Energy Efficient Routing Algorithm Based on Harmony Search

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Abstract. Under the premise of limited node energy, an efficient and energy-saving wireless sensor network routing algorithm was proposed to prolong the lifetime of overall network. By analysing the operation pattern of wireless sensor network, the energy model and transmission model was introduced, and BTPHS algorithm based on the above two was proposed. BTPHS algorithm divided the network lifetime into 3 periods. According to the characteristics of the energy distribution and energy consumption in different periods of the network, two new node selection strategies were proposed and a new objective function as a reference standard was provided. The adjustment process of the HS algorithm is abandoned, which makes less parameters in proposed routing algorithm. The experiment results indicate that BTPHS algorithm can prolong the lifetime of overall WSN network effectively.

1. Introduction
With the rapid development of Internet of things technology, more and more environments need to provide real-time detection. Wireless Sensor Network collects environmental information by distributing different types of sensor nodes on demand within the control area. Due to the uncertainty of the environment, the nodes cannot get further energy supply after deployment, which requires the network to have some self-organization ability to avoid the emergence of the energy black hole.

Routing problem is a typical NP-Hard problem. At present, meta-heuristic Algorithm [1] is used to solve this kind of problem. Most scholars at home and abroad focus on genetic algorithm (GA) [2], harmonic search (HS), ant colony optimization (ACO) [3], Particle swarm optimization (PSO) [4] and so on. When solving practical problems, these algorithms are often developed and designed according to different application scenarios and specific problems, and there is no uniform and effective solution. Based on the above research background, this paper selects harmony search algorithm as the basic algorithm, and proposes a routing search strategy which can effectively prolong the running time of the network. Compared with previous similar algorithms, this algorithm is more focused on increasing the participation of edge nodes in the WSN network usage [5]. On the basis of the traditional HS algorithm, this algorithm combined with the new harmony memory library routing coding method, and introduced a more effective segmented objective function. At the same time, a node removal strategy and an angle migration method are added in the late stage of route selection to further increase the usage frequency of edge nodes in the late stage of operation and extend the lifetime of WSN to a certain extent, good energy balance can be achieved.

2. The Algorithm Presented in This Paper
In this section, firstly, we introduce the system model for the Algorithm, and then briefly describe the energy transfer model used in the information transfer process [6]; Finally, based on the classic HS Algorithm, the BTPHS algorithm proposed in this paper is introduced in detail.

2.1. System Model
In the design of this algorithm, it is mainly aimed at the large-scale deployment node environment without the follow-up energy supplement. Therefore, the distribution and usage of sensor nodes are agreed as follows:
(1) N Sensor nodes are randomly distributed in a limited area of \(M \times M\);
(2) After the sensor node is determined, it cannot be moved at will, and cannot be charged halfway, and the initial energy of each node is the same;
(3) Sink node collects all the monitoring information, has an uninterruptible power supply, and also has some computing power and storage space to perform complex routing algorithms;
(4) The process of information transfer between each node follows the energy transfer model;
(5) All nodes can detect their residual energy and have a unique identification ID.

2.2. Energy Transfer Model
Suppose that in a basic wireless channel, the Energy Consumption Coefficient of the transmitter or receiver is EE and the energy consumption coefficient of the \(E_{elec}\) transmitter amplifier is \(E_{amp}\). The communication energy consumption model is shown in figure 1.

![Figure 1. Communication energy consumption model.](image)

When the node is working, information collection, data receiving and sending, heat loss and so on will consume energy, in which the energy consumed by information transmission occupies the majority. Therefore, in the communication energy consumption model, only the energy loss in the communication process is considered.

When \(l\) bit data is transmitted to \(d\) meter in the communication process, the energy consumption of node transmission is as follows:

\[
E_{tx}(l, d) = E_{elec} \cdot l + E_{amp} \cdot l \cdot d^2
\]

The node receives energy consumption as follows:

\[
E_{rx}(l) = E_{elec} \cdot l
\]

The total energy consumption between two nodes is:

\[
E(X) = 2E_{elec} \cdot l + E_{amp} \cdot l \cdot d^2
\]

2.3. The Improvement of This Paper
As mentioned above, based on the WSN routing characteristics, the new path generation and harmony memory storage form have been changed accordingly. In order to further balance the distribution of energy in network operation, this section proposes a BTPHS algorithm which focuses on energy consumption balance in the later stage of network operation. There are three improvement strategies in
this algorithm: Cross Mutation, Angle Migration, node removal strategy and segmented objective function.

2.3.1. Cross Variation
To make the cross-mutation operation easier to understand, the following definitions are given: There are two different paths \( X_i \) and \( X_j \) in HM. If two different wireless sensor nodes \( u \) and \( v \) exist in \( X_i \) and \( X_j \) at the same time, they are called as a group of torsion nodes [7]. In the early stage of the implementation of HS Algorithm, the search scope is wide, the generated path is generally on the long side, and the Algorithm execution time is bound to increase. This improved method can generate new harmonies on the basis of the existing excellent harmonies, and at the same time, it can ensure the diversity of the circuit. The cross-mutation links exchange parts of two known lines in HM, and then two new lines are generated. In particular, a set of torsion nodes is first identified, then the sections between the torsion nodes are selected separately in the two lines, and then the switched sections form a new routing line. Two lines in HM can be found in figure 2.

\[
\begin{align*}
X_1 &= (s,11,13,18,22,24,d) \\
X_2 &= (s,12,18,26,25,24,d)
\end{align*}
\] (4)

![Figure 2](image)

**Figure 2.** Cross-mutation process.

A set of twisted nodes is determined; the paths between the twisted nodes of the two lines are selected and exchanged, resulting in two completely new paths:

\[
\begin{align*}
X_1^* &= (s,11,13,18,26,25,24,d) \\
X_2^* &= (s,12,18,22,24,d)
\end{align*}
\] (5)

The new path generated by the operation not only takes into account the superiority of the harmony of HM, but also avoids the cycle operation of the Algorithm, shortens the algorithm time and guarantees the diversity of the new harmony.

2.3.2. Angle Migration Method and Node Removal Strategy
Node deployment by its own battery power supply, there are strict power constraints, so in the routing algorithm design, the network’s energy consumption is needed to balance. Especially in the later period of network operation, the key node is different from the edge node, and takes part in many information transmission tasks, which consumes more energy [8]. Therefore, the main idea of BTPHS algorithm is to increase the usage frequency of edge nodes and reduce the exposure rate of key nodes. In reference [8], a new improved algorithm is proposed. The Algorithm is used in the whole network operation phase, in which the generation strategy of the next hop node is based on the residual energy
of the neighbour node. Therefore, the unbalanced energy distribution is only reflected in the neighbour nodes of the current node, and does not better reflect the global energy distribution characteristics. In order to take into account the impact of the overall energy of the network, BTPHS Algorithm divides the whole network life cycle into three stages according to the size of the real-time minimum energy $E_{min}$ in the network. In each stage, different node selection strategies are adopted when selecting the next hop node using HS algorithm (each node has an initial energy value of $E_0$ during the initial phase of the network).

Strategy 1: When the value of $E_{min}$ is between $[0.3E_0, E_0]$, the energy of the whole network is more balanced. In the early stage of network operation, the next hop node in the selection, using the classic round bet. The roulette wheel is constructed from the neighbour node’s current energy in proportion to the total energy. At this stage, the strategy can quickly identify the current network trunk road, convenient for subsequent branches to use.

Strategy 2: When the value of $E_{min}$ is between $[0.1E_0, 0.3E_0]$, the energy in the network begins to appear a certain degree of deviation, in the middle stage of the network operation, the next hop node in the selection, using the angle offset method. The steps for selecting the next hop of node $i$ by using the angle offset method are as follows:

Firstly, the concrete coordinates $(x_s, y_s), (x_d, y_d)$ of the source node $s$ and sink node $d$ are determined, and a trunk Vector $d$ pointing to the node $D$ is generated. The Computation rules for $D$ are as follows:

$$
\begin{cases}
    x_d = x_d - x_s \\
    y_d = y_d - y_s
\end{cases}
$$

Count the number of all the neighbour nodes of node $i$ as $N_0$ corresponding coordinates $(x_t, y_t)$, form the set of coordinates; start with the coordinates of node $i$ $(x_i, y_i)$, then calculate the points to the coordinates $P_t$:

$$
P_t : ((x_t, y_t), (y_t, y_i)), t = 1, 2, 3, \ldots, N_0
$$

Calculate the angle $\theta$ between the $N_0$ directional coordinates $P_t$ and the main Vector $D$. The value of $\theta$ is controlled by the corresponding cosine function value, the calculation rules are as follows:

$$
\cos \theta = \frac{x_d \cdot x_i + y_d \cdot y_i}{|D||P_t|}
$$

In the premise of the system model, the distribution of nodes is random, so the value of $\theta$ is also random. There is a one-to-one relationship between the value of cosine function and the deviation angle. When the deviation angle exceeds 90°, the value of cosine function will appear negative. At this point, the information may cause a post back situation. Therefore, the offset needs to be terminated. The nodes in the direction of trunk vector are used to transmit information with higher frequency and lower residual energy. BTPHS algorithm controls the value of $\theta$, interferes with the selection of the next hop node, deviates from the direction of the trunk vector, and increases the exposure rate and participation of the edge node.

Strategy 3: When the value of $E_{min}$ is between $[0, 0.1E_0]$ , the energy gap in the network is very large, and it is in the later stage of the network operation, the next hop node adopts the node removal strategy when it is selected. The basic idea of the strategy is as follows:

The fault-tolerance rate of the network is different in every period of time, and each period may cause a bigger energy gap because of the different judgment mechanism. The cut-off mark of the network operation is the time when the energy of the node is 0 for the first time. Therefore, BTPHS algorithm is selectively deleted when the next hop node is near death. In the next selection, if the current energy value of the node $p$ is below $0.1E_0$, the algorithm will temporarily delete the node $p$, so that it does not enter the next selection range [9]. The number of nodes to delete also needs to be
limited, delete too many nodes, resulting in information cannot be transmitted to the destination node. Therefore, the total number of nodes to delete cannot exceed $0.2N$.

2.3.3. Segmented Objective Function

The objective function is the final evaluation target of BTPHS Algorithm, and the success of path selection depends on the selection process of the objective function. In the selection of objective function, many factors need to be considered to ensure that the whole searching process is approaching to the optimal solution [10]. Factors included in the measurement include the length $L$ of the new path (i.e. the number of path nodes in the information transfer process), the average residual energy $E(X)$ of the path nodes, the global minimum energy $E_{min}$, and so on. Not only has that, according to the characteristics of energy distribution in different stages of the network, the objective function also needed to be changed accordingly to ensure that the whole network develops in a benign direction. Based on the three node selection strategies mentioned in section 3.4.2, the BTPHS Algorithm classifies the objective function into three distinct segments, as shown in formula (9).

$$f(x) = \begin{cases} 
\frac{L}{E(X)E_{mn}}, & 0.3E_0 < E_{mn} < E_0 \\
\frac{L}{E(X)E_{mn}}, & 0.1E_0 < E_{mn} < 0.3E_0 \\
\frac{1}{E(X)E_{mn}}, & 0 < E_{mn} < 0.1E_0 
\end{cases}$$

In the early stage of network operation, BTPHS Algorithm mainly focuses on generating routing paths with short path length and relatively low energy consumption, so as to form an optimal harmonic search database as soon as possible; In the Middle Period of network operation, the energy loss of some nodes is serious, the BTPHS algorithm begins to avoid these nodes when selecting the lines, and the generated lines are no longer required to be the shortest in length, but the energy consumption of the whole network is still low; In the later stages of network operation, individual nodes are already on the verge of energy exhaustion, In the process of generating a new path, these nodes are considered dead, and the length of the new path will inevitably increase. At this point, the BTPHS algorithm will no longer consider path length when re-evaluating the new path standard. Obviously, according to the mathematical meaning expressed in formula (9), the shorter the path length, the larger the average residual energy of the path and the minimum residual energy of the network, and the larger the objective function value, the more likely the routing scheme that accords with these characteristics will be preserved.

3. Experiments

This section presents the simulation results of BTPHS algorithm. The simulation software uses Matlab2018a and runs on a Mac mini 2014, a 2.6 GHz Intel Core i5, and 8 GB of Ram. According to the effective communication radius, 8 different node distribution scenarios are randomly generated. The number of nodes in the scenario increases from 10 to 80, with an increment of 10 nodes. In order to verify the feasibility of BTPHS algorithm, two contrast algorithms, EEHSBR and IHSBEER, which are also based on harmony search algorithm, are introduced in the experimental part. For each test scenario, two metrics are used to evaluate the performance of the Algorithm: Network Lifetime (that is the number of rounds sent when the first node in the network dies) and average residual energy (the average of the energy of all nodes in the network).

In order to verify the feasibility of BTPHS algorithm, this paper designs two different transmission modes in data transmission: fixed-node continuous transmission and full-node cyclic transmission.
Fixed node continuous transmission: all sensor nodes have the same initial energy, and packets are sent from a fixed node to a sink node. Full-node looping: all sensor nodes have the same initial energy, and each sensor node periodically sends packets to the sink node. The relevant parameters are shown in Table 1. The experimental results are the average values of 20 times of simulation.

### Table 1. Parameter settings.

| Parameter setting | Parameter value |
|-------------------|-----------------|
| Packet size       | 4098bits        |
| Communication Radius | 150m          |
| Initial energy    | 10J             |
| $E_{elec}$        | 50nJ/bit        |
| $E_{amp}$         | 100pJ/bit/m$^2$ |
| HMS               | 5               |
| HMCR              | HCMR$_{min}$    |
|                   | HCMR$_{max}$    |
| $T_{max}$         | 500             |

### 3.1. Node Scheduling Test

The experiment in this section is mainly focused on the angle offset and node removal strategies proposed in section 2.3.2. In 8 different node distribution scenarios, the node activity of the Algorithm was tested in the whole node cyclic sending process. Node activity reflects the usage frequency of nodes in WSN, and defines the residual energy value of current nodes. The lower the residual energy, the more energy the node consumes and the higher the frequency of the node, that is, the higher the activity of the node. In this paper, three different residual energy thresholds are selected to carry out three sets of contrast experiments. The test conditions are as follows: Test A: Network death, the remaining energy is less than $E_0$; Test B: Network death, the remaining energy is less than $0.9E_0$; Test C: Network death, the remaining energy is less than $0.8E_0$. The results are shown in figures 3, 4, and 5.

The main goal of the angle migration and node removal strategy is to use as many edge nodes as possible for transmission. In WSN, information transmission mainly depends on the nodes on the main road, considering the propagation time and the cost of survival, it is difficult to use edge nodes to replace sensor nodes on the main road. Test A indicates the number of all participating nodes during the whole network lifetime, which is counted as long as the nodes are involved in transmitting the information.

As can be seen in figure 3, the performance of the three algorithms is basically the same in the environment with fewer nodes. When the number of nodes in the environment increases, the number of nodes mobilized by BTPHS Algorithm increases significantly.

Figures 4 and 5 can be seen as mild and moderate usage behaviours of edge nodes. The residual energy can quickly measure whether the node participates in the network transmission many times.
The threshold of residual energy is lowered and the activity of the selected node is higher. In both cases, the BTPHS Algorithm outperforms the EEHSBE Algorithm and the IHSBEER algorithm, this is because of the improved strategy presented in section 2.3.2 when generating the information transfer path, the choice of the next hop node provides more possibilities for the edge node and increases the exposure rate of the edge node. Three sets of experimental results, shown in figures 3, 4 and 5, further verify the feasibility of the angle shift and node removal strategy.

3.2. Experiment Results with Constant Transmission from A Fixed Node

Figures 6 and 7 respectively show the comparison of the two indicators in eight experimental settings. The horizontal axis of the two experimental graphs shows the number of sensor nodes in different scale scenarios, the vertical axis of figure 6 represents the life cycle of the network (when there is an energy black hole, the number of rounds of information passed through the network), the vertical axis of figure 7 shows the average residual energy.

![Network lifetime comparison](image1)

![Comparison of mean residual energy](image2)

**Figure 6.** Network lifetime comparison.  **Figure 7.** Comparison of mean residual energy.

As can be seen from the results in figure 6, the BTPHS Algorithm presents the best results in some scenarios, especially in environments with a large number of nodes. The more nodes in the WSN scope, the more complicated the routing relationship between nodes, and the more neighbour routing per node. Therefore, late in the network cycle, the risk resistance of the WSN network will be greater, after removing the suspected dead nodes artificially, the network can still generate a feasible routing scheme to further extend the network usage time.

As you can see from figure 7, there is not much difference in the residual energy control among the three algorithms based on harmony search. From this, it can be concluded that harmony search algorithm is suitable for solving NP-hard problem. In this environment, there’s not much difference in residual energy shows that the routing schemes generated by the three algorithms are more balanced in the overall energy consumption. A higher energy surplus means a lower energy cost, and the optimization of the IHSBEER algorithm reduces the average energy consumption during network operation. BTPHS algorithm focuses on the use of edge nodes, in the late cycle of the Algorithm, sacrifice path length, increase the exposure rate of edge nodes, the total energy consumption of the path immediately increased, in line with the original design logic. So in terms of the average residual energy performance, BTPHS algorithm is slightly lower than IHSBEER algorithm in most of the experimental scenarios. This phenomenon shows that BTPHS algorithm performs better in energy balance, and can work more under the existing energy environment by using low-exposure nodes.

3.3. Experimental Results Under Full-Node Cyclic Transmission

Figures 8 and 9 show the comparison of the two indicators in each of the eight experimental settings.
As can be seen in figure 8, the BTPHS algorithm still performs well in eight different node distributions. The node distribution range is larger, the total number of nodes is more, but the node distribution density per unit area is smaller. From the test data, it can be seen that the number of rounds obtained by the BTPHS algorithm has increased significantly, especially in the test environment of 50 nodes, compared with EEHSBR algorithm, the improvement is 12.9%, compared with IHSBEER algorithm, and the improvement is 5.52%. The cross mutation in BTPHS algorithm can effectively avoid the use of dying nodes by reversing the cutting and splicing of nodes to achieve a wide range of path changes in the later stage of network operation. The test results shown in figure 9 are broadly similar to the experimental data in Environment 1.

With the increase of network area and the decrease of node density, the energy consumption of BTPHS algorithm is higher than that of other algorithms when transmitting the same data packet to sink node, the number of rounds maintained is a further improvement over other algorithms, this test result proves the feasibility of BTPHS algorithm.

4. Conclusion

From the comparison of the two test environments, we can see that BTPHS algorithm performs particularly well in the environment with many nodes. The energy loss is slightly less than that of EEHSBR and IHSBEER. At the same time, the probability of the edge node entering the routing scheme is improved due to the introduction of the angle migration method and node removal strategy, further partaking the use frequency of nodes on the trunk road. The objective function is updated from a single evaluation standard to a three-phase evaluation to ensure that the BTPHS algorithm in different stages to choose the best current forwarding path. On the premise of energy efficiency, the scalability of the network can be improved. For most current applications, such as smart home, industrial and manufacturing automation, the number of nodes is moderate. Combined with Matlab simulation results can be concluded that BTPHS algorithm in the field of routing choice has broad prospects for development.

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