


Research Article

A Novel Dynamic Routing Approach to Distributed Wireless Sensor Network in Aircraft Environment

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The trend to implement the monitoring system with a wireless sensor network has been becoming urgent due to guaranteed flight safety and the passengers comfortability in travel. In this paper, a new dynamic routing algorithm is proposed to prolong the lifetime of the monitoring system with a distributed network based on the K -coverage method, and filter algorithm to be used for data fusion. Finally, the simulation results validate the effectiveness of the proposed approach.

1. Introduction

In recent years, the civil aviation industry has developed rapidly in China. Passenger and cargo transitions have maintained fast growth from 2014 to 2018. In this case, air travel is considered to be the priority option [1]. The flight safety, environmental quality, and comfort in cabin are focused by passengers. [2]. To meet the extremely high requirements of flight safety and avoid the miss alarms, the sensors used in the monitoring system are always with strict sensitivities. However, this kind of system will lead to false alarms. For examples, on November 13, 2017, the flight CZ6406 of China Southern Airlines was diverted to Changsha Airport due to a fire false alarm in cargo during flight. On March 19, 2019, a Boeing 777 aircraft of British Airways was made a forced landing in St. John's, Canada, after takeoff because of the same issue [3]. The frequent occurrence of false alarm events will cause a lot of economic losses and give passengers uncomfortable travel experience. Therefore, it is very important to reduce the fire false alarm rate in airplanes. At present, wired single-point sensors in airplanes can no longer meet the practical demands. A wireless sensor network including a large number of nodes with a specific algorithm can be used to play an important

role than that of single-point wired sensors [4]. Furthermore, this kind of network can be applied in different areas such as UAV systems and environment monitoring. [5–8]. Wang et al. designed a WSN for pollutant monitoring in the cabin [7] and analyzed network failures cases [8]. They also proposed to use WSN for monitoring fire in the cargo compartment of commercial aircraft and deployed sensors based on the K -coverage index redundantly. However, they did not discuss the energy consumption and lifetime of WSN for aircraft applications [9]. In this article, a dynamic deployment method of WSN is discussed. This method is mainly focused on the dynamic balance of coverage and energy consumption in WSN aircraft environment application.

The coverage of the monitoring area and the available service time of the network are two important indicators needed to be considered for a WSN operation. So an energy-saving approach applied in cabin WSN based on the low-energy adaptive clustering hierarchy (LEACH) protocol is taken into consideration [10]. However, due to the strong randomness of the LEACH protocol in the cluster establishment phase, it will lead to creating unreasonable topology [11]. Many articles combined LEACH with other algorithm to improve overall performance. Kaddi et al. proposed a kangaroo method-based LEACH protocol, which has a good

energy consumption performance and can prolong WSN lifetime [12]. Mohapatra et al. proposed a partitioned-based energy-efficient-LEACH (PE-LEACH) protocol which tends to the energy-based fault-tolerant technique, and it performs better than the LEACH protocol [13].

Therefore, in this article, a novel coverage index, K -coverage, with a certain probability is proposed to be a criterion of network lifetime. Then an improved binary artificial bee colony-LEACH (LEACH, LEACH-IBABC) algorithm is proposed with the index mentioned above. This approach makes active nodes and cluster head nodes to the global optimization in order to reduce the energy consumption and extend the lifetime of WSN. The structure of this article is arranged as follows: First, a probabilistic sensing model with a dynamic K -coverage deployment index with a certain probability is proposed. Second, a new LEACH-IBABC algorithm is proposed for the dynamic K -coverage deployment of WSN applied in aircraft cabins. Third, simulation verification and analysis are discussed. Finally, conclusions are drawn. The main contribution of this article is to combine the classical LEACH protocol with a new IBABC algorithm to reduce WSN energy consumptions and prolong network lifetime based on the constraint of the new coverage index, dynamic K -coverage.

2. Sensing Model and Coverage Rate Index of Wireless Sensor Network

2.1. Probabilistic Sensing Model of Wireless Sensor Nodes. In practical applications, the sensing probability of the monitoring grid points does not simply follow a Boolean model. It is determined by the distance, d_{ml} , between the sensor node (SN) and the monitored target, the physical parameters of the node, and the interference of the surrounding environment. The sensing probability can more accurately reflect the coverage capability of wireless sensor nodes for the real environment [14]. The probability mentioned above varying with distance d_{ml} is noted as the probabilistic sensing model (PSM).

Definition 1. Effective sensing radius: in terms of the probabilistic sensing model, when d_{ml} is smaller than the effective sensing radius $R_{s,max}$ of the wireless sensor node, the target point to be monitored (TPM) can be effectively monitored and covered, so the sensing probability p_{ml} is 1. Otherwise, the probability p_{ml} is less than 1. $R_{s,max}$ is a threshold value of d_{ml} . Furthermore, that probability exponentially decreases as the Euclidean distance between SN and TPM increases.

Suppose that the deployed sensor nodes are homogeneous in this article, the sensing model is optimized and obtained in (1) by deriving from the model proposed in [15]:

$$p_{ml} = \begin{cases} 1, & d_{ml} \leq R_{s,max}, \\ e^{-\alpha d_{ml}}, & d_{ml} > R_{s,max} \text{ and } p_{ml} \geq p_{thr}, \\ 0, & p_{ml} < p_{thr}, \end{cases} \quad (1)$$

where m is the index of SN. l is the index of TPM. And the parameter α ($\alpha > 0$) describes the decreasing rate of the sensing (monitoring) probability p_{ml} when distance d_{ml} increases. As d_{ml} is continuously increasing till p_{ml} is less than a predefined threshold p_{thr} , the possibility of TMP successfully monitored is too small to make error monitoring results. Therefore, p_{ml} is zero in this condition. p_{thr} ($0 < p_{thr} < 1$) is a relatively small value close to 0.

To calculate the threshold value of d_{ml} , let $e^{-\alpha d_{ml}} = p_{thr}$, then the threshold value of d_{ml} can be obtained as shown in the following equation:

$$d_{ml} = \frac{1}{\alpha} \ln \frac{1}{p_{thr}}. \quad (2)$$

Substituting (2) into (1), we can obtain the following equation:

$$p_{ml} = \begin{cases} 1, & d_{ml} \leq R_{s,max}, \\ e^{-\alpha d_{ml}}, & R_{s,max} < d_{ml} < \frac{1}{\alpha} \ln \frac{1}{p_{thr}}, \\ 0, & d_{ml} \geq \frac{1}{\alpha} \ln \frac{1}{p_{thr}}. \end{cases} \quad (3)$$

Equation (3) shows a complete piecewise function of p_{ml} according to variable d_{ml} .

Taking an effective sensing radius $R_{s,max} = 1.5$ m as an example, Figure 1 shows the change of the monitoring probability p_{ml} as the distance d_{ml} varies.

As shown in Figure 1 ($\alpha = 0.3$), if the distance between SN and TPM is 0, the monitored probability of TPM is 1. If the distance between SN and TPM is larger than $R_{s,max}$, the probability value p_{ml} decreases smoothly. And the probability decreases sharply at the beginning, and the decreasing speed is faster in the early stage than that in the latter stage. When the distance is larger than $(1/\alpha) \ln(1/p_{thr})$, p_{ml} is 0.

2.2. Probabilistic Sensing Model-Based Dynamic K -Coverage Deployment with a Certain Probability of WSN in Aircraft Cabin. In general, the coverage rate of wireless sensor networks is defined as shown below:

$$\text{COV}(S) = \frac{\bigcup_{i=1}^{N_s} \text{Area}(s_i)}{L \times W \times H}, \quad (4)$$

where the length of the area to be monitored is L . The width is W . The height is H . And the set of all sensor nodes $S = \{s_1, s_2, \dots, s_{N_s}\}$. $\text{Area}(s_i)$ represents the coverage area of SN, which is the center of a sphere with the sensing radius. Due to the complexity of the calculation, a regional three-dimensional meshing method is used to find a deployment solution to WSN in aircraft cabin. In Figure 2, the solid dots are wireless sensor nodes. The hollow dots are grid points. In this article, consider each grid point as a TPM in the aircraft environment.

As mentioned before, the monitoring probability matrix $P = [p_{ml}]_{NS \times NGP}$ where $m = 1, 2, \dots, N_s$, N_s is the number of

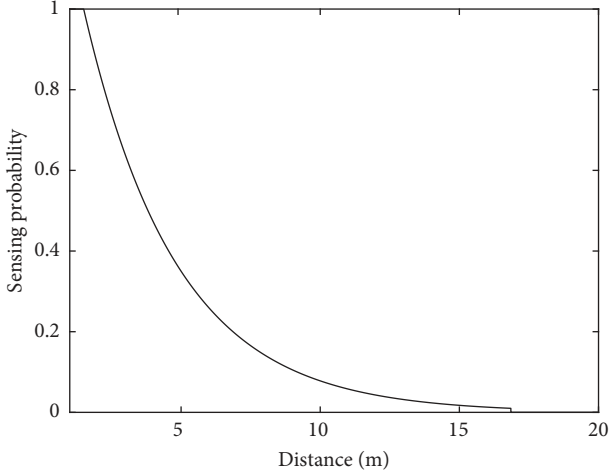


FIGURE 1: The relationship between sensing probability and distance when $\alpha = 0.3$.

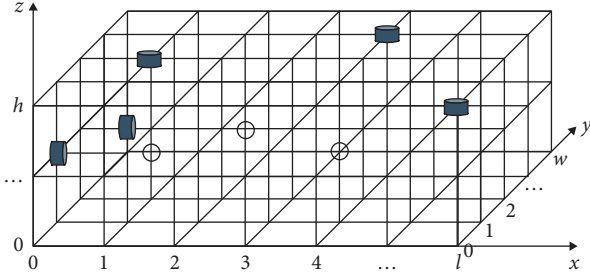


FIGURE 2: Schematic diagram of the three-dimensional area meshing.

sensor nodes, $l = 1, 2, \dots, N_{GP}$, and N_{GP} is the total number of grid points (equivalent to TPM). The set of all sensor nodes is expressed as $S = \{s_q | q \in [1, N_s]\}$.

For any grid point l , the covering probability is the joint probability shown below:

$$p_l = 1 - (1 - p_{1l})(1 - p_{2l}) \cdots (1 - p_{N_s l}) = 1 - \prod_{m=1}^{N_s} (1 - p_{ml}). \quad (5)$$

In this article, a constant value, p_A , is defined as monitoring accuracy. And the joint probability of all monitored TPMs should not be smaller than p_A . The parameter p_A should be larger for the higher requirements of environments.

When $K = 1$ and $\forall p_l \geq p_A$, the wireless sensor network has achieved the coverage for grid point l with joint probability p_A .

When $K > 1$, assume that the subset of the sensor nodes $SEN_q \subseteq S$ contains n_s sensor nodes ($1 \leq n_s \leq N_s$), and each sensor node in the subset is different from others. Each subset SEN_q is independent of others:

$$\begin{aligned} \bigcup_{q=1}^K SEN_q &\subseteq S, \\ \forall 1 \leq q_1, q_2 \leq K, \\ SEN_{q_1} \cap SEN_{q_2} &= \emptyset. \end{aligned} \quad (6)$$

If there are at least K SEN_q subsets and all the sensor nodes of each subset cover the grid point l with the joint probability p_A , all the nodes of set S achieve K -coverage at grid point l with the probability p_A . Moreover, if each grid point in the area to be monitored is K -coverage with probability p_A , the wireless sensor network can achieve K -coverage with probability p_A in that area. By changing the values of the monitoring accuracy p_A and the coverage degree K , the coverage index of the network can be adjusted.

In this article, when plenty of sensor nodes have been deployed in the aircraft cabin, the dynamic K -coverage and deployment algorithm is used to decide which sensor nodes are activated in each cycle, so that the active nodes of the wireless sensor network should ensure that each grid point in the cabin is covered by at least K groups of sensor nodes with probability p_A .

Parameters K and p_A are two important coverage indicators of WSN. The larger the values of K and p_A are, the more the nodes are required, the more accurate the fire monitor is, however, the higher the energy consumption is. On the contrary, it is impossible to meet the coverage and accuracy requirements if these two parameters are too small. In the next section, a new routing protocol is proposed to save energy.

3. Intelligent-Based Dynamic Routing Approach to Energy saving

A routing protocol is one of the key technologies in wireless sensor network-related technologies. In recent years, four types of protocols have been developed for wireless sensor networks. They are geographic-based routing protocols, data center-based routing protocols, cluster-based routing protocols, and hybrid routing protocols. And each type of protocol has produced many branches.

The cluster-based routing protocol separates the sensor nodes into different groups. And each group of sensor nodes is organized by a cluster head (CH). All cluster heads are controlled by a base station (BS) or sink node. The LEACH protocol is the most basic and popular cluster-based routing protocol. The clustering method of the LEACH protocol is shown in Figure 3.

3.1. Energy Consumption Model of Sensor Node. To prolong the lifetime of WSN applied in aircraft, it is necessary to develop an energy-saving algorithm.

The energy consumption of nodes in wireless sensor networks is mainly divided into the following categories:

- (1) The inherent operating energy consumption
It is created from SN hardware themselves without sensing and communicating with other nodes.
- (2) The energy consumption on collecting and sensing
It occurs in collecting information and detecting the environment. The time interval of collecting environmental information, T_{sense} , will affect the energy consumption speed.
- (3) The energy consumption of data transmission

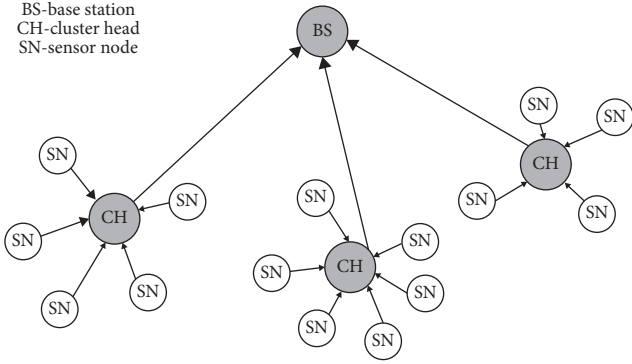


FIGURE 3: Schematic diagram of LEACH protocol topology.

It occurs in transmitting the sensing data amplified by the power amplifiers.

Figure 4 is a block diagram of a conventional wireless sensor network node module.

A wireless sensor network node is composed of four hardware modules: sensing module, processing module, wireless communication module, and energy supply module.

According to the energy consumption model in [16], the energy consumption of data transmitting and receiving from sensor node m_1 to m_2 can be visually shown in Figure 5.

As shown in Figure 5, the energy consumed by the transmitter can be calculated by using the following equation:

$$E_{Tx}(L, d) = E_{Tx-elec}(L) + E_{Tx-amp}(L, d) \\ = \begin{cases} E_{elec} \cdot L + \epsilon_{fs} \cdot L \cdot d^2, & d < d_0, \\ E_{elec} \cdot L + \epsilon_{mp} \cdot L \cdot d^4, & d \geq d_0, \end{cases} \quad (7)$$

where L is the number of bits of data transmitted between two nodes. Parameter d is the distance between any two communication nodes. E_{elec} represents the energy consumption of the circuit. Parameters ϵ_{fs} and ϵ_{mp} represent the energy consumption of the transmitter amplifier per square meter per bit. d_0 is the threshold distance and is defined in equation (8). If d is less than d_0 , the free space channel model is adopted, and the power amplifier coefficient is ϵ_{fs} . Otherwise, the multipath attenuation model is used, and the power amplifier coefficient is ϵ_{mp} :

$$d_0 = \sqrt{\frac{\epsilon_{mp}}{\epsilon_{fs}}}. \quad (8)$$

The energy consumption of the receiver is shown in the following equation:

$$E_{Rx}(L) = E_{Rx-elec}(L). \quad (9)$$

The energy consumption on data fusion of the cluster head can be calculated by the following equation:

$$E_A = L \cdot E_{DA}, \quad (10)$$

where E_{DA} represents the required energy for data fusion per bit assuming that there is no energy consumption in the collecting process.

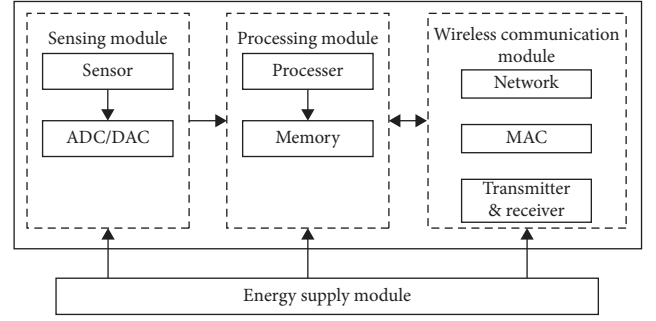


FIGURE 4: Block diagram of the sensor node model.

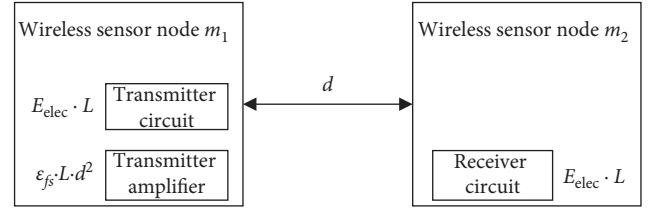


FIGURE 5: Schematic diagram of energy consumption for SN data transmission.

3.2. LEACH-IBABC Algorithm. This section proposes a new protocol algorithm-LEACH-IBABC based on the basic LEACH protocol and energy consumption model mentioned above.

Normally, “round” is a basic unit in the LEACH protocol. Each node of the wireless sensor network has a specific probability to be a cluster head in one round. Based on this idea, the load of the network can be distributed to each node uniformly to prolong the lifetime of the network [17].

A wireless sensor network organized by the LEACH protocol includes at least one base station or sink node. The base station or sink node collects data from all cluster heads without considering the energy consumption. In this article, all nodes are assumed to own the same initial energy, and the transmission energy consumption is symmetrical between the communication pair. A node can adjust the transmission power automatically to minimize energy consumption by calculating the distance between the transmitter and receiver ends based on the strength of the received signal.

All sensor nodes participate in coverage and sensing for the basic LEACH protocol. Therefore, the network coverage is high in the early operation stage. However, when some nodes' energy is exhausted, the network coverage ratio might not be guaranteed and may decrease rapidly. Then the wireless sensor network with a low coverage ratio is not suitable for aircraft cabin scenarios. However, as mentioned above, WSN should ensure that the coverage ratio meets the K -coverage index with probability p_A to decrease false alarms and missed alarms.

Inspired by the LEACH-C algorithm, the base station can be used as a center to manage the status of each node (working or sleeping) and cluster working mode (cluster head or cluster member) [18]. This algorithm operates in the cluster establishment phase of each round. In the operation

process, an optimal node subset S_D selected from the K -covered node set S is set to work mode and participates in the dynamic coverage of WSN in this round. And other nodes are in sleep mode to save energy. It is an NP hard problem to select the optimal node subset. To solve this problem, the artificial bee colony algorithm-based LEACH protocol is proposed. In this article, since each node has only two states: working and sleeping, a binary artificial bee colony (BABC) algorithm is used. Compared to the classic ABC algorithm, the improved BABC algorithm uses different search formulas at each stage.

The objective of the optimal operating node subset is selected to satisfy K -coverage with probability p_A with most $E_{\text{rest_sum}}$ and least n_s . $E_{\text{rest_sum}}$ is the total residual energy of the operating nodes at the end of this round, and n_s is the total number of operating nodes. In this case, it will not only balance the network load energy consumption and allow nodes with the highest energy to work first, but also ensure coverage ratio and avoid triggering too many nodes simultaneously. Therefore, the total energy consumption of the wireless sensor network is reduced.

In the initialization stage, the food source corresponds to a feasible solution to the practical problem. At this stage, each dimension of each feasible solution generates a random number r_{ij} ($0 < r_{ij} < 1$), and the value of the dimension is determined according to equation (11). Then each feasible solution is assigned to an employed bee:

$$v_{ij} = \begin{cases} 0, & 0 \leq r_{ij} \leq 0.5, \\ 1, & 0.5 < r_{ij} \leq 1, \end{cases} \quad (11)$$

where $i = 1, 2, \dots, \text{NP}$, $j = 1, 2, \dots, N_s$, and v_{ij} is the j th dimension of the i th feasible solution. NP is the number of feasible solutions, also represents the number of employed bees. N_s is the number of sensor nodes, also represents the dimension of the feasible solution in this article. The initial feasible solution of the IBABC algorithm is shown in Figure 6.

After allocating the employed bee to each feasible solution in the initialization stage, the fitness value of each solution is calculated by equation (12). The fitness value of the solution corresponds to the quality of the feasible solution:

$$\text{fit}_i(k) = E_{\text{rest_sum}}(k) \times \text{COV}(k, S) - \alpha \cdot n_s(k), \quad (12)$$

where $\text{fit}_i(k)$ represents the fitness value of the i th solution in the k th iteration. $E_{\text{rest_sum}}(k)$ represents the total predicted residual energy at the end of the current round according to the current topology. $\text{COV}(k, S)$ means the network coverage ratio in the k th iteration. $n_s(k)$ is the number of operating nodes in the k th iteration. The impact factor of the node numbers, α , is a constant equal to 0.1 in this article. In general, at the end of the current round, the more the residual energy is, the larger the network coverage ratio is, the fewer the number of awakened nodes are, the larger the fitness value and the better the quality of the solution are. The steps for the coverage ratio $\text{COV}(S)$ based on the probability sensing model are shown in Table 1.

	1	2	3	.....	N_s
Feasible solution 1	0	1	1	.....	1
Feasible solution 2	1	0	0	.....	0
Feasible solution 3	0	0	1	.....	1
\vdots	\vdots	\vdots	\vdots	\vdots	\vdots
Feasible solution NP	1	0	1	.....	1

FIGURE 6: Schematic diagram of the feasible solution of the IBABC algorithm.

TABLE 1: Pseudocode for calculating $\text{COV}(S)$ of K -covered network coverage rate based on probability p_A .

Function PSM_K-coverage_Calculate_Coverage_Rate()(PSMKCCR)
BEGIN
01. for each grid point $T_j(x_{Tj}, y_{Tj}, z_{Tj})$
02. Calculate the total probability p_j that all sensors cover grid point T_j
03. $p_j = 1 - (1 - P_{1j})(1 - P_{2j}) \dots (1 - P_{N_s j}) = 1 - \prod_{i=1}^{N_s} (1 - P_{ij})$
04. Define node set $\text{UNUSED} = S, \text{USED} = \phi, \text{SS} \subseteq \text{UNUSED}$
05. for $q = 1 : K$
06. if $\exists \text{SS} \subseteq \text{UNUSED}, p_j \geq p_A$
07. TEMP++
08. Put the sensor nodes in SS into USED
09. end
10. if TEMP == K
11. T_j is covered with probability p_A , covpoint++
12. TEMP is set zero
13. end
14. end
15. end
16. covrate = covpoint / [(l + 1)(w + 1)(h + 1)]
END

In the employed bee stage, each employed bee i selects a neighbor u randomly and generates a random number φ_{ij} ($0 < \varphi_{ij} < 1$). Then the candidate feasible solution is generated according to the following equation:

$$v_{ij}(k, t + 1) = \begin{cases} v_{ij}(k, t), & \varphi_{ij} > \frac{\text{fit}_i(k)}{\text{fit}_i(k) + \text{fit}_u(k)}, \\ v_{uj}(k, t), & \text{otherwise,} \end{cases} \quad (13)$$

where k represents the current iteration. $i \neq u$. That means the selected neighbor cannot be the same as the current feasible solution. $v_{ij}(k, t)$ is the j th dimension of the i th solution. $v_{uj}(k, t)$ is the j th dimension of the feasible solution of a selected neighbor, u . $v_{ij}(k, t + 1)$ is derived from $v_{ij}(k, t)$ and $v_{uj}(k, t)$. The employed bee uses a greedy selection method to judge whether to select the candidate feasible

solution. If the candidate feasible solution is better than the original feasible solution, the original feasible solution will be replaced. Otherwise, the original state is unchanged, and the cumulative times of inactivity for a feasible solution increases by 1.

In the follower bee stage, the probability of each feasible solution selected by the follower bee can be calculated by the following equation:

$$p_i(k) = \frac{\text{fit}_i(k)}{\sum_{i=1}^{NP} \text{fit}_i(k)} + 0.1, \quad (14)$$

where k represents the current iteration. $p_i(k)$ is the probability that the i th feasible solution is selected by a follower bee in the k th iteration. If a follower bee selects a feasible solution, a candidate feasible solution is calculated using equation (13) to improve the quality of the current feasible solution. If the quality of the candidate feasible solution is better than that of the current feasible solution, the current feasible solution is replaced. Then the employed bee uses this new candidate feasible solution. Otherwise, the original state remains unchanged, and the cumulative times of inactivity for a feasible solution increases by 1. This is similar to that in the employed bee stage.

In the scout bee stage, the cumulative times of inactivity for a feasible solution is checked with the threshold *Limit*. If the variable value is larger than *Limit*, the employed bee for exploring the current feasible solution changes into a scouter. And a new feasible solution is generated by equation (11), and the cumulative times of inactivity for a feasible solution is reset. Then the scouter changes into an employed bee. In the process, only one scouter exists. If the scouter stage is over, the optimal solution of all feasible solutions is recorded.

After selecting the optimal operating node subset S_D , it is necessary to find a group of cluster head node subset S_{DH} from S_D to act as the cluster heads in this round. Since the dimension of S_D is not too large, the fitness value of all feasible solutions can be obtained by the ergodic method. The steps are listed as follows:

- (1) To predict the energy consumption of each node in the current round according to the energy consumption model and calculate the residual energy of each node.
- (2) To ensure that the total energy consumption of the operating nodes is the lowest under the S_{DH} network topology, and make sure that the standard deviation of the node energy consumption is the smallest. The fitness value is calculated by using the following equation:

$$\text{fit}_{i_DH} = E_{\text{sum}} \cdot \text{SD}(E_{m_sum}). \quad (15)$$

In equation (15), fitness value fit_{i_DH} is used to evaluate the topology quality of the i th feasible solution. If the consumption of energy of the whole WSN and the standard deviation of the node energy consumption are smaller simultaneously, the fitness value is smaller, and the quality of

this topology organized by LEACH-IBABC is better, which brings a more balanced energy consumption.

In the aircraft environment, it is necessary to ensure that the operating nodes can meet the coverage index. In this article, the network is considered to get the maximum lifetime when the coverage index cannot be reached due to the exhaustion of some nodes. Figure 7 shows the flow chart of the LEACH-IBABC algorithm.

4. Simulation and Analysis of the Proposed Method

This section presents the simulation validation and compares the lifetime of WSN between the LEACH and LEACH-IBABC algorithms. This article considers a WSN with the K -coverage ($K=3$) index deployed in an aircraft cargo model with 80 sensor nodes in total. Each node has the same initial energy. The simulation parameters are set as follows:

- (1) Cluster head selection probability $p = 0.1$
- (2) The initial energy of each sensor node $E_0 = 0.02 \text{ J}$
- (3) Transmitting and receiving circuit energy consumption $E_{\text{elec}} = 50 \text{ pJ}/(\text{bit m}^{-2})$
- (4) Transmitter amplifier energy consumption parameters $\varepsilon_{\text{fs}} = 10 \text{ pJ}/(\text{bit m}^{-2})$ and $\varepsilon_{\text{mp}} = 0.0013 \text{ pJ}/(\text{bit m}^{-4})$
- (5) Data fusion energy consumption $E_{\text{DA}} = 5 \text{ pJ/bit}$
- (6) The data packet length $L_d = 4000 \text{ bit}$, and the control packet length $L_c = 32 \text{ bit}$
- (7) PSM is used as the sensing model of sensor nodes, and the monitoring accuracy $p_A = 0.99$
- (8) Coverage degree $K = 1$

The corresponding simulation results are shown in Figures 8 and 9. As illustrated in Figure 8, the network using the LEACH algorithm cannot meet 2-coverage with probability 0.99 after the 106th round and cannot meet the 2-coverage with probability 0.9 after the 131st round. However, the network with the LEACH-IBABC algorithm cannot meet 2-coverage with probability 0.99 after the 154th round and cannot meet 2-coverage with probability 0.9 after the 189th round. As curves shown in Figure 8, the LEACH-IBABC algorithm prolongs the network lifetime. When the monitoring coverage index is 2-coverage with probability 0.99, the WSN runs 48 more rounds, so the network lifetime is increased by 45.3%. When the monitoring coverage index is 2-coverage with probability 0.9, the WSN runs 58 more rounds, so the network lifetime is increased by 44.3%.

The residual energy comparisons between two algorithms as the number of active rounds change are shown in Figure 9. When it goes to the 106th round, the residual energy of WSN using LEACH-IBABC is 2.43 J more than the WSN using LEACH. This helps the WSN using LEACH-IBABC runs 48 more rounds. When it goes to the 131th round, the residual energy of WSN using LEACH-IBABC is 3.18 J more than the WSN using LEACH. This helps the WSN using LEACH-IBABC runs 58 more rounds. The total residual energy by using the LEACH-IBABC algorithm

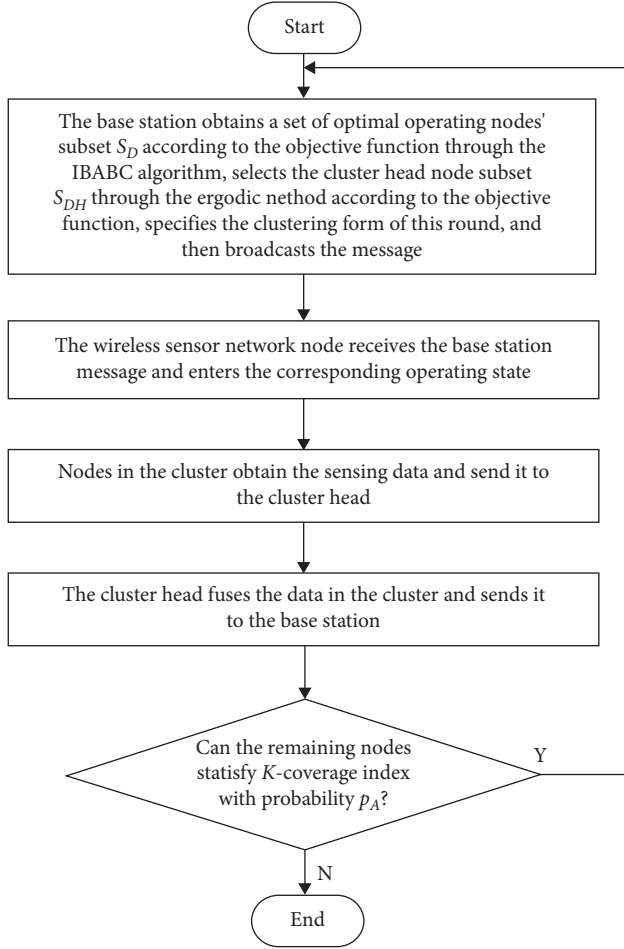


FIGURE 7: Flow chart of LEACH-IBABC algorithm.

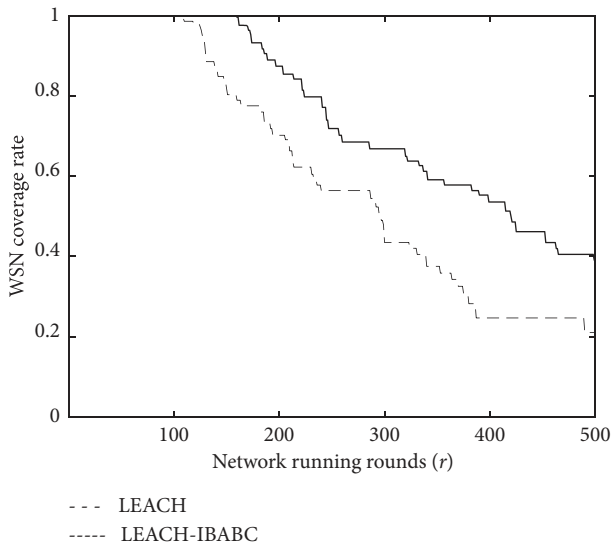


FIGURE 8: Coverage rate comparison of LEACH and LEACH-IBABC vs the number of running rounds.

reduces slower than that of the LEACH algorithm in the early stage.

Therefore, the LEACH-IBABC approach can be used to organize the global optimal topology and reduce the overall

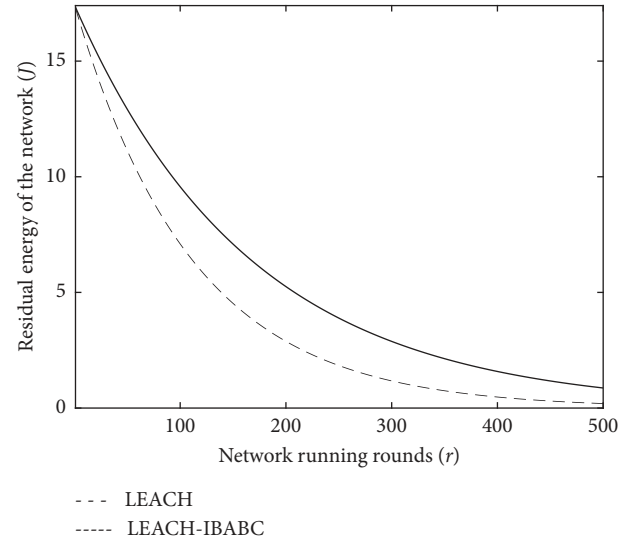


FIGURE 9: Residual energy comparison of LEACH and LEACH-IBABC vs the number of running rounds.

energy consumption of the network. On one hand, the base station handles the task of topology allocation of WSN, so the calculation burden of the nodes is reduced greatly. On the other hand, each node only needs to select the different states according to the base station information and send the collected sensing information to the cluster head directly. Therefore, the energy consumption of nodes is reduced, and the lifetime of the network is prolonged.

5. Conclusions

In this article, a dynamic routing approach to WSN, the LEACH-IBABC algorithm, is proposed for the aircraft environment. In this method, the IBABC algorithm is designed to select the operating node subset S_D which is a global optimization by using the artificial bee colony algorithm. In this case, the nodes with more residual energy have the priority to participate in the current round and meet the requirements of the K -coverage index with a probability p_A . The others are in sleep mode. Then the optimal cluster head node subset S_{DH} is selected with the proposed algorithm to decrease energy consumption and make a better load balance. Therefore, the information selected from the nodes is estimated by using the Kalman filter. Finally, the simulation results prove that the proposed algorithm can reduce energy consumptions and prolong network lifetime based on the constraint of the coverage index.

Data Availability

The figures.zip data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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