Multi-Objective Optimization Algorithm Based on Improved Harmony Search for Wireless Sensor Network

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Abstract
Energy consumption of clustering routing protocol is one of the exigent problems that need to be solved in wireless sensor network, but traditional LEACH protocol can result in uneven energy consumption and poor loading balance because of the random way of selecting cluster nodes. This paper puts forwards a wireless sensor network clustering protocol algorithm based on multi-objective optimization, which turns the cluster head selecting into the multi-objective problems including the distance between common node and Sink node, and the distance between cluster node and Sink node etc., and adopts the improved Harmony Search algorithm to optimization aiming at unstable convergence problem of original algorithm. Finally we give some analysis and comparison between the improved algorithm and the origin alone, and the results show that the wireless sensor network protocol based on improved Harmony Search algorithm can increase the node energy-efficiency and prolong the network survival lifetime.

Key words: Wireless Sensor Network; Multi-Objective; Harmony Search Algorithm.

1. INTRODUCTION
As a new technology, wireless sensor network (WSN) is recognized as the fourth industry revolution of IT technology and the developing direction of the next-generation computer network. It changes the interaction method between people and environment, and becomes the indispensable part of our life (Akyildiz et al., 2002; Sun, 2005). In 1999, WSN was proposed which will become the next developing opportunity of next century in the mobile computing and networking International Conference held in the United States. The US Business Week regarded the WSN as one of the most influential 21 technologies in twenty-first Century (Terry and Vander, 2003), and MIT Technology Review also regarded the WSN as the top of ten emerging technologies which will change the future of the world (Robert, 2003). The WSN is deployed in the adverse environment to execute the periodic monitoring tasks. Therefore, how to design a high performance routing protocol in WSN, and decrease the energy consumption has become the key need to be solved in WSN application.

In order to decrease the energy consumption, some researches put forward the concept of cluster network topology, and the LEACH which was proposed by Heinzelman et al. is the first clustering routing protocol in WSN, and its basic thinking is selecting cluster node equiprobably in a random cycle, assigning whole network energy to each sensor node averagely, and finally reducing the energy consumption and prolonging the network survival lifetime (Heinzelman et al., 2000). But the random way of selecting cluster node makes each node possibly become the cluster node, and it also makes the possibility that low-energy node becomes the cluster node. If the cluster node exhausts its energy, it will become a blind one, resulting in premature death for the network. And then the literature (Yonis, et al., 2004) took node rest energy and inter cluster communication cost into account, and realized the even energy cluster in the process after several iteration. Literature (Ye et al., 2004) combined the random selecting mechanism and local competition mechanism to select the cluster nodes. Literature (Handy et al., 2002; Chen et al., 2002) put the rest energy into cluster node selecting algorithm in which. Literature (Chen et al., 2010) put forward the uneven energy cluster node competition algorithm, and increased the probability of cluster nodes when the node had more rest energy. Literature (Chen et al., 2010) put forward a double rounds clustering protocol for improving energy efficient in WSN.

These existing researches, however, just focus on routing protocols to local optimization. Therefore, in this paper, we put forward a multi-objective optimization algorithm based on Improved Harmony Search for WSN clustering protocol, and then compare this algorithm with original Harmony Search algorithm, and finally use Matlab for network simulation to verify.

2. MULTI-OBJECTIVE MODELING
2.1. Transmission Unit of WSN
The design of WSN routing protocol is related with energy consumption of transmission, so we adopt first order radio model in WSN in this paper, and the formula of energy consumption is as Formula 1 with K bit packet and d distance.
Here, \( E_{\text{elec}} \) is the energy consumption of each bit packet while transmitting or receiving, \( \epsilon_{\text{f}} \) and \( \epsilon_{\text{mp}} \) are constant, and \( d_{ab} \) is Euclidean distance between node a and node b, and \( d_0 \) is the constant which is defined as Formula 2.

\[
d_0 = \sqrt{\epsilon_{\text{mp}}} \quad (2)
\]

The expression of energy consumption is as Formula 3 while receiving K bit packet

\[
E_R(k) = kE_{\text{elec}} \quad (3)
\]

Here, given the cluster is combined with m nodes, the energy consumption between cluster node c and common node n in one round are as Formula 4 and Formula 5.

\[
E_c = nE_R + E_{\text{sink}} \quad (4)
\]

\[
E_n = nE_{\text{sink}} \quad (5)
\]

\( E_c \) is the energy consumption of cluster c, and \( E_n \) is the energy consumption of node n once.

### 2.1. Building Multi-Objective Model

In the existing researches of WSN clustering protocol algorithms, they introduced the rest energy of each node while selecting the cluster and resolve the problem of premature death for the network by LEACH protocol, but the single target would easily reduce the optimization.

Multi-objective optimization is designed to make multi-objective optimization under certain restriction. It is constituted by N variable parameters, H target functions and T restriction conditions, and the relationship of target functions, restriction conditions and variable parameters is defined as Formula 6.

\[
\text{Miny} = F(x) = (f_1(x), f_2(x),..., f_n(x))
\]

\[
\text{s.t.} \quad g_i(x) \leq 0 \quad i = 1,2,...j
\]

\[
= 0 \quad j = 1,2,...p
\]

Here, \( x = (x_1,x_2,...,x_m) \in X \) is an n-dimensional decision variable in space \( \mathbb{R}^n \). \( X \) is n-dimensional decision space. \( y = (f_1(x), f_2(x),..., f_n(x)) \in Y \) is an m-dimensional target vector, and \( Y \) is the m-dimensional target space. \( g_i(x) \) and \( h_j(x) \) are the inequality and equality restriction function. So in this paper, we turn the cluster head selecting into the multi-objective problems including the distance between common node and Sink node, the distance between cluster node and Sink node and the energy consumption and build the related multi-objective models.

1) Objective Model f(om1)

\[
D1 = \sum_{k=1}^{n} d_{k\text{sink}} \quad (7)
\]

\( D1 \) is the Euclidean distance between common node and Sink node, \( n \) is the node number, and \( d_{k\text{sink}} \) is the Euclidean distance between node k and Sink node.

2) Objective Model f(om2)

\[
D2 = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{\text{cc}} + \sum_{i=1}^{m} d_{i\text{sink}} \quad (8)
\]

\( D2 \) shows two distances including the Euclidean distance between common node and cluster node, and the Euclidean distance between cluster node and Sink node, \( m \) is the total clusters number. Of two, \( d_{\text{cc}} \) is the Euclidean distance between common node i and cluster node c with n number nodes in cluster node c, and \( d_{i\text{sink}} \) is the Euclidean distance between cluster node c and Sink node.

3) Objective Model f(om3)


\[ E = \sum_{i=1}^{m} \sum_{j=1}^{n} E_{ij} + \sum_{i=1}^{m} nE_{i} + \sum_{i=1}^{m} T_{r_{sink}} \]  

\( E \) is the total energy consumption, including the energy consumption of transmitting data from common node to cluster node, and the receiving data energy consumption of cluster, and the energy consumption of transmitting data from cluster node to Sink node. \( \sum_{j=1}^{n} E_{ij} \) is the total energy consumption while transmitting data from \( n \) nodes to cluster \( c \), \( nE_{i} \) is the total consumptions while the cluster \( c \) receiving the data from \( n \) nodes, and \( T_{r_{sink}} \) is the total consumption while transmitting data from cluster \( c \) to Sink node.

3. IMPROVED HARMONY SEARCH ALGORITHM

Traditional multi-objective optimization method also aggregates the multi-objective problems into a single objective function by mathematical transformation, and then gets the best solution by single optimization method. These methods are designed to be simple and fast computing, but they can not be evaluated by using the Pareto efficiency and there are some limitations in solving the problem.

3.1. Original Harmony Search Algorithm

Harmony Search algorithm (HS) is a novel Heuristic intelligent optimization algorithm which was put forward by Geem (Geem et al., 2010), which has the advantages of fast convergence and simple realization, and has been applied successfully to many combinatorial optimization problems (Hasanebi et al., 2010; Ayvaz, 2010).

Basic Harmony Search algorithm initializes the harmony memory at first, and then generates a new harmony from the harmony memory. If the New Harmony is better than the worst one in the harmony memory, it puts the New Harmony into the memory instead of the worst one. The algorithm continues to run until convergence or the maximum number of iterations is reached. So the process of basic Harmony Algorithm can be divided into the following five steps: parameters initialization, harmony search memory initialization, new harmony vector generation, harmony memory update and termination conditions judgments.

1) Parameters Initialization

Main parameters of Harmony Search algorithm includes: Harmony Memory Size (HMS), Harmony Memory Considering Rate (HMCR), Pitch Adjusting Rate (PAR) and bandwidth (BW). In addition, it should set the termination condition and the restrict condition of optimization before runs. As to a non-constrained optimization problem, it can be described as the Formula 10.

\[
\begin{align*}
\min f(X), & \quad X=(x_1, x_2, ..., x_n) \\
x_i \in [x_{\text{min}}, x_{\text{max}}], & \quad i=1, 2, ..., n
\end{align*}
\]  

(10)

In this formula, \( f(X) \) is the objective function and \( X \) is the decision variables.

2) Harmony Search Memory Initialization

Initialization of each dimension of harmony vector as the random in the interval is denoted as Formula 11, while Initializing method of harmony search memory.

\[ x^i_j = x_{\text{min}} + (x_{\text{max}} - x_{\text{min}}) \times \text{rand}(0,1) \]  

(11)

In this formula, \( \text{rand}(0,1) \) is the uniform distribution random between 0 and 1, and the harmony memory is defined as Formula 12.

\[
HM = \begin{bmatrix}
X^1 & \ldots & f(X^1) \\
\vdots & \ddots & \vdots \\
X^{\text{HMS}} & \ldots & f(X^{\text{HMS}})
\end{bmatrix} = 
\begin{bmatrix}
x^1_1, & \ldots, & x^1_n, & f(X^1) \\
\vdots & \vdots & \vdots & \vdots \\
x^{\text{HMS}}_1, & \ldots, & x^{\text{HMS}}_n, & f(X^{\text{HMS}})
\end{bmatrix}
\]  

(12)

3) New Harmony Vector Generation

The core part of Harmony Search algorithm is the New Harmony vector generation and it generates the new vector by the following three ways, they are: harmony memory learning, fine pitch based on learning, and random selection of a new pitch. The probability of learning from memory is determined by harmony memory considering rate, as to a New Harmony vector, if one component \( x^i_j \) takes value from memory, the
component can take a value from the ith column of memory. But before this process, it should generate a rand between 0 and 1 and operate as the following formula 13.

\[
\begin{cases}
  x_{i}^{\text{new}} = x_{i} \in \{x_{i_{1}}, x_{i_{2}}, ..., x_{i_{\text{HMS}}}\}, \quad \text{rand}_{1} < \text{HMCR} \\
  x_{i}^{\text{new}} = x_{\text{min}} + (x_{\text{max}} - x_{\text{min}}) \text{rand}, \quad \text{rand}_{1} \geq \text{HMCR}
\end{cases}
\]  

(13)

Here, any pitch of new vector has HMCR probability to take the value from memory, and has the (1-HMCR) probability to take the value from rand. If the ith pitch is taken from the memory, this pitch is tuned by Formula 14 with the probability of PAR.

\[
\begin{cases}
  x_{i}^{\text{new}} = x_{i}^{\text{new}} \pm \text{rand}(0,1) \text{bw}, \quad \text{rand}_{1} < \text{PAR} \\
  x_{i}^{\text{new}} = x_{i}^{\text{new}}, \quad \text{rand}_{1} \geq \text{PAR}
\end{cases}
\]  

(14)

4) Harmony Memory Update

We should estimate it by objective function after generating the New Harmony vector. If the new Harmony is better than the worst harmony in memory, the worst harmony will be taken place by the new one. As to the minimum optimization problem in Formula 10, if the value of New Harmony is less than the value from worst harmony in memory, it means the New Harmony is better than the worst harmony, and then the worst harmony can be deleted from the memory and the new one will be put into the memory.

5) Termination Conditions Judgments

Finally, we check the terminate condition, if not satisfied, come back to Step3, otherwise, come into the end. As to terminate condition, we can set precision threshold, for example, as to minimum optimization, if the optimization result is less than the threshold, the algorithm terminates.

3.2 Improved Harmony Search Algorithm

Optimization effects are mostly depend on the initialization of HM, the selection of parameters such as HMCR and the new ways of solution. So if the Harmony Search algorithm faces poor optimization or unsuitable parameters selection or complex optimization objective, some shortage such as weak local searching ability and convergence precision will appear.

The flowchart of Improved Harmony Search Algorithm shown in Figure 1, it adopts the binary encoding mode, and the length of the code is the same as the number of nodes in the network. At first, the new algorithm initials individual by random, and then determines harmony memory(HM) by four parameters, they are objective model f(om1), f(om2),f(om3)shown in the second chapter and the left energy, and then generates the random r, if r is smaller than HMCR, generating new harmony coding, otherwise ,keeping the original one. Then we join disturbances probability PAR, if it comes to the ending condition, the algorithm is terminates, otherwise, we dynamically update value of HCRM and PAR, and then update the harmony Memory.

Figure1. Flowchart of improved HS algorithm

3.3 Design of Clustering Routing Algorithm Based on Multi-Objective

The design process of clustering routing algorithm based on multi-objective is following.
1) Set up basic parameters, including clusters number N, the least nodes number in each cluster Nm and the transmitting times T, finally, deploy each node.  
2) Initialize the clusters of WSN by multi-objective optimization at first; after the clusters are determined, other nodes join into these clusters according the distance.  
3) Record T times energy consumption by the data transmitting among the common node, cluster node and Sink node.  
4) At the end of the data transmitting, if the survival number is smaller than Nm, the algorithm terminates, otherwise, it executes the Steps 2~4 successively.

4. SIMULATION

4.1 Simulation Environment

The monitoring area is a rectangle of 50m×50m, with 100 nodes in this wireless sensor network. The Sink node location is (75, 25). The length of the message during the data transmitting is 4000b, and the iteration times are 200. Other parameters are shown in Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_0$</td>
<td>0.2J</td>
</tr>
<tr>
<td>$e_{fs}$</td>
<td>10pJ.b^{-1}.m^{-2}</td>
</tr>
<tr>
<td>$e_{mp}$</td>
<td>0.0013pJ.b^{-1}.m^{-4}</td>
</tr>
<tr>
<td>N</td>
<td>4</td>
</tr>
<tr>
<td>$HMCR_{min}$</td>
<td>0.6</td>
</tr>
<tr>
<td>$HMCR_{max}$</td>
<td>0.8</td>
</tr>
<tr>
<td>$PAR_{min}$</td>
<td>0.05</td>
</tr>
<tr>
<td>$PAR_{max}$</td>
<td>0.3</td>
</tr>
</tbody>
</table>

4.1 Simulation Results Analyses

As we know, the original Harmony Search algorithm can enormously increase the network survival time compared to LEACH algorithm and cluster load level. Therefore, in this part, we focus the simulation on the improved Harmony Search algorithm and the original Harmony Search algorithm.

1) Network Survival Nodes Ratio and Transmitting Times

Network survival time is an important index to reflect the effectiveness of routing protocol, in this paper, we use the relationship between the survival nodes ratio and the time to represent the survival time in the network. In addition, we use the transmitting times between common node and Sink node as another index, and the more the number of transmission, the greater the amount of data reception. Figure 2 shows the comparison between the improved Harmony Search algorithm and the original Harmony Search algorithm.

![Figure 2. comparison of the performance for different algorithms](attachment:image.png)

From Figure 2, we can see that, because of the self-adaptive parameters, the performance of improved algorithm can be improved by 10% or thereabouts.
2) Cluster Load Level

Because the imbalance of the number of cluster members will lead to the difference between the total amount of data collection and the total transmission of data between different clusters, so we put the cluster load level as another important index to estimate the protocol performance. Here, the cluster load can be approximated by the size of the cluster, and we use the formula of load balance factor (LBF) in Formula 15.

\[ LBF = \frac{n_c}{\sum_{i=1}^{n_c} (x_i - \mu)^2} \] (15)

Here, \( n_c \) is the clusters number, \( x_i \) is the nodes number in cluster \( i \), and \( \mu \) is number of average neighbor nodes in each cluster. The formula is as Formula 16.

\[ \mu = \frac{N - n_c}{n_c} \] (16)

**Figure 3.** Comparison of LBF for different algorithms

From formula 15, we know that the greater the value of LBF, the better the load balance of the network. From Fig 3, we can see that fluctuation of improved algorithm is less than the original algorithm.

3) Influence on Sink Node Location

In this part, the Sink node is placed in location (75, 75) and location (50, 50) to estimate the influence on network performance. From Fig 4, we can see that, no matter where Sink is, the improved algorithm performance is better than the original Harmony Search algorithm.

**Figure 4.** Comparison of the performance for different distances between Sink and network
5. CONCLUSIONS

Aiming the existing problem of cluster selection for WSN, this paper has adopted the multi-objective optimization algorithm based on improved Harmony Search, and has done some analysis and comparison between the improved algorithm and original algorithm. The experiment results have demonstrated that the improved algorithm proposed can increase node energy-efficiency and prolong network survival lifetime.

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