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Research on routing optimization of WSNs based on improved LEACH protocol

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Abstract

LEACH routing protocol equalizes the energy consumption of the network by randomly selecting cluster head nodes in a loop, which will lead to the defect of unstable network operation. Therefore, in order to solve this problem, it is necessary to reduce the energy consumption of data transmission in the routing protocol and increase the network life cycle. However, there is also a problem that cluster heads count with a wide range and the cluster head forwarding data consumed greatly power in the LEACH, which remains to be solved. In this paper, we put forward an approach to optimize the routing protocol. Firstly, the optimal number of cluster head is calculated according to the overall energy consumption per round to reduce the probability of excessive cluster head distribution. Then, the cluster head is used as the core to construct the Voronoi Diagram. The nodes in the same Voronoi diagram become a cluster, that the energy consumption communication in intra-cluster would be less. Finally, in order to optimize the multi-hop routing protocol, an ant colony algorithm is added using a cluster head near the BS to receive and forward it from a remote cluster head. According to the MATLAB simulation data, the protocol can significantly prolong the lifetime of WSNs compared with the LEACH protocol and increase the energy efficiency per unit node in per round. Energy consumption of the proposed approach is only. The approach improved the First Node Death (FND) time by 127%, 22.2%, and 14.5% over LEACH, LEACH-C, and SEP, respectively.

Keywords: Ant colony algorithm, LEACH energy efficient, Routing protocol, WSNs

1 Introduction

With the advancement of technology, WSNs are widely applicate in society and playing a vital role such as environment monitoring [1], weather forecasting [2], precision agriculture [3], petroleum drilling [4], natural disaster prevention [5], urban transportation [6], diagnose wall collapse [7], and indoor positioning [8]. The outperformance of WSNs has many practical applications because of its low cost, low power, high integration, and high sensitivity [9]. However, sensor nodes still have problems such as too random layouts, large quantities required, and limited battery conditions in field applications. Therefore, improving the efficiency of sensor nodes, reducing node energy consumption, and extending network time are still the hot issue of WSNs [10].

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The energy consumption of the communication transmission protocol is basically proportional to the transmission distance in WSNs. Therefore, in order to reduce the extra loss of energy and more energy is used for data transmission, resulting in a routing protocol [11]. There are two main types of routing protocols: flat routing protocols and hierarchical routing protocols [12–16]. The LEACH protocol distributes all energy loads of the WSNs balancing into each node, and this can effectively reduce energy consumption compared to the flat routing protocol. The LEACH protocol adopts data transmission local control technology and low-energy MAC layer protocol, which better fulfill the needs of energy control and WSNs throughput of a large range of nodes [17].

The cluster head election is the core of LEACH protocol. Define a threshold (T_n) firstly and all nodes are given different random values in per round. If the random value of the sensor node is no more than the

T_n, the node acts as a CH in the current round. The T_n is given as:

$$T_n = \begin{cases} \frac{p}{1-p*\left(r \bmod \frac{1}{p}\right)}, n \in G \\ 0, n \notin G \end{cases} \quad (1)$$

where p is the initial percentage of CHs, r represents the round number, $r \bmod (1/p)$indicates the node count that has been assigned as the CH in the period, and G indicates the node set that has not been served as the CH in the front $1/p$ wheel. Therefore, it is essential to re-elect the CH, and the number of cluster heads is utmost unstable. On the one hand, since the CH needs to perform data fusion on the received data and send it to the base station, excessive CHs will inevitably bring the additional load to the entire network. On the other hand, fewer cluster heads make that the coverage area of one cluster will be too wide to increase the energy consumption of data transmission. In this algorithm, all nodes use the single-hop transmission protocol. If the transmission distance is too far, the CH will consume the mass of power for data transmission, which may cause the CH to die prematurely due to energy exhaustion.

Cluster-head selection is a complex optimization problem. Heuristic algorithm is an effective solution to complex optimization problems, such as ant colony optimization [18], particle swarm optimization [19], and genetic algorithm [20]. Many optimization algorithms are applied to overcome the above shortcomings. In [21], a new variant of bat algorithm combined with centroid strategy was proposed, which develops a two-stage cluster-head node selection strategy and can save more energy compared to the standard LEACH protocol. In [22], a new LEACH-based clustering algorithm called enhanced multi-hop LEACH (EM-LEACH) was proposed, which improved the network efficiency, particularly in terms of energy distribution. In [23], an enhanced algorithm called ESO-LEACH was proposed. The enhanced proposed algorithm is successful in extending network lifespan adequately, and it gives superior vitality proficiency and longer system lifespan than conventional LEACH. In order to ensure the stability of CH quantity and higher energy utilization of the whole network, an improved algorithm based on the LEACH protocol is proposed in this paper.

The structure of this paper is as follows: Section 2 concisely presents the related literature work in this field. Section 3 establishes a network model (LEACH-VA). In Section 4, presents the LEACH-VA network model simulation and data analysis. In Section 5, presents the summary analysis and proposes the prospect of the new algorithm.

2 Related work

Clustering routing protocol based on LEACH protocol has been researched by many scholars. The research direction is divided into three aspects: make the clustering more uniform, optimize the election of cluster head and control cluster head count.

In the hierarchical routing protocol, homogeneous clustering can balance the energy consumption better, which cause a cluster head to die prematurely due to excessive energy consumption impossible. Unequal Clustering Size (UCS) build clusters of non-uniform sizes according to the distance from the CH to the BS to balance the energy of the network [24]. Hybrid Energy-Efficient Distributed clustering (HEED) makes CHs distribution more uniform in a full distribution manner, which works according to the residual power of the primary parameter node and the communication cost within the subordinate parameter cluster [25]. DK-LEACH dynamically adjusts the number of cluster heads according to the distribution density of nodes, making the energy distribution uniform [26]. Energy Efficient Clustering Scheme (EECS) selects CHs with more residual energy through local radio communication while achieving better cluster distribution [27]. Efficient Clustering LEACH (ECLEACH) is dedicated to improving the CH intensive problem [28].

Nodes with less energy are selected as CH possible in LEACH protocol. If the node with more residual energy as a reference factor, both LEACH-C [29] and Energy Efficient LEACH (EE-LEACH) protocols [30] select a CH if the node with more residual energy as a reference factor. LEACH Clustering Protocol Based on Three Layers (LEACH-T) divides WSNs into three layers and elects a cluster head in each layer [31]. Stable Election Protocol (SEP) determines whether a sensor node selected a CH according to the weighted probability [32]. CL-LEACH forward data according to more current energy of the node to better balance network energy [33]. In LEACH, nodes with more residual energy are selected as CHs with higher success rates by deterministic cluster head selection (LEACH-DCHS) [34].

The election of cluster heads by LEACH protocol has great randomness and cluster head count fluctuates greatly. Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN) controls the number of cluster heads better by adjusting the threshold size [35]. The Cell-LEACH protocol is also like the LEACH protocol [36]. Both V-LEACH and TL-LEACH balance inter-cluster energy consumption by electing sub-cluster heads [37, 38]. LEACH-MAC maintains cluster stability by controlling the randomness of clustering algorithms [39]. Shahin Pourbahrami proposed using cluster nodes and cell clustering to optimize cluster head elections [40].

The long-distance transmission from the cluster head to the base station consumes a lot of energy in practical applications. Al-Sodairi Sara Ouni Riha used energy-efficient multi-hop protocol to optimize network energy consumption [41]. DL-LEACH utilizes the double-hop tiering method to combine single-hop short-distance transmission and multi-hop long-distance transmission, effectively improving data transmission efficiency [42]. N. G Palan proposed to apply an energy model advantage point to apply it to all nodes in the network [43]. Arifin proposed the energy analysis of WSNs based on LEACH protocol under black hole attack [44]. Nitin Mittal proposed to use energy-aware heuristics to balance the load between nodes to ensure a higher stability period [45]. Julie E G proposed a routing protocol based on the CCE Virtual Backbone cluster to calculate the message success rate and maximum connection parameters [46].

However, the authors did not propose to cut down the power consumption of negotiated communication within a cluster. In the paper, we are committed to stabilizing the number of CHs and reducing the extra load on the network caused by too more or too fewer CHs. We use the Voronoi diagram to reduce the data transmission consumption of negotiated communication with the cluster, and optimize the multi-hop transmission routing protocol by the ant colony algorithm to reduce the energy consumption of long-distance data transmission.

The low-energy adaptive clustering hierarchy (LEACH) was developed and analyzed. It combined the ideas of energy-efficient cluster-based routing and media access together with application-specific data aggregation to achieve good performance in terms of system lifetime, latency, and application-perceived quality [47]. In [48], the article analyzed four different clustering protocols. The comparison was based on the number of control packets, number of rounds, live nodes, and data delivery to the base station and the residual energy in each round. A hierarchical routing improved algorithm based on the LEACH algorithm was proposed, which solves the disadvantage that cluster-head frequently built cluster and consumes lots of energy [49].

3 Network model (LEACH-VA)

Assume WSN area is in $100 \times 100\ \mathrm{m}^2$ and is randomly distributed 100 sensor nodes in this area. The BS is located in the symmetric center of the WSNs. These 100 sensor nodes are used for data collection, fusion, and forward. The establishing processes of the network model are as follows.

3.1 Cluster modeling

In LEACH protocol, assuming each node has the same initial energy of the network, it appears different generally. Every time slot has data communication. Usually, the nodes have a higher probability to be selected as a CH which has more residual energy. In addition, it reduces the possibility that the nodes will stop working due to energy depletion.

The energy of CHs is mainly consumed in three aspects: data in receiving, merging, and sending to the BS from member nodes. Because most cluster heads are far from the BS, which mostly protocols use multiple paths attenuation channel model. The energy consumption of the CH function is given follow:

$$\begin{aligned} E_{\mathrm{CH}} &= lE_r\left(\frac{n}{k}-1\right) + lE_{\mathrm{DA}}\frac{n}{k} + l\varepsilon_r d_1^4 \\ &\approx lE_r\frac{n}{k} + lE_{\mathrm{DA}}\frac{n}{k} + l\varepsilon_r d_1^4 \end{aligned} \tag{2}$$

where n is the number of sensor nodes in WSNs; in this article, $n = 100$. k denotes the scale of the cluster head; in this article, $k = 0.05\%$. l represents the bit counts in one packet. d_1 indicates the distance from the cluster head to the BS. E_r represents the energy consumed to receive information. E_{DA} represents the energy consumed to fuse data. ε_r represents the energy consumption factor of multiple paths attenuation channel power amplifier.

The energy consumption of a member node expressed as:

$$E_{\mathrm{CN}} = lE_r + l\varepsilon_r d^2 \tag{3}$$

where d represents the distance from sensor nodes to the CH. ε_r represents the energy dissipation coefficient of free space channel model power amplifier.

The area covered by each cluster is A^2/k on average. The distribution density of nodes in WSNs is $\rho(x, y)$. The expected value d^2 is given as:

$$E_{\left(d^2\right)} = \iint \left(x^2+y^2\right)\rho(x,y)d_x d_y = \iint r^2\rho(r,\theta)d_r d_\theta \tag{4}$$

If the distribution of clusters is treated as a circular area, the above formula can be reduced to:

$$E_{\left(d^2\right)} = \rho\int_{\theta=0}^{2\pi}\int_{r=0}^{\frac{M}{\sqrt{\pi k}}} r^3 d_r d_\theta = \frac{\rho}{2\pi}\frac{A^4}{k^2} \tag{5}$$

Assume that the node density distribution within the cluster is uniform, $\rho = 1/A^2k$, the above formula is given as:

$$E_{\left(d^2\right)} = \frac{1}{2\pi}\frac{A^2}{k} \tag{6}$$

At this point, the energy consumption of the member node E_{CN} is given as:

$$E_{\mathrm{CN}} = lE_r + l\varepsilon_f \frac{1}{2\pi}\frac{A^2}{k} \tag{7}$$

The energy consumption of a cluster $E_{\mathrm{Total}-c}$ is expressed as:

$$E_{\mathrm{Total}-c} = E_{\mathrm{CH}} + \left(\frac{n}{k}-1\right)E_{\mathrm{CN}} \approx E_{\mathrm{CH}} + \frac{n}{k}E_{\mathrm{CN}} \tag{8}$$

The total energy consumption of WSNs E_{WSN} is given as:

$$E_{\mathrm{WSN}} = kE_{\mathrm{Total}-c} = l\left(nE_r + nE_{\mathrm{DA}} + k\varepsilon_r d_1^4 + nE_r + n\varepsilon_f \frac{1}{2\pi}\frac{A^2}{k}\right) \tag{9}$$

To minimize the total energy consumption E_{WSN} of WSNs, let E_{WSN} derivate k and make it equal to zero. The final value k is given as:

$$k = \frac{\sqrt{n}}{\sqrt{2\pi}}\sqrt{\frac{\varepsilon_f}{\varepsilon_r}\frac{A}{d_1^2}} \tag{10}$$

The length of the cluster head to the BS is various and within a range of value. The range of values of k is determined by replacing the range of values of d_1. We simulate different k values to get the optimal number of cluster head count. Substituting other simulation parameters into the above equation, it can be concluded that the cluster head count ranges from 3 to 10.

All cluster heads used as a regional point of the Voronoi Diagram. First, a cluster head is randomly used as the generator element, and then, two cluster heads are selected to generate their dual Delaunay triangulation that is extended clockwise. Next, find the circumcircle of each triangle. Finally, the Voronoi diagram is generated by connecting the circle and the outermost vertical line of the triangle. The specific schematic is shown in Fig. 1.

In order for more energy to be applied to the communication period, nodes in a Voronoi diagram automatically become a cluster. The specific intra-cluster negotiation principle is as followed: nodes are connected to an adjacent cluster head. If the connection does not intersect with the Voronoi diagram, it becomes a cluster. The connection has an intersection with the Voronoi diagram, and the next adjacent cluster head is selected for negotiation.

The clustering period is divided into electoral cluster heads and cluster negotiation. The member nodes communicate directly with the cluster head. Cluster heads fuse received data and forward it to the BS. The example of clustering is shown in Fig. 2.

3.2 Constructing a communication phase model

The establishment of cluster heads needs some time and energy per round. The stable communication period takes longer than the cluster head setup period to use energy as much as possible for data transmission in an ideal state. In the communication phase, the time is too long, which is not conducive to other nodes communicating with the BS. Because the energy consumed to CH increases, it consumes quickly. Therefore, the communication time per round needs to be calculated to obtain the optimal solution.

We ensure that the battery power of node can be served as cluster head once in its lifetime and be a member node to normal communication in other rounds. All nodes have a sufficient residual energy to play as a CH and $n/k-1$ times the member node. The initial energy of the sensor node is assumed as:

$$E_0 = n_{\frac{f}{r}} \times \left(lE_r\frac{n}{k} + lE_{\mathrm{DA}}\frac{n}{k} + l\varepsilon_r d^4\right) + \left(\frac{n}{k}-1\right) \times \left(lE_r + l\varepsilon_r\frac{1}{2\pi}\frac{A^2}{k}\right) \tag{11}$$

where n_f is the average number of frames in each round, which can be expressed as:

$$n_{\frac{f}{r}} = \frac{E_0/l}{\left(E_r\frac{n}{k} + E_{\mathrm{DA}}\frac{n}{k} + \varepsilon_r d^4\right) + \left(\frac{n}{k}-1\right) \times \left(E_r + \varepsilon_f\frac{1}{2\pi}\frac{A^2}{k}\right)} \tag{12}$$

The transmission time of l denotes as $t_s = \frac{l}{R_b}$. The total time within a frame is expressed as $t_f = \frac{n}{k}\frac{l}{R_b}$. The cluster head rotation time can be expressed as:

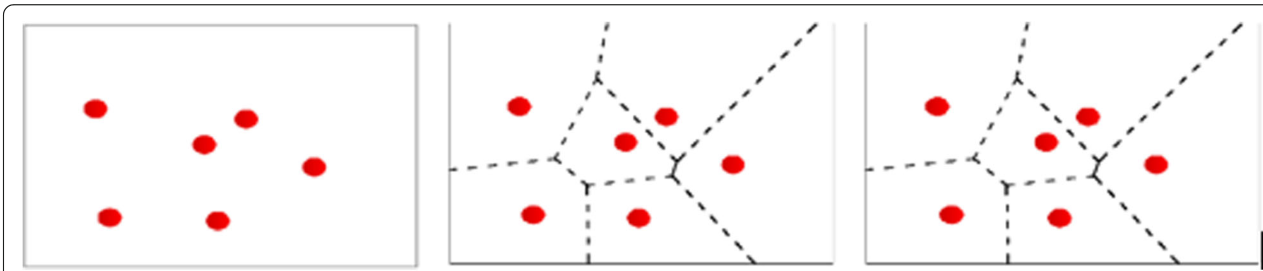

Fig. 1 The process of Voronoi diagram

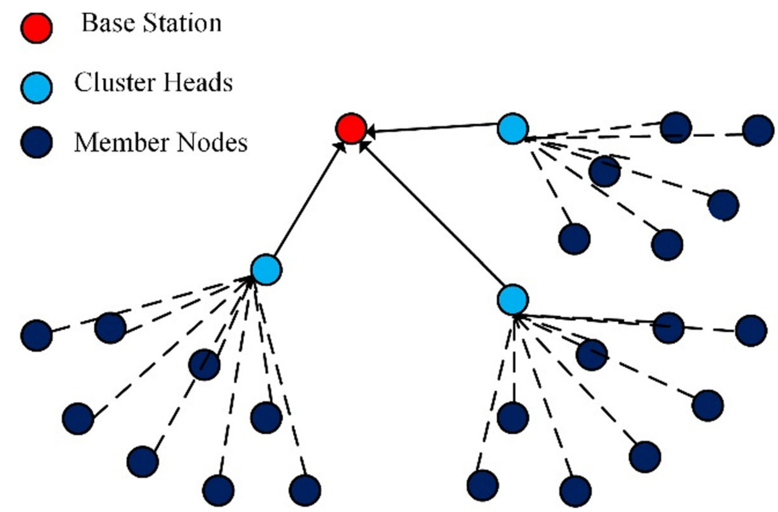

Fig. 2 Example of clustering

$$t_{\text{Total}} = n_{\frac{f}{r}} \times t_f = \frac{n}{kR_b}\frac{E_0}{\left(E_r\frac{n}{k} + E_{\text{DA}}\frac{n}{k} + \varepsilon_r d^4\right) + \left(\frac{n}{k}-1\right) \times \left(E_r + \varepsilon_f\frac{A^2}{2\pi k}\right)} \quad (13)$$

Substitute simulation parameters into the above formula. The wireless transmission rate of the data R_b is 1 Mb/s. The time of rotation of the cluster head is usually 18 s in an ideal state.

3.3 Multi-hop transmission path based on ant colony algorithm optimization

Ant colony algorithm is the process of ants searching for food in nature [50].

Taking into consideration, the TSP problem of n is cited as an example. The probability that a cluster selected next one in the path is given as:

$$P^k_{\text{ij}}(t) = \begin{cases} \dfrac{\left[\tau_{\text{ij}}(t)\right]^\alpha\left[\eta_{\text{ij}}(t)\right]^\beta}{\sum\limits_{l\subset\text{allowed}_k}\left[\tau_{\text{ij}}(t)\right]^\alpha\left[\eta_{\text{ij}}(t)\right]^\beta}, j\in\text{allowed}_k \\ 0, j\notin\text{allowed}_k \end{cases} \quad (14)$$

where τ_{ij} represent pheromone concentration and subscript indicates the corresponding path, $\eta_{\text{ij}}(t)$ is the inspiring factor for selecting the next cluster head ($\eta^\beta_{\text{ij}}(t) = 1/d_{\text{ij}}$, $d_{\text{ij}} = E_{\text{imit}} - E_{\text{cur}}$), allowed$_k$ statistics k past nodes, α is pheromone inspired factor, β is expectation inspired factor, and α and β need to be determined by experiment.

In order to prevent the inspired factor from being overwhelmed by the residual information, pheromone volatilization mechanism is introduced to update the pheromone on the path. The way to update the pheromone after the path is given as:

$$\tau_{\text{ij}}(t+n) = (1-\rho)*\tau_{\text{ij}}(t) + \Delta\tau_{\text{ij}}(t, t+s) \quad (15)$$

$$\Delta\tau_{\text{ij}}(t, t+s) = \sum_{k=1}^{m}\Delta\tau^k_{\text{ij}}(t, t+s) \quad (16)$$

The probability function of k selecting the next hop is determined by the pheromone. However, since the pheromone concentration and the node energy are not quite different at the initial stage of establishing a path, the effect on establishing the optimal path is weak. The distance inspired probability transfer function is introduced as follows:

$$P^k_{\text{ij}} = \frac{\left(\left(d_{\max}-d_{j,\text{goal}}\right)*\omega + \mu\right)^\lambda}{\sum\limits_{j\in\text{allowed}(t)}\left(\left(d_{\max}-d_{j,\text{goal}}\right)*\omega + \mu\right)^\lambda} \quad (17)$$

where ω, μ, and λ are constants, usually $\omega = 10$, $\mu = 2$, $\lambda = 2$, and allowed(t) representing a collection that k has not accessed, $d_{\max}$ is the maximum of all $d_{j,\text{ goal}}$, and $d_{j,\text{ goal}}$ denotes the length of the node j to the destination node.

$$d_{j,\text{goal}} = \sqrt{\left(x_j - x_{\text{goal}}\right)^2 + \left(y_j - y_{\text{goal}}\right)^2} \quad (18)$$

In the non-initial state, selecting the next-hop node needs to filter the nodes that have been accessed through the taboo table. For the purpose to balance the network energy load, the state transition formula is given as:

$$P_{ij}^{k}(t) = \begin{cases} \dfrac{\left\lfloor \tau_{ij}(t)^{\alpha} * \eta_{ij}(t)^{\beta} \right\rfloor E_{j\text{-current}}}{\sum\limits_{s_j \in \text{allowed}_k} \left[\tau_{ij}(t)^{\alpha} * \eta_{ij}(t)^{\beta}\right] E_{p\text{-current}}}, s_j \in \text{allowed}_k \\ 0, s_j \notin \text{allowed}_k \end{cases} \quad (19)$$

where $E_{j-\text{current}}$ represents the current energy of the CH. j and $E_{p-\text{current}}$ denote the average current energy of the sensor nodes, and $\text{allowed}_k = \{0, 1, 2, \ldots, n-1\}$ indicates a set of nodes that can be selected. In order to achieve better convergence, the inspired function is improved accordingly as:

$$\eta_{ij}(t) = \frac{1}{d_{ij} + d_{j\text{-goal}}} \quad (20)$$

The above formula increased the proportion of a single neighbor in all nodes. When selecting the next node, neighbor nodes with low energy consumption are more likely to be selected. Reduce the probability of energy exhaustion of individual nodes quickly and speed up the search for the optimal next node rate to prolong network lifetime.

Pheromone update determines the speed of convergence. In order to make the algorithm of the paper get better results, we combine global update and partial update. The algorithm is given as:

$$\tau_{ij}(t+n) = (1-\rho)\tau_{ij} + \rho \Delta \tau_{ij}^{gb}, (i,j) \in T^{gb} \quad (21)$$

$$\Delta \tau_{ij} = \frac{Q}{L_{gb}} \quad (22)$$

where $\rho (0 < \rho < 1)$ indicates the pheromone volatility coefficients, T^{gb} indicates the best path, L^{gb} represents the optimal path length, and Q represents a constant and appropriately selected according to the actual experiment and updated local information dynamically. k starts from the boundary, the closer to the central the less pheromone is released. When k is reaching the other boundary, the pheromone reduced to the minimum. The pheromone update model is given as:

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij} + \rho \Delta \tau_{ij} \quad (23)$$

$$\Delta \tau_{ij} = \frac{Q}{L_{tot}} \quad (24)$$

$$L_{tot} = \sum_{s=1}^{w} d_s^1 + \sum_{s=1}^{w} d_s^2 + \ldots + \sum_{s=1}^{w} d_s^m$$
$$d_s \in \{d_{ij}\}, s = 1, 2, \ldots, w, j = 1, 2, \ldots, n \quad (25)$$

where w denotes the number of nodes k have visited, d_s^k denotes the length of k walks, and L_{tot} represents the sum of length that k has passed.

The flow chart of ant colony algorithm is shown in Fig. 3.

4 Simulation results and analysis

4.1 Experimental platform construction and simulation

The simulation area set 100 m × 100 m distributed with 100 sensor nodes randomly. These nodes simulate to collect environment parameters such as temperature and humidity. The base station set in the center of the area at the position (50, 50) where the BS station and the sensor nodes represented as a red triangle and a solid dot, respectively. Figure 4a shows 100 nodes randomly distributed in the region. Figure 4b shows the elected cluster heads. Figure 4c shows the clustering. Figure 4d shows the optimal path.

The simulation parameters are divided into two parts mostly, one part in the LEACH and the other part concentrated in the ant colony algorithm. Most of the parameters refer other related papers to set. The specific parameters are shown in Table 1.

4.2 Results and analysis

4.2.1 the stability of cluster head number

Cluster head counts impact the energy efficiency of protocol greatly. If the number of cluster heads is less, the data transmission length of sensor nodes to CH will be too long which leads to extra energy consumption, and the excessive data received and forwarded by the cluster head makes it consume excessive energy. If the number of cluster heads is large, the total load of the network is obviously increased, the total energy consumption of each round of networks is increased, the network data fusion efficiency is reduced, and the lifetime of the network is not prolonged.

Figure 5 shows the cluster head count per round for LEACH protocol, LEACH-C protocol, SEP protocol, and LEACH-VA protocol. As can be seen from the figure, the cluster head fluctuations in the proposed LEACH-VA protocol gives better results and outperformance as compared to LEACH, LEACH-C, and SEP protocols. In LEACH protocol cluster head election mode, cluster head selection and cluster head count are randomly generated based on the threshold function model, which has great randomness. From the figure that cluster head count fluctuates in the range of $5 \le k \le 18$ in LEACH protocol and $3 \le k \le 10$ in LEACH-VA protocol.

The LEACH-VA protocol needs to calculate optimal cluster head count based on the total energy requirement of WSNs per round, thereby reducing the randomness of cluster head counts. With node death in WSNs, the function of stabilizing cluster head count is still valid in LEACH-VA protocol. When there are a large number of dead nodes in the wireless sensor network, in order to better balance the energy consumption of the

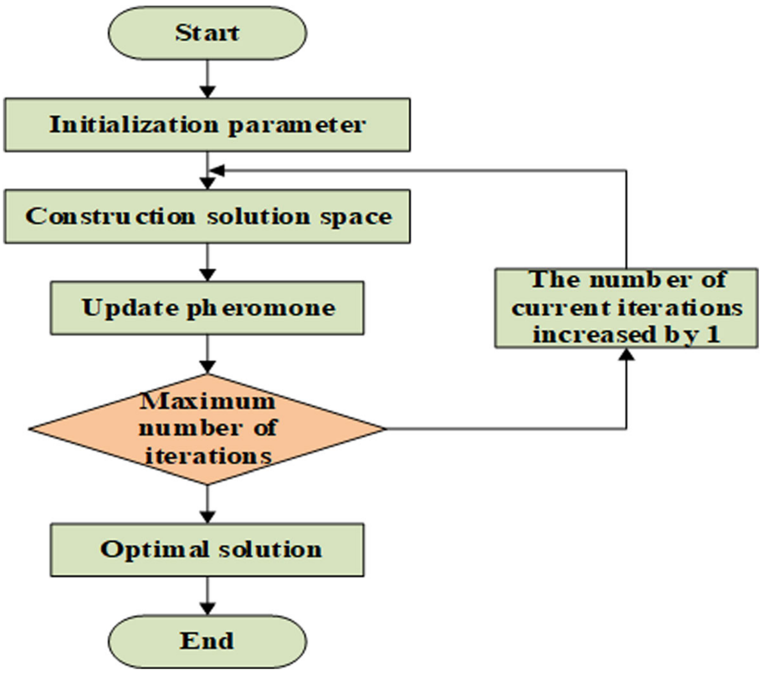

Fig. 3 The flow chart of ant colony algorithm

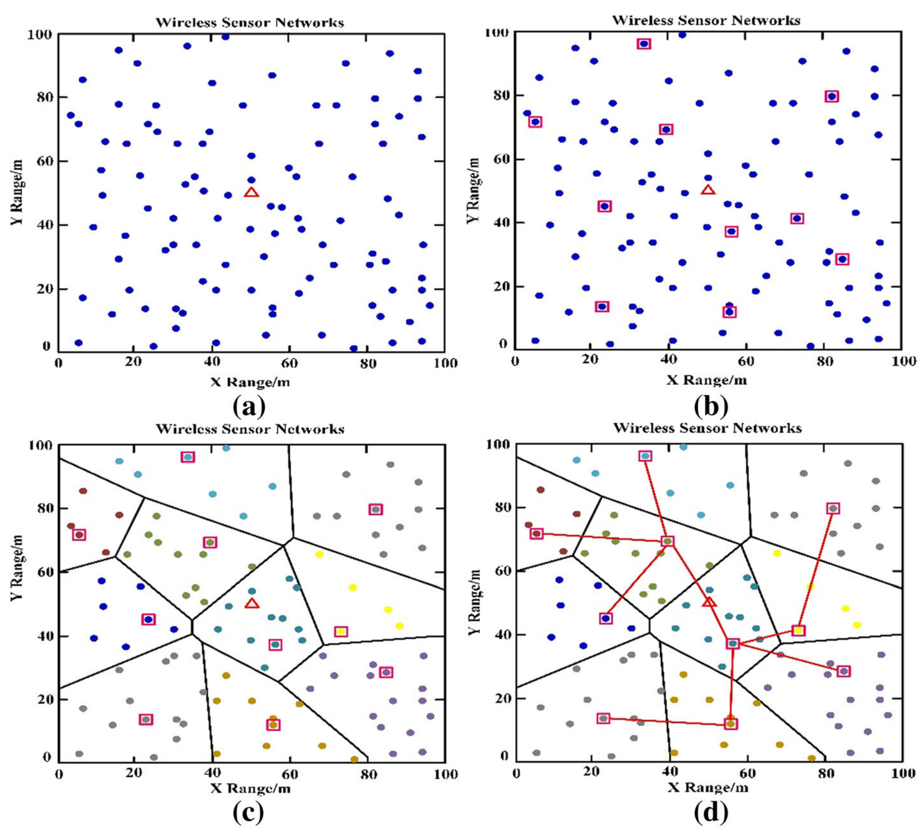

Fig. 4 a shows 100 nodes randomly distributed in the region. (**b**) shows the elected cluster heads. (**c**) shows the clustering. (**d**) shows the optimal path

Table 1 Simulation parameters

Notation	Value	Notation	Value
E_0/J	0.5	n	100
p	0.05	d_0/m	87
α	0.5	E_{DA}/(nJ/bit)	5
β	1	E_r/(nJ/bit)	50
ρ	0.5	l/bit	4000
τ_0	100	ε_r/((pJ/bit)/m^4)	0.0013
τ_{max}	5000	ε_f/((pJ/bit)/m^2)	10
τ_{min}	5	E_{Tx}/(nJ/bit)	50

network, the total capacity of the cluster will be reduced accordingly.

4.2.2 Network lifetime

With this parameter measurement, we can monitor the life cycle of the WSN area. It is composed of two parts, the stable period and the unstable period. The time between the FND and the Last Node Death (LND) denotes the unstable period. In the paper, it is mainly used in the field of environmental monitoring, and it requires a large area to place sensor nodes. Due to the wide distribution area, if large-area nodes die, some collected data cannot accurately evaluate the environmental parameters. Therefore, this paper evaluates network lifetime according to FND to evaluate whether LEACH-VA has clear advantages compared with the above three protocols.

Figure 6 indicates the distribution of dead node count in LEACH, LEACH-C, SEP, and LEACH-VA protocols over rounds. From the figure, it is shown that the FND rounds of four protocols are 991, 1847, 1970, and 2257. Compared with LEACH, LEACH-VA increased FND by 127%, increased by 22.2% over LEACH-C, and increased by 14.5% over SEP. Therefore, the method proposed in the paper has significantly improved performance during the stabilization phase.

This performance improvement is due to the stable number of cluster heads. LEACH, LEACH-C, and SEP observed cluster head fluctuates obviously, especially when the FND appears. LEACH-VA protocol reduces these fluctuations by as follows. Firstly, it is valid to steady cluster head count, effectively reduces the probability of CHs to be intensive, and decreased the energy loss of CHs. Then, clustering protocol uses Voronoi diagram geometry principle to validly decrease the energy consumption of negotiated communication with intra-cluster. LEACH-VA effectively prolongs the survival time of WSNs and optimizes energy utilization of unit nodes.

4.2.3 Number of packets received at the BS

The number of data packets received by the base station is also a parameter for evaluating the high energy utilization rate. The more balanced the energy distribution in the network, the more packets the base station receives. Figure 7 observes that the number of packets received at the BS for LEACH, LEACH-C, SEP, and LEACH-VA protocols, where the length of one packet is 4000/bit. As can be seen from this picture, LEACH-VA increases packet counts received at the BS by 71.4% as

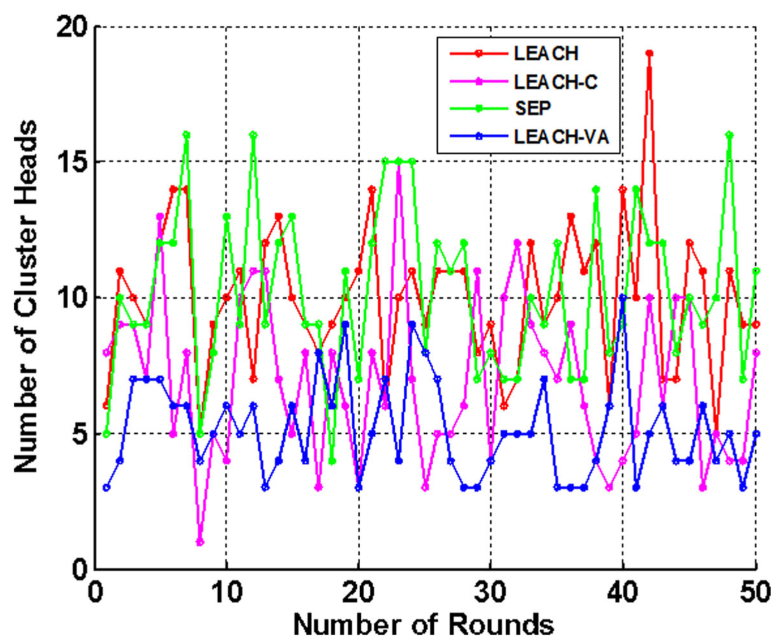

Fig. 5 Number of rounds versus the number of cluster heads

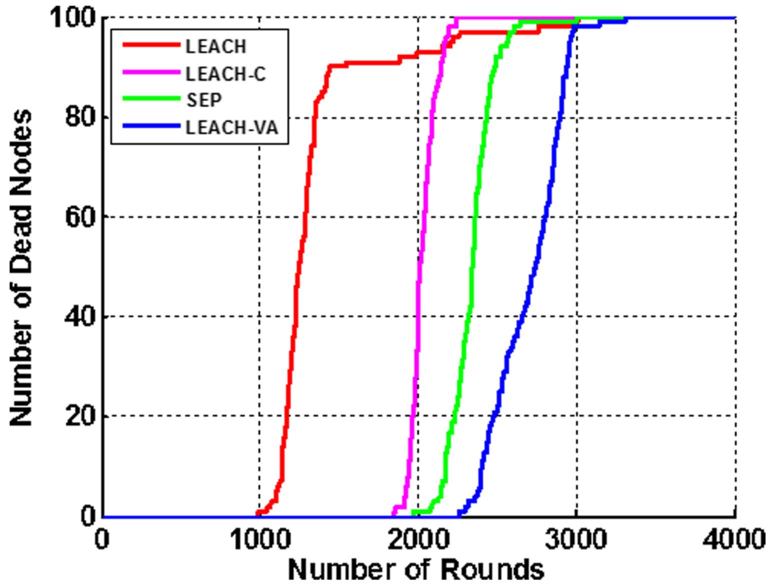

Fig. 6 Number of rounds versus the numbers of node death

compared to LEACH, 33.3% over LEACH-C, and 14.3% against SEP.

The significant increase in packet counts received by the base station is due to reduce the probability of cluster head clusters and effective reduction of energy consumption of negotiated communication within the cluster. Based on the stable number of cluster heads and the geometric principle of the Voronoi diagram, the clusters are more uniform, the energy consumption between the clusters is better, and the energy utilization of the unit nodes is also improved. Moreover, in the paper, multi-hop transmission routing protocol according to ant colony optimization algorithm used to forward the data packets of long-distance cluster head by neighboring cluster head of the BS to reduce the energy consumption of direct communication.

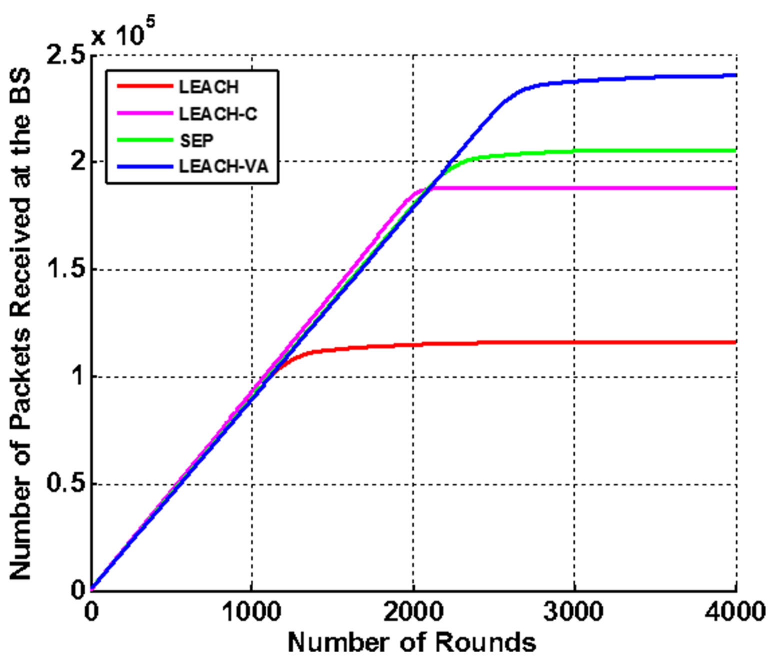

Fig. 7 Round versus a number of packets received at the BS

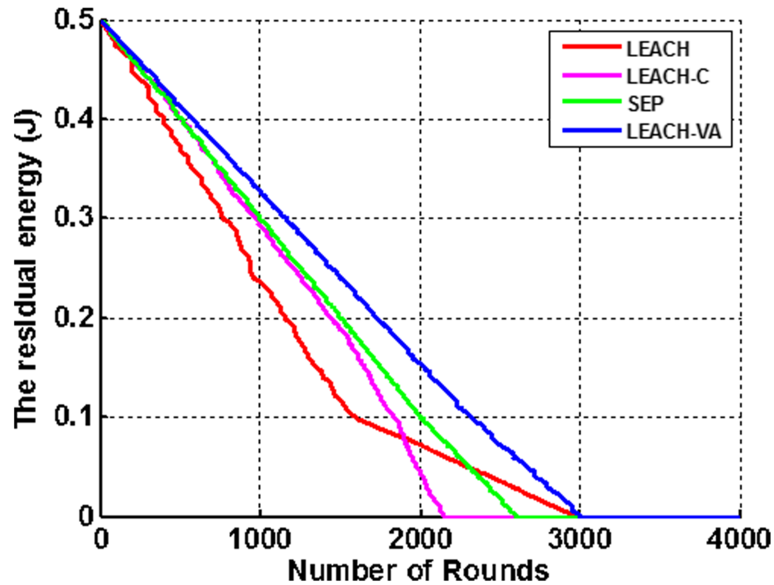

Fig. 8 Round versus the number of residual energy

4.2.4 Residual energy

Node energy consumption is divided into mainly four parts: data transmission, data reception, data fusion, and negotiation communication within the cluster. The more uniform energy consumption the longer lifetime nodes alive.

The conclusion is drawn that the energy consumption of the LEACH-VA protocol is more uniform than the LEACH, LEACH-C, and SEP protocols (Fig. 8). The change of threshold function value will cause the change of the cluster head count. A large number of cluster heads produced during the leaching process are the main reason that causes leaching energy consumption. LEACH-C and SEP protocols do not consider the energy consumption of negotiation communication within the cluster. More energy is used in LEACH-VA protocol for data transmission to increase energy utilization.

The method proposed in the paper reduces energy consumption between clusters and reduces the energy consumption of negotiated communication within the cluster. It also optimizes the data transmission of multi-hop paths. The residual energy has improved both in the establishment phase and stabilization phase (Fig. 8), which makes energy saved and the network lifetime is increased.

5 Conclusion

Wireless sensor networks are widely used in different fields. LEACH protocol has always been the focus of research on wireless sensor networks. Aiming at the problem of traditional LEACH protocol, the paper proposes a method that uses improved LEACH protocol and the Voronoi diagram principle to cluster. Firstly, the optimal number of cluster head is calculated to the overall energy consumption per round. Secondly, Voronoi diagram is established. Finally, the ant colony algorithm is added to the protocol to optimize the multi-hop routing protocol. The experimental shows that the proposed approach can control cluster headcount to fluctuate within$3 \le k \le 10$ this range. Compared with classic LEACH, LEACH-VA protocol effectively increases the FND by 1300 rounds, the network lifetime is increased by 127%, and the data packets received of BS are increased by 71.4%. Because node energy consumption is more balanced, there is a large area of node death, which will not affect its energy consumption, and energy consumption per unit node is only 2.0084×10^{-4}J. Because the total number of clusters does not exceed 10, the ant colony algorithm is used to optimize the path will bring some delay for the WSNs. Therefore, the model proposed in the paper appears to be more accurate and fast. In the future, it is worth studying to optimize multiple paths.

The purpose of this study is to increase the life cycle of WSNs and reduce the energy consumption of data transmission. Therefore, in future studies, LEACH protocol should be optimized in combination with intelligent algorithms, compared with different methods, and applied in practice.

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Authors' contributions

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References

1. T. Alhmiedat, Low-power environmental monitoring system for ZigBee wireless sensor network. KSII Transaction on Internet and Information Systems **11**(10), 4781–4803 (2017)
2. S.A. Malek, S.D. Glaser, R.C. Bales, Wireless sensor networks for improved snow water equivalent and runoff estimates. IEEE Access **7**, 18420–18436
3. O. Kaiwartya, A.H. Abdullah, Y. Cao, et al., T-MQM: testbed-based multi -metric quality measurement of sensor deployment for precision agriculture-a case study. IEEE Sensors Journal **16**(23), 8649–8664 (2016)
4. H. Liang, J. Zou, Z. Li, M. Junaid, Y. Lu, Dynamic evaluation of drilling leakage risk based on fuzzy theory and PSO-SVR algorithm. Futur Gener Comput Syst **95**, 454–466 (2019)
5. D. Chen, Z. Liu, et al., Natural disaster monitoring with wireless sensor networks: a case study of data-intensive applications upon low-cost scalable systems. Mobile Networks & Applications **18**(5), 651–663 (2013)
6. M.A. Kafi, Y. Challal, D. Djenouri, et al., A study of wireless sensor networks for urban traffic monitoring: applications and architectures. Procedia Computer Science **19**, 617–626 (2013)
7. H. Liang, An sand plug of fracturing intelligent early warning model embedded in remote monitoring system. IEEE Access **7**, 47944–47954 (2019)
8. S. Han, Z. Gong, W. Meng, et al., Automatic precision control positioning for wireless sensor network. IEEE Sensors Journal **16**(7), 2140–2150 (2016)
9. M.S. Elgamel, A. Dandoush, A modified Manhattan distance with application for localization algorithms in ad-hoc WSNs. AD HOC Networks **33**, 168–189 (2015)
10. M. Erazo-Rodas, M. Sandoval-Moreno, et al., Multiparametric monitoring in equatorial tomato greenhouses (III): environmental measurement dynamics. Sensors **18**(8) (2018)
11. S. Singh, P. Kumar, J. Singh, A survey on successors of LEACH protocol. IEEE Access **5**, 4298–4328 (2017)
12. A. Pau, C. Juan, et al., Performance evaluation of video streaming over ad hoc networks using flat and hierarchical routing protocols. Mobile Networks and Applications **13**(3-4), 324–336 (2008)
13. S. Peng, Energy neutral directed diffusion for energy harvesting wireless sensor networks. Computer Communication. **63**, 40–52 (2015)
14. J. Kulik, W. Heinzelman, H. Balakrishnan, Negotiation-based protocols for disseminating information in wireless sensor networks. Wireless Networks **8**, 169–185 (2002)
15. X. Fu, G. Fortino, P. Pace, G. Aloi, W. Li, Environment-fusion multipath routing protocol for wireless sensor networks. Information Fusion (2019). https://doi.org/10.1016/j.inffus.2019.06.001
16. S. Soro, W.B. Heinzelman, Prolonging the lifetime of wireless sensor networks via unequal clustering. IEEE International Parallel & Distributed Processing Symposium **365** (2005)
17. F. Bagci, Energy-efficient communication protocol for wireless sensor networks. Ad Hoc & Sensor Wireless Networks **30**(3-4), 301–322 (2016)
18. Y. Zhai, L. Xu, Ant colony algorithm research based on pheromone update strategy, 2015 7th Int. Conf. Intell. Human-Machine Syst. Cybern. **1**(2), 38–41 (2015)
19. W. Ding, W. Fang, Target tracking by sequential random draft particle swarm optimization algorithm. IEEE Int Smart Cities Conf. **2018**, 1–7 (2018)
20. N. Thi, H. Thi, T. Binh, N. Xuan, An efficient genetic algorithm for maximizing area coverage in wireless sensor networks. Inf. Sci. (Ny). **488**, 58–75 (2019)
21. J.P.D. Comput, Z. Cui, Y. Cao, X. Cai, J. Cai, J. Chen, Optimal LEACH protocol with modified bat algorithm for big data sensing systems in Internet of Things. J. Parallel Distrib. Comput. (2018) https://doi.org/10.1016/j.jpdc.2017.12.014
22. S. Al-sodairi, R. Ouni, Sustainable computing: informatics and systems reliable and energy-efficient multi-hop LEACH-based clustering protocol for wireless sensor networks. Sustain. Comput. Informatics Syst. **20**, 1–13 (2018)
23. G.K. Nigam, C. Dabas, ESO-LEACH: PSO based energy efficient clustering in LEACH. J. King Saud Univ. - Comput. Inf. Sci. **1**, 4–11 (2018)
24. N. Mazumder, H. Om, Distribute fuzzy approach to unequal clustering and routing algorithm for wireless sensor networks. International Journal of Communication Systems **31**(12) (2018)
25. O. Younis, S. Fahmy, Heed: a hybrid energy-efficient distributed clustering approach for ad-hoc sensor networks. IEEE Trans On Mobile Computing **3**(4), 660–669 (2004)
26. X.X. Ding, M. Ling, Z.J. Wang, et al., DK-LEACH: an optimized cluster structure routing method based on LEACH in wireless sensor networks. Wireless Personal Communications **96**(4), 6369–6379 (2017)
27. M. Ye, C. Li, G. Chen, et al., EECS: an energy efficient clustering scheme in wireless sensor networks. Journal of Frontiers of Computer Science & Technology **3**(2-3), 99–119 (2007)
28. M. Bsoul, Al-Khasawneh, et al., An energy-efficient threshold-based clustering protocol for wireless sensor networks. Wireless Personal Communications **70**(1), 99–112 (2013)
29. W. Heinzlman, A. Chandrakasan, H. Balakrlshnan, An application-specific protocol architecture for wireless microsensor networks. IEEE Transactions on Wireless Communication **1**(4) (2012)
30. G.S. Arumugam, T. Ponnuchamy, EE-LEACH: development of energy-efficient LEACH protocol for data gathering in WSN. Eurasip Journal on Wireless Communications & Networking, vol., 76 (2015)
31. M.A. Al Sibahee, S.F. Lu, et al., LEACH-T: LEACH clustering protocol based on three layers. International Conference on Network & Information Systems for Computers. **59**, 36–40 (2017)
32. S. Kumar, S.K. Verma, A. Kumar, Enhanced threshold sensitive stable election protocol for heterogeneous wireless sensor network. wireless personal communications **85**(4), 2643–2656 (2015)
33. P. Marappan, P. Rodrigues, An energy efficient routing protocol for correlated data using CL-LEACH in WSN. Wireless Networks **22**(4) (2015)
34. Y. Liu, J. Gao, Y. Jia, et al., A cluster maintenance algorithm based on LEACH-DCHS protocol. Computer Engineering & Applications **45**(30, Palladam, INDIA), 165–166 (2009)
35. T. Samant, P. Mukherjee, et al., TEEN-V: a solution for intra-cluster cooperative communication in wireless sensor networks. International Conference on I-SMAC **2017**, 209–213 (2017)
36. A. Yektaparast, F.H. Nabavi, A. Sarmast, *An improvement on LEACH protocol (Cell-LEACH), Advanced Communication Technology (ICACT) 2012 14th International Conference on* (2012), pp. 992–996
37. A. Singh, S. Rathkanthiwar, S. Kakde, in *2016 International Conference on Communication and Signal Processing (ICCSP)*. Energy efficient routing of WSN using particle swarm optimization and V-leach protocol, vol 1 (Adhiparasakthi Engn Coll, Dept Elect & Common Engn, Melmaruvathur, INDIA, 2016), pp. 2078–2082
38. V. Loscri, G. Morabito, S. Marano, A two-levels hierarchy for low-energy adaptive clustering hierarchy (TL-LEACH). Proc. IEEE 62nd Veh. Technol. Conf., 1809–1813 (2005)
39. B. PK, K. Kant, LEACH-MAC: a new cluster head selection algorithm for Wireless Sensor Networks. Wireless Networks **22**(1), 49–60 (2016)
40. S. Pourbahrami, *Optimization of LEACH method using distribute nodes and cell clustering*, vol 2017 (IEEE 4th International Conference on Knowledge -Based Engineering and Innovation (KBEI), Iran Univ Sci & Technol, Tehran, IRAN, 2017), pp. 83–87
41. S. AS, O. Ridha, Reliable and energy-efficient multi-hop LEACH-based clustering protocol for wireless sensor networks. Sustainable Computing -Informatics and Systems **20**, 1–13 (2018)
42. L. JY, J. KD, M. SJ, et al., Improvement on LEACH protocol of a wide-area wireless sensor network. Multimedia Tools and Applications **76**(19), 19843–19860 (2016)
43. N.G. Palan, B.V. Barbadekar, S. Patil, Low energy adaptive clustering hierarchy (LEACH) protocol: a retrospective analysis. International Conference on Inventive Systems and Control (ICISC), 363–374 (2017, 2017)
44. K.A.Z. Ariffin, R.M. Mokhtar, A.H.A. Rahman, Performance analysis on LEACH protocol in wireless sensor network (WSN) under black hole attack. Advanced Science Letters **24**(3), 1791–1794 (2018)

45. N. Mittal, U. Singh, B.S. Sohi, A stable energy efficient clustering protocol for wireless sensor networks. Wireless Networks **23**(6), 1809–1821 (2016)
46. E.G. Julie, S. Tamilselvi, Y.H. Robinson, Performance analysis of energy efficient virtual back bone path-based cluster routing protocol for WSN. Wireless Personal Communications **91**(3), 1171–1189 (2016)
47. W.B. Heinzelman, A.P. Chandrakasan, S. Member, H. Balakrishnan, An application-specific protocol architecture for wireless microsensor networks. IEEE Trans. Wirel. Commun. **1**(4), 660–670 (2002)
48. M. Omari, W. H. Fateh, M. Omari, S. Laroui, and A. Leach, Simulation, comparison and analysis of wireless sensor networks protocols: LEACH, LEACH -C, LEACH-1R, and HEED, 2015 4th Int. Conf. Electr. Eng, pp. 1–5, 2015.
49. Y.-Z. Li, A.-L. Zhang, Y.-Z. Liang, *Improvement of LEACH protocol for wireless sensor networks, Third International Conference on Instrumentation Measurement Computer Communication and Control* (2013), pp. 322–326
50. Y. Jian, Y. Li, ScienceDirect Research on intelligent cognitive function enhancement of intelligent robot based on ant colony algorithm. Cogn Syst Res **56**, 203–212 (2019)

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