and most promising areas on known mathematical functions; the results are shown in Table 2.

The obtained results prove to the ability of the bee swarm algorithm to solve optimal and suboptimal problems.

The results of simulation modeling show the superiority of the bee swarm algorithm in comparison with the well-known low-energy adaptive clustering algorithm LEACH (Low-Energy Adaptive Clustering Hierarchy) [9] in terms of the duration of the BSN functioning. The simulation model features are presented in detail in [12] with adding the bee swarm procedure.

The simulation was carried out with the following initial data:

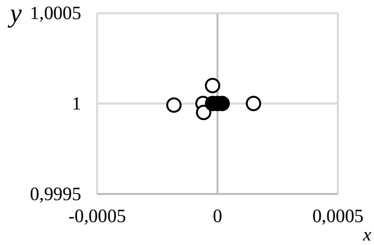
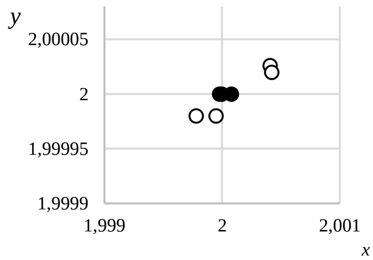
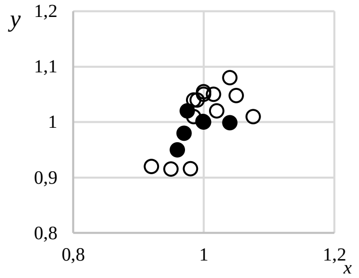
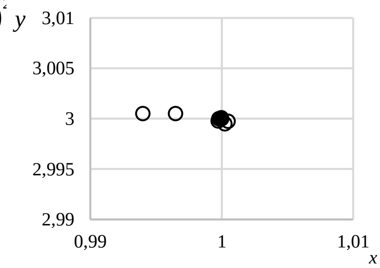
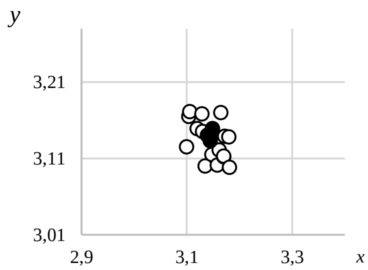
– N= 100;
– a = 100 m, b = 100 m;
– average length of a data packet $\overline{L} = 32$ bit;
– energy consumed for data collection E_a = 5 nJ;
– residual energy of the sensor node E = 0,5 J;
– d = 40 m;
– duration of one round is 1 s;
– data transfer rate 9 600 bps;
– generation energy of one bit E' =10 nJ;
– transmission energy of one data bit E'' = 50 nJ.

The downfall of the first WSN sensor node with the search for the cluster head using the LEACH algorithm occurred at the 645th round, and for the WSN with the search for the cluster head using the bee swarm algorithm – at the 847th round. Choosing a cluster head according to the algorithm of a bee swarm allows saving energy and, therefore increasing the duration of WSN life cycle. We should note that this saving will only grow with the increasing number of sensor nodes in the cluster and the number of rounds in the WSN operation cycle.

Figure 2 shows the change in the value of a data packets delivery coefficient from sensor nodes to the head node over the time of WSN operation. It is obvious that the delivery rate of 100% in the WSN when choosing the cluster head according to the bee swarm algorithm remains longer than with the LEASH algorithm due to the energy savings obtained.

Table 2

Search results for the best and promising areas in test functions

Function	Function notation	Searching results: ○ promising areas, ● best areas	Error value	Search time, s
Sinus	$f(x)=\dfrac{\sin(x)}{x}$		$2{,}7\cdot10^{-5}$	$8\cdot10^{-7}$
Parabola	$f(x)=(x-2)^2-2$		$5\cdot10^{-4}$	$6\cdot10^{-7}$
Rosenbrock	$f(x,y)=(1-x)^2+100\left(y-x^2\right)^2$		$4\cdot10^{-3}$	$4\cdot10^{-7}$
Booth	$f(x,y)=(x+2y-7)^2+(2x+y-5)^2$		$4\cdot10^{-4}$	$6\cdot10^{-7}$
Easom	$f(x,y)=-\cos(x)\cos(y)\times$ $\times\exp\left(-\left((x-\pi)^2+(y-\pi)^2\right)\right)$		$2\cdot10^{-3}$	$5\cdot10^{-7}$

Conclusion

The choice of the information interaction method is one of the relevant scientific tasks when organizing the Internet of things.

In order to rationally use the energy that is necessary for the functioning of the Internet of things, we propose to determine not only the cluster head, but also sensor nodes close to it in terms of the objective function value at the beginning of the clustering procedure. The objective function is the residual energy level and the Euclidean

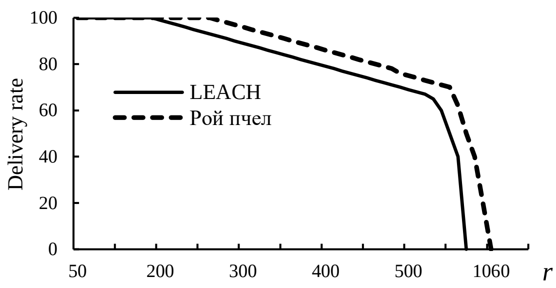


Fig. 2. The dependence of the value of the data packet delivery coefficient on the WSN operation duration

distance metric. Thus, the phase of choosing the cluster head node starting from the second round of the cycle becomes unnecessary, and the sensor nodes get rid of some calculations associated with choosing the cluster head.

The simulation modeling results show the advantage of adding the bee swarm algorithm to the WSN clustering procedure in terms of such WSN quality indicators as the time of the first sensor node downfall, the number of functioning nodes that have enough energy to perform their inherent operations, and the data package delivery rate.

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Развитие идеи кластеризации сетей интернета вещей

Е.В. Горина [1], *к.э.н., elena_rez@mail.ru*
Ф. Бимбетов [2], *аспирант, fbimbetov@gmail.com*
Т.М. Татарникова [2,3], *д.т.н., профессор, tm-tatarn@yandex.ru*

[1] *Санкт-Петербургский государственный университет промышленных технологий и дизайна, г. Санкт-Петербург, 191186, Россия*
[2] *Санкт-Петербургский государственный электротехнический университет «ЛЭТИ» им. В.И. Ульянова (Ленина), г. Санкт-Петербург, 197376, Россия*
[3] *Санкт-Петербургский государственный университет аэрокосмического приборостроения, г. Санкт-Петербург, 190000, Россия*

Разработка новых алгоритмов, методов и технологий, способствующих снижению энергопотребления в сетях интернета вещей, является актуальной задачей. Сенсорные узлы интернета вещей расходуют ограниченные энергетические ресурсы при выполнении вычислительных операций, операций приема и передачи данных. Одним из известных подходов к снижению потребления энергии сенсорными узлами является кластеризация сети. Головной узел кластера берет на себя функции ретранслятора данных, поступающих от сенсорных узлов.

В статье предлагается алгоритм, который развивает идею кластеризации сетей интернета вещей. Алгоритм основан на интеллекте роя пчел, согласно которому сразу в начале цикла определяются глава кластера текущего раунда и потенциальные главы кластеров для последующих раундов цикла. Таким образом, фаза выбора головного узла кластера, начиная со второго раунда цикла становится лишней, а сенсорным узлам нет необходимости выполнять энергоемкие вычисления по выбору главы кластера.

Ключевые слова: *сенсорные узлы, кластеризация, интернет вещей, алгоритм роя пчел, энергопотребление, имитационное моделирование.*

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