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S. BHUSHAN[1], S. ANTOSHCHUK[2]

India, Delhi, [1]School of Computer and Information Science, Indira Gandhi National Open University; Ukraine, [2]Odesa National Polytechnic University

E-mail: s.bhushan2k5@gmail.com, asgonpu@gmail.com

A HYBRID APPROACH TO ENERGY EFFICIENT CLUSTERING FOR HETEROGENEOUS WIRELESS SENSOR NETWORK

Meta-heuristic methods have shown good efficiency in solving optimization problems related to a wide range of practical applications in wireless sensor networks (WSN). Biogeography based optimization (BBO) is an evolutionary technique inspired by the migration of species between habitats which have been applied in solving global optimization problems. The article presents a hybrid approach for clustering wireless sensor networks that combines the meta-heuristic algorithm BBO, and K-environments. The simulation results show that the proposed approach (named KBBO) significantly improved the efficiency of such WSN parameters as stability time, lifetime, residual energy and throughput.

Keywords: clustering, network life time, stability period, BBO, optimization.

A wireless sensor network (**WSN**) consists of a large number of sensor nodes which can sense physical properties of environment such as humidity, temperature, sound, etc., collect sensed data and transmit it to the base station through a wireless link. Sensor nodes are characterized by limited energy, low processing capability, low communication range and low memory capacity. Recently, sensor nodes have become smarter and cheaper due to development in micro-electro-mechanical systems (**MEMS**) [1]. Due to availability of smarter and cheaper sensors, WSN has received wide acceptability with potential application in large domains: environment monitoring, disaster warning systems, health systems and military applications [2]. Unlike a traditional network, the major research challenge in WSN is how to maximize the network lifetime by reducing energy consumption of the sensor nodes.

Clustering is a key technique to reduce energy consumption and extend the lifetime of the network. Besides reduction in energy consumption and extending network lifetime, clustering technique has many other advantages: scalability, latency reduction, collision avoidance, less overhead and load balancing [3]. Selection of cluster heads (**CHs**) in energy efficient clustering mechanisms depends upon several factors: residual energy of a node, initial energy, average energy of a network and energy consumption of the node [4].

Clustering is also a key technique for implementing energy efficient routing in WSN. Low energy-adaptive cluster hierarchy (**LEACH**) [5], standard evaluation protocol (**SEP**) [6], hybrid energy-efficient distributed clustering (**HEED**) [7] and power-efficient gathering in sensor information systems (**PEGASIS**) [8] are some prominent clustering-based routing protocols. The probabilistic models are used to select CHs in these protocols which may result in random selection of CHs irrespective of distribution of nodes and the residual energy of the network. In recent days a number of metaheuristic techniques such as genetic algorithm (**GA**) [9], particle swarm optimization (**PSO**) [10] and biogeography based optimization (**BBO**) [11] have been applied in design of energy-efficient clustering-based routing protocols for WSN. Intelligent hierarchical clustering routing (**IHCR**) [12] and evolutionary routing protocol (**ERP**) [13] are two important protocols.

Heuristic approach for finding a solution to optimal CHs in WSNs is not easy, because this is an NP-complete problem [14]. A total time complexity to find the optimal solution increases exponentially with the increase in the network size. BBO has been found to be a powerful search and optimization technique, because it combines both exploration and exploitation features based on migration [15]. BBO, like GA, is an evolutionary algorithm applied to solve global optimization problems. In this work, a BBO-based clustering technique is used to search for appropriate cluster heads that would allow for optimal resulting clusters. To have good quality habitats, *K*-means clustering is applied to seed the population of the BBO protocol. *K*-means clustering [16] is one of the most popular data clustering techniques which partitions the data into K-clusters, so that similar data is put in the same cluster.

The main contribution of the paper is the following:

— population initialization through K-means clustering to select good quality features in a habitat;

— clustering through the BBO protocol;

— performance comparison with high performance heuristic and metaheuristic techniques.

Literature Survey

Many heuristic techniques have been proposed for cluster based routing for WSNs. LEACH is the most prominent protocol which does load balancing by dynamically rotating CHs among sensor nodes in order to save energy. However, the main drawback is that a selection of a CH is done probabilistically. As a result, a node with very low energy may be selected as a CH which may not last for a long time. Therefore a large number of protocols have been proposed to improve the performance of LEACH such as SEP, HEED and PEGASIS, and its variants.

Besides heuristics, several metaheuristic techniques have been used for design of energy-efficient clustering and routing. Martin et al. [12] have used GA for energy efficient cluster-based routing to extend the network lifetime and minimize the energy consumption of the network. Its cluster head selection process is based on multi-objective parameters: the sum of all distances from sensor nodes to the CH and from the CH to the base station, the sum of distances from sensors node to CH, distances from the CH to the sink, standard deviation in cluster distance, transfer energy and number of transmissions.

Bara'a et al. [13] have further enhanced the clustering parameters of IHCR by adding three parameters: intra-cluster distance, inter-cluster distance and the number of CHs. Unlike the previous two algorithms, where GA has been used for CH selection, in [17] GA has been used for load balancing of CHs. Its fitness function is based on standard deviation of the gateway load to achieve even distribution of the load per cluster.

In [18] two algorithms (one for routing and one for clustering) using PSO have been proposed. The main objectives for routing is to minimize the maximum transmission distance between two nodes in the routing path and maximum hop count of the gateways, whereas clustering path of the algorithm achieves load balancing by minimizing distance between sensor nodes and their corresponding gateways.

In [19], the BBO-based clustering has been proposed. Metrics like clustering density and clustering head dispersion were used to select CHs. Similarly in [20], BBO-based clustering and multi-hop routing algorithms are proposed with different fitness functions. Multi-objective parameters which include residual energy of a CH, intra-cluster distance and distance between the CH and the base station. The formulation of fitness function for routing algorithm is based on residual energy, Euclidean distance and node degree. Unlike the above mentioned protocols, where population initialization is random, the proposed protocol follows the deterministic approach to population initialization. The entire population is seeded with K-means algorithm to have good quality genes. BBO will be used further for clustering.

An Overview of BBO

BBO [11] is a population-based optimization algorithm inspired by immigration and emigration of species (animals, birds, fish) between habitats (islands) in search of good living condition (rainfall, temperature, etc). Each candidate solution also called a habitat with a habitat suitability index **(HSI)**. Variables of an individual solution represents features of habitability are called suitability index variables **(SIVs)**. High HSI represents a good solution. The poor solution represents habitat with low HSI. The low HSI receives new features from high HSI. There are three kinds of operators in BBO namely, migration, elitism and mutation. Migration is used for information sharing. Elitism is used to keep best solution for the next generation. The objective of mutation is to increase exploration among the population. One unique feature of BBO is that the original population is not discarded after each generation unlike GA. Rather, it improves its solution in each iteration by changing its features (SIVs). Like PSO, BBO also shares its SIVs (features) with other solutions, but does it directly, while PSO shares information among solutions indirectly through a velocity variable.

The Proposed Protocol, KBBO

In the current work the authors propose a new hybrid evolutionary algorithm named KBBO which combines K-means and the BBO to solve the clustering problem in WSN. A combination of deterministic and metaheuristic approaches for population initialization and clustering respectively provide a good BBO-based clustering solution. The proposed protocol goes through several rounds. Each round has two phases: setup phase and steady state phase. In the setup phase, sensor nodes are partitioned into clusters. The setup phase of the algorithm is same as that of LEACH but based on BBO algorithm. In the second phase, each non-CH node uses its TDMA schedule to transmit its data to the base station through its respective CHs in multi-hop manner.

In BBO a habitat represents a set of sensor nodes elected as CHs, normal nodes and dead nodes. Therefore a size of a habitat is a number of sensor nodes in a network. A binary representation is used to distinguish nodes. CH is represented as 1, a non-CH node as 0 and a dead node. The habitat in the population is seeded with *K*-means algorithm.

In KBBO, the fitness function *F* is defined as follows:

$$F = \frac{intra\text{-}cluster\ distance}{inter\text{-}cluster\ distance} = \frac{\sum_{i}^{CH_k} \sum_{\forall S_j \in CH_i} d\left(S_j, CH_i\right)}{\sum_{i=1}^{CH_k} \sum_{\forall CH_i \neq CH_j} d\left(CH_i, CH_j\right)},$$

where C_j is a sensor node; C_i, CH_j are two different cluster heads; d denotes the Euclidean distance.

In order to achieve optimal clustering in WSN, intra-cluster distance must be minimized where as inter-cluster distance must be maximized.

GA based clustering algorithm in KGA has setup phase which is a clustering formation phase and steady phase in which intra-cluster and inter-cluster communication takes place. The setup phase of the algorithm is same as that of LEACH but based on BBO algorithm.

Simulation Results

Network Model

The following are the assumptions with respect to WSN in the proposed protocol:

— sensors are randomly deployed throughout the sensing area;

— sensor nodes are heterogeneous in terms of initial energy;

— energy consumption of the sensor node during data transmission depends upon the (i) distance between a sender and a receiver and (ii) the size of data;

— a node calculates distance to other nodes and CHs based on Euclidean distance;

— sensor nodes communicates with a sink node deployed in the middle through their respective CHs;

— nodes are stationary after deployment;

— communication links are symmetric.

Energy Model

In this work a simple radio model [5] is used to model the energy dissipation. The free space model (d^2 power loss) is employed in case the distance between the transmitter and the receiver is less than a threshold value d_0, otherwise multipath fading channel model (d^4 power loss) is employed. The energy consumption for a l bit message between two nodes at a d distance is calculated thus

$$ET_x(l, d) = E_{\text{elec}} \cdot l + \varepsilon_{fs} \cdot l \cdot d^2 \ \text{ at } d \le d_0, \quad ET_x(l, d) = E_{\text{elec}} \cdot l + \varepsilon_{mp} \cdot l \cdot d^4 \text{ at } d > d_0; \qquad (2)$$

$$ER_x(l, d) = E_{\text{elec}} \cdot l. \qquad (3)$$

where $ET_x(l, d)$ is l bit transmission energy consumption at a distance of d; $ER_x(l, d)$ is l bit receiving energy consumption; E_{elec} is per bit energy consumption of transmitter and receiver circuits; ε_{fs} and ε_{mp} refer to energy consumption factor of amplification for the free space and multipath fading models respectively.

Performance Metrics

The performance of KBBO has been compared with SEP, HCR and ERP on five metrics: network lifetime (number of alive nodes vs. number of rounds), residual energy, stability period and throughput for 10% and 20% advanced nodes. The results have been further validated quantitatively (through tables) The network and energy models are used as defined in LEACH.

— *Network lifetime*. It is defined as the number of rounds when all the nodes exhaust their energy and eventually they die.

— *Stability period*. It refers to the time interval from the start of the network operation (first round) until the first node dies.

— *Residual energy*. It measures the remaining energy of the network every round which is calculated by subtracting the energy consumed by the nodes from the total energy per round.

— *Number of alive nodes per round*. It refers to a number of advanced nodes or normal nodes whose residual energy values is greater than zero.

— *Throughput*. It is a number of packets received at the sink node from the CHs.

Simulation Settings

The protocol has been implemented using Intel Core i3 processor with 2GB RAM with 100 sensor nodes which are randomly deployed over the area of 100×100 m. The location of the sink is in the middle of the deployment area.The parameters for simulation settings are shown in **Table 1**.

Table 2 shows that the stability of the KBBO protocol is better than that of SEP and HCR for the case of 20% advanced nodes.

Network Lifetime

Network lifetime can be shown by capturing the number of live nodes at each round till every node in the network dies. To clearly depict the effectiveness of the proposed algorithm, the results are shown quantitatively in **Tables 3** for 10% and 20% of advanced nodes in the network

Table 1

Parameters setting for simulation

Description	Value
Network size	100×100 m
Location of sink, BS	(50, 50)
Number of nodes, n	100
Initial energy of nodes, E_0	0,5 J
Proportion of advanced nodes, m_0	0,1
Energy factor for advanced nodes, α	1
Energy dissipated per bit, E_{elec}	50 nJ/bit
Transmit amplifer if $d_{BS} \le d_0$, E_{fa}	10 pJ/bit/m^2
Transmit amplifer if $d_{BS} > d_0$, E_{mp}	0.0013 pJ/bit/m^4
Data aggregation energy by CH, E_{DA}	5 nJ/bit/message
Size of data packet	4000 bits

Table 2

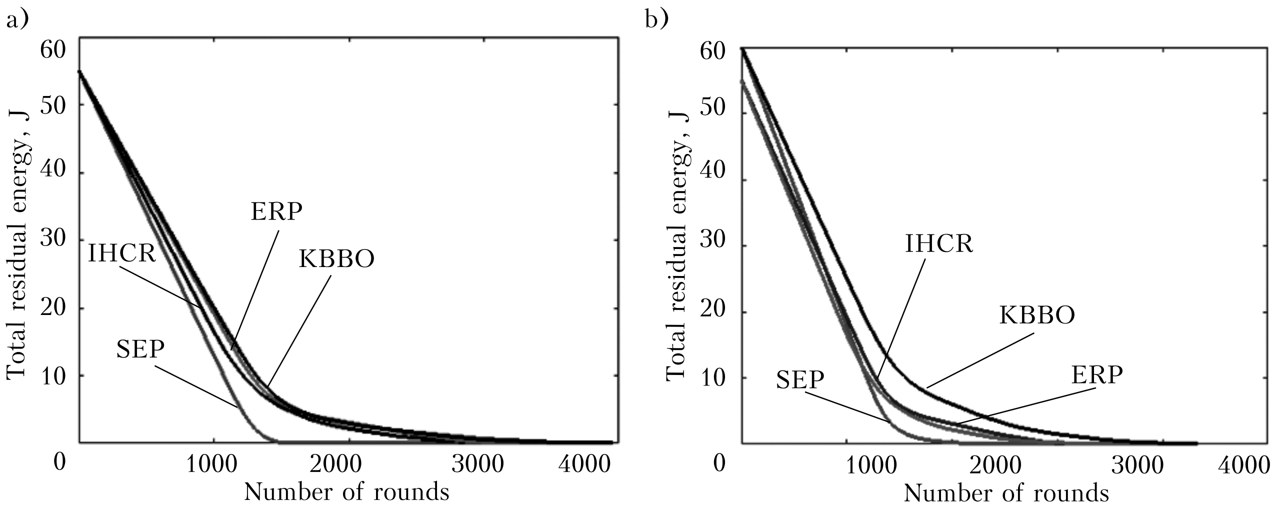
Stability period for different protocols for different number of advanced nodes M

M	SEP	HCR	ERP	KBBO
10%	864	914	1012	888
20%	999	920	1079	1034

Table 3

Round history of dead nodes for different number of advanced nodes M

Dead nodes, %	M = 10%				M = 20%			
	SEP	HCR	ERP	KBBO	SEP	HCR	ERP	KBBO
10	1153	1047	1205	1225	1185	1050	1190	1204
20	1204	1099	1256	1283	1219	1146	1258	1308
30	1232	1159	1295	1342	1250	1208	1312	1363
40	1278	1255	1364	1386	1284	1276	1364	1432
50	1300	1303	1390	1431	1323	1353	1408	1494
60	1328	1372	1432	1516	1368	1430	1480	1573
70	1370	1459	1535	1622	1424	1569	1572	1719
80	1445	1940	1683	1720	1529	1928	1887	2086
90	1494	1956	2445	2123	1791	2529	2747	2938
100	1563	3220	3317	3952	2236	3536	3673	4336



Dependence of the residual energy on the number of rounds for 10% (a) and 20% (b) of advanced nodes respectively. Table 3 shows that in case of KBBO, nodes die much later than in case of SEP, HCR and ERP. In the KBBO 10% of nodes die at the 1225th round while in other protocols, nodes died very early — at the 1153th, 1047th, and 1205th round for SEP, HCR, and ERP respectively. In KBBO, all nodes die only at the 3952nd round (at the 1562nd round in SEP, at 3220th round in IHCR and at 3317th round in ERP). With 20% advanced nodes, the performance of KBBO is significantly better than that of ERP.

Residual Energy

Figure shows the comparison of KBBO with the other protocols in terms of residual energy versus number of rounds with 10% and 20% of advanced nodes. The curve is less steep due to fairness in the energy load distribution and gradual dissipation of energy in the proposed protocol.

Conclusion

Many clustering-based routing techniques have been proposed in order to save energy and extend the network lifetime. LEACH is the most prominent protocol but it has its own limitation. Selection of CHs is done probabilistically and the network lifetime is not maximized significantly. Selection of optimal CHs in WSN is an optimization problem. Metaheuristic techniques offer an effective alternative for solving optimization problems. In this paper, a new protocol KBBO is proposed based on the BBO. BBO is the latest evolutionary technique for solving optimization problems. The proposed technique is explained through population initialization, setup phase and transmission phase algorithms. The performance of KBBO has been rigorously tested and compared with SEP, IHCR and ERP on several metrics: network life time (number of alive nodes vs. number of rounds), residual energy, stability period and throughput for 10% and 20% of advanced nodes. The results have been further validated quantitatively (through tables). The results show the superiority of the KBBO protocol over several parameters.

REFERENCES

1. Jennifer Yi., Mukherjee B., Ghosal D. Wireless sensor network survey. *Computer networks*, 2008, vol. 52, no 12, pp. 2292-2330.

2. Akyildiz I.F., SuWeilian, Sankarasubramaniam Y., Cayirci E. A Survey on Sensor Networks. *IEEE Communications Magazine*, 2002, vol. 40, no 8, pp. 102-114.

3. Xuxun L. A survey on clustering routing protocols in wireless sensor networks. Sensors, 2002, vol. 12, no 8, pp. 11113-11153.

4. Katiyar Vi., Narottam Ch., Surender So. Clustering algorithms for heterogeneous wireless sensor network: A survey. *International Journal of Applied Engineering Research*, 2010, vol. 1, no 2, p. 273.

5. Heinzelman W. B., Chandrakasan A. P., Balakrishnan H. An application-specific protocol architecture for wireless microsensor networks. *IEEE Transactions on wireless communications*, 2002, vol. 1, no 4, pp. 660-670.

6. Smaragdakis G., Matta I., Bestavros A. *SEP: A stable election protocol for clustered heterogeneous wireless sensor networks*. Boston University Computer Science Department, 2004.

7. OssamaYo., Fahmy So. HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. *IEEE Transactions on mobile computing*, 2010, vol. 3, no 4, pp. 366-379.

8. Lindsey S. PEGASIS: Power-efficient gathering in sensor information systems. *IEEE Aerospace conference proceedings*, 2002, vol. 3.

9. Michalewicz Zb. *Genetic algorithms + data structures = evolution programs*. Springer, 2009.

10. Kennedy J. Particle swarm optimization. *Encyclopedia of machine learning*, Springer US, 2011, pp. 760-766.

11. Simon D. Biogeography-based optimization. *IEEE transactions on evolutionary computation*, 2008, vol. 12, no 6, pp. 702-713.

12. Matin A. W., Hussain S. *Intelligent hierarchical cluster-based routing*. 2006, vol. 7, 8 p.

13. Bara'a A. A., Khalil E. A. A new evolutionary based routing protocol for clustered heterogeneous wireless sensor networks. *Applied Soft Computing*, 2012, vol. 12, no. 7, pp. 1950-1957.

14. Basagni S. A. generalized clustering algorithm for peer-to-peer networks. *Proc. Workshop on Algorithmic Aspects of Communication*, 1997.

15. Ma H., Simon D., Siarry P., Yang Z., Fei M. Biogeography-based optimization: A 10 year review. *IEEE transaction on emerging topics in computational intelligence*, 2017, vol. 9, no 5, pp. 391-407.

16. Han J., Kamber M. *Data Mining: Concepts and Techniques*. Morgan Kaufman Publishers. 2006.

17.Kuila Pr., Suneet K.G., Prasanta K. J. A novel evolutionary approach for load balanced clustering problem for wireless sensor networks. *Swarm and Evolutionary Computation,* 2013, no 12, pp. 48-56.

18. Kuila Pr., Prasanta K. J. Energy efficient clustering and routing algorithms for wireless sensor networks: Particle swarm optimization approach. *Engineering Applications of Artificial Intelligence*, 2014, no 33, pp. 127-140.

19.Raju P., Pandey H. M. A., Saraswat M. BEECP: Biogeography optimization-based energy efficient clustering protocol for HWSNs. *Ninth International Conference on IEEE.Contemporary Computing*, 2016.

20. Lalwani Pr., Haider B., Chiranjeev K. BERA: A biogeography-based energy saving routing architecture for wireless sensor networks. *Soft Computing*, 2016, pp. 1-17. http://10.0.68.77/ijst/2015/v8i16/61986

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Ш. Ш. БХУШАН[1], С. Г. АНТОЩУК[2]

Індія, Делі, [1]Національний відкритий університет Індіри Ґанді
Україна, [2]Одеський національний політехнічний університет
E-mail: s.bhushan2k5@gmail.com, asgonpu@gmail.com

ГІБРИДНИЙ ПІДХІД ДО ЕНЕРГОЕФЕКТИВНОЇ КЛАСТЕРІЗАЦІЇ ДЛЯ ГЕТЕРОГЕННОЇ БЕЗДРОТОВОЇ СЕНСОРНОЇ МЕРЕЖІ

Гетерогенні бездротові сенсорні мережі (БСМ) сьогодні знаходять широке застосування у моніторингу навколишнього середовища, в системах безпеки, охорони здоров'я та військовій сфері. Основною проблемою БСМ є необхідність максимізувати час життя мережі, зменшуючи при цьому споживання енергії вузлів сенсора. Для її вирішення удосконалюють протоколи маршрутизації за рахунок удосконалення процедури кластерізації для БСМ. Метаевристичні методи показали гарну ефективність при вирішенні задач оптимізації, пов'язаних з широким спектром практичних застосувань в бездротових сенсорних мережах. Оптимізація на основі біогеографії (BBO) — це еволюційний метод, заснований на міграції видів між середовищами існування, який широко застосовується при вирішенні завдань глобальної оптимізації. Визначено завдання оптимізації в термінах і позначеннях моделей біогеографії: кожний острів представляє одне рішення, відображене ознакою життєздатності — цільовою функцією, значення якої є індексом придатності острова-рішення. Хороше рішення має високий показник придатності. У статті представлено гібридний підхід для кластеризації бездротових сенсорних мереж, який об'єднує метаевристичний алгоритм BBO та метод кластерізації K-середніх.

Для дослідження запропонованого підходу до енергоефективної кластерізації для гетерогенної бездротової сенсорної мережі на його основі розроблено протокол маршрутизації, названий KBBO. Продуктивність KBBO була ретельно протестована та порівнена з відомими протоколами SEP, IHCR та ERP за кількома показниками: тривалість життєвого циклу мережі (кількість живих вузлів, кількість раундів), залишкова енергія, період стабільності та пропускна здатність на 10% та 20% розширених вузлів. Результати моделювання показали, що пропонований підхід дозволив значно покращити ефективність вказаних параметрів БСМ.

Ключові слова: кластеризація, час життя мережі, період стабільності, BBO, оптимізація.

Ш. Ш. БХУШАН[1], С. Г. АНТОЩУК[2]

Индия, Дели, [1]Национальный открытый университет Индиры Ганди
Украина, [2]Одесский национальный политехнический университет
E-mail: s.bhushan2k5@gmail.com, asgonpu@gmail.com

ГИБРИДНЫЙ ПОДХОД К ЭНЕРГОЭФФЕКТИВНОЙ КЛАСТЕРИЗАЦИИ ДЛЯ ГЕТЕРОГЕННЫХ БЕСПРОВОДНЫХ СЕНСОРНЫХ СЕТЕЙ

Гетерогенные беспроводные сенсорные сети (БСМ) сегодня находят широкое применение в мониторинге окружающей среды, в системах безопасности, здравоохранения и военной сфере. Основной проблемой БСМ является необходимость максимизировать время жизни сети, при этом уменьшая потребление энергии узлов сенсора. Для ее решения совершенствуют протоколы маршрутизации за счет совершенствования процедуры кластеризации для БСМ. Метаэвристические методы показали хорошую эффективность при решении задач оптимизации, связанных с широким спектром практических применений в беспроводных сенсорных сетях. Оптимизация на основе биогеографии (BBO) — это эволюционный метод, основанный на миграции видов между средами существования, который широко применяется при решении задач глобальной оптимизации. Определены задачи оптимизации в терминах и обозначениях моделей биогеографии: каждый остров представляет одно решение, отраженное признаком жизнеспособности — целевой функцией, значение которой является индексом годности острова-решения. Хорошее решение имеет высокий показатель годности. В статье представлен гибридный подход для кластеризации беспроводных сенсорных сетей, объединяющий метаэвристический алгоритм BBO и метод кластеризации K-средних.

Для исследования предложенного подхода к энергоэффективной кластеризации для гетерогенной беспроводной сенсорной сети на его основе разработан протокол маршрутизации, названный KBBO. Производительность KBBO была тщательно протестирована и сравнивалась с известными протоколами SEP, IHCR и ERP по нескольким показателям: продолжительность жизненного цикла сети (количество живых узлов, количество раундов), остаточная энергия, период стабильности и пропускная способность на 10% и 20% расширенных узлов. Результаты моделирования показали, что предлагаемый подход позволил значительно улучшить эффективность указанных параметров БСМ.

Ключевые слова: кластеризация, время жизни сети, период стабильности, BBO, оптимизация.

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