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RESEARCH ON A HEURISTIC SEARCHING ALGORITHM FOR ENERGY-AWARE ROUTING IN WIRELESS SENSOR NETWORKS

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ABSTRACT

Because cluster-head nodes in wireless sensor networks may be far away from the base station, or there exists many obstacles in deployment environments of wireless sensor networks to affect the data transmission performance, they would consume excessive energy in the process of the massive data transmission, which may lead to their earlier death. To solve this problem, a LEACH-A* algorithm is presented in this paper, which utilizes the distance among cluster-head nodes and their corresponding energy and combines with the heuristic searching algorithm to provide the multi-hop communication mode. It can avoid earlier death of some cluster-head nodes, and shift the energy consumption burden from cluster-head nodes to the whole sensor network, thus to prolong the life cycle of the network and improve the transmission quality.

Keywords: *Wireless Sensor Networks (WSN), LEACH, Heuristic Searching Algorithm, NS2*

1. INTRODUCTION

In LEACH route protocol, data transmission between the BS (base station) and cluster-head nodes is implemented by means of single hop. Because cluster-head nodes in wireless sensor networks may be far away from the base station, or there exists many obstacles in deployment environments of wireless sensor networks to affect the data transmission performance, they would consume excessive energy in the process of the massive data transmission, which may lead to their earlier death and even shorten network lifetime [1][2]. So, we should reduce single hop communication between the base station and cluster-head nodes.

Nowadays, current research mainly focuses on how to employ multi-hop methods to realize data transmission between cluster-head nodes and the base station by optimizing route selection among cluster-head nodes, and to prolong the life cycle of the network and improve the transmission quality. LEACH-EE is an efficient clustered routing protocol. The main idea is to traverse all cluster-head nodes in the wireless sensor network by searching a shortest path to transmit data with the base station. It is a key problem to find this shortest path. The traditional and classical shortest path solving algorithms are Dijkstra and Floyd.

In addition, many intelligent algorithms such as fuzzy method [3][4], ant colony algorithm[5]-[7], and other swarm intelligence methods[8]-[10] are used to optimize route selection among cluster-head nodes in wireless sensor networks. The main idea of heuristic searching algorithm is to get better position by evaluating all positions in state space and then repeat this searching process until finding the object. A* algorithm is one of the kind of heuristic searching algorithms, and it's usually used to solve optimal routing problems and strategy design problems [11].

In this paper, a heuristic searching algorithm A* is used to find optimal path, optimize routing selection among cluster-head nodes, and form a optimal multi-hop spanning tree for data transmission. A LEACH-A* algorithm is presented in section 2, which utilizes the distance among cluster-head nodes and their corresponding energy and combines with the heuristic searching algorithm to provide the multi-hop communication mode. In section 3, performance indicators such as network lifetime, network energy consumption, and

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received data of the base station are compared among LEACH, LEACH-C and LEACH-A from simulation results. Section 4 summarizes the key issue of the paper.

2. LEACH-A* ROUTING ALGORITHM

It is very important to use cost function for positioning in heuristic searching algorithm A*. Different cost functions can lead to different effects. The following cost function is:

$$f(n) = g(n) + h(n) \quad (1)$$

In formula (1), $f(n)$ is the cost function of the node n, $g(n)$ is the real cost from source node to current node in state space, and $h(n)$ is the estimated cost of an optimal path from current node to target node. $h(n)$ is the essence of the heuristic searching algorithm A*, and we can find the optimal path through heuristic searching of $h(n)$.

2.1. Presuppositions

At first, the wireless sensor network is divided into clusters through by means of node location algorithm. After clustering and timing sequence distribution of TDMA, we can employ LEACH-A* algorithm to solve a multi-hop data transmission path according to position and energy consumption information of nodes. Then, the network enters into stable transmission stage.

Assumed that the following hypotheses in the wireless sensor network:

1) Energy of a base station (BS) is infinite.
2) Positions of BS and sensor nodes are fixed.
3) Sensor nodes are homogeneous and have same initial energy.
4) All sensor nodes can transmit data with the BS.
5)All sensor nodes know their position according to some node localization algorithms, and broadcast their own location.
6) Energy consumption of all sensor nodes are adopted the first communication radio energy consumption model.

A node can be defined as the following structure:

```
Struct Node
{
  Ch_id;   // ID number of the cluster-head node
  X_pos;   // X direction coordinate
  Y_pos;   // Y direction coordinate
  Select;  // if the node adds a route
  //data transmission energy consumption
  // from cluster-head node i to its neighbor
  DisToAdj[i];
  //data transmission energy consumption
  // from cluster-head node j to base station
  DisToBs[j];
  Energy;     // Residual energy
};
```

2.2. Leach-A* Algorithm Derivation

The cost function of the heuristic searching algorithm LEACH-A* is $f(n) = g(n) + h(n)$. $g(n)$ denotes energy consumption of data transmission from one cluster-head node to its neighbor cluster-head nodes, which can be viewed as key nodes. It is a critical factor for LEACH-A* algorithm to solve cost function $h(n)$ to find the optimal route by means of key nodes.

The definitions of parameters are as follows:

S	Source Node;
G	Target Node;
N	Intermediate node in path from S to G;
N'	A node next to N;
$E(N,N')$	Energy consumption from N to N';
$g_S^*(N)$	Minimal energy consumption from S to N;
$h^*(N)$	Minimal energy consumption from N to G;
$f_S^*(N)$	Minimal energy consumption cost function, which equals to $g_S^*(N) + h^*(N)$;
$g_S(N)$	Current energy consumption from S to N;
$h(N)$	Current energy consumption from N to G;
$f_S(N)$	Current energy consumption cost function from S to N, which equals to $g_S(N) + h(N)$;
$f_\varepsilon^S(N)$	Equals to $g_\varepsilon^*(N) + g_S(N) + h(N)$, and ε is a key node in the path;
$E_{\min}$	Minimal energy consumption in data fusion;
$E_{\max}$	Maximal energy consumption in data fusion;

There exists a linear relation among cluster-head nodes. In other words, if a cluster-head node has precursor cluster-head node or successor cluster-head node, for example N' is successor cluster-head node of N, then any cluster-head node relation (N,N') can be expressed as the following formula:

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$$h(N) \le E(N,N') + h(N') \quad (2)$$

$E(N,N')$ is energy consumption of current path from N to N'. For any one of cluster-head nodes ε, if ε is not the node in the linked list CLOSEDLIST, we can define that:

$$f_\varepsilon(N) = g_\varepsilon^*(S) + f_s(N) \quad (3)$$

$f_s(N)$ is current consumed energy of a path from ε to G and through node S and N. So, we can draw the following conclusions:

1) $g_\varepsilon^*(P)$ is the cheapest energy cost for ε to P.

2) $g_p(N)$ is the energy incurred from P to N.

3) $h(N)$ is estimated energy from N to G.

Assumed that $SS_1S_2.....S_k$ is the minimal energy consumption route as the optimal route from S to G, we can deduce the following conclusion:

$$f_\varepsilon^s(S_1) \le f_\varepsilon^s(S_2) \le ... \le f_\varepsilon^s(S_i) \le f_\varepsilon^s(S_{i+1}) \le ... \le f_\varepsilon^s(S_k) \le f_\varepsilon^s(G)$$
(4)

In a wireless sensor network, the energy consumption of every cluster-head node includes three parts. Energy consumption for data transmission can be calculated according to the node positioning algorithm and the first communication radio energy consumption model. During data fusion, too massive data may lead to earlier death of nodes, while too little data may lead to frequent data transmission and much energy consumption. In this case, a maximal energy consumption and minimal energy consumption of data fusion model is presented.

Assume that $E_{received}$ is energy consumption of nodes in the process of data reception, E_{fusion} is that of data fusion, and E_{send} is that of data transmission. As P is an intermediate node in LEACH-A*algorithm, we have the following inference:

$$g(p) = \sum_{k=1}^{n} E_k \quad (5)$$

As $E_{\min}^j$ and $E_{\max}^j$ is the minimal and maximal energy consumption of the cluster-head node, every cluster-head node can be expressed as the following formulas:

$$E_{\min}^j = \sum_{k=1}^{n}(E_{received} + E_{\min\_fusion} + E_{send}) \quad (6)$$

$$E_{\max}^j = \sum_{k=1}^{n}(E_{received} + E_{\max\_fusion} + E_{send}) \quad (7)$$

Any one of cluster-head node Y can be expressed as:

$$h(y) = |Y-Z| * E_k + |Z-G| * E_k = |Y-Z| * E_k + h(z) \quad (8)$$

Through the above formula, we can deduce that

$$f_\varepsilon^s(N) = g_\varepsilon^*(N) + g_s(N) + h\ (N) \quad (9)$$

In the above formula 9, $g_s(N)$和$h\ (N)$ can be calculated, but $g_\varepsilon^*(N)$ cannot be calculated easily. There exists maximal and minimal value in the consumed energy process of data confusion, so

$$g_\varepsilon^1(S) = |\varepsilon - s| * E_{\min} \quad (10)$$

$$g_\varepsilon^2(S) = |\varepsilon - s| * E_{\max} \quad (11)$$

$$g_\varepsilon^1(S) \le g_\varepsilon^*(S) \le g_\varepsilon^2(S) \quad (12)$$

$$\{f_\varepsilon^s(N)\}_{\min} = g_\varepsilon^1(S) + g_\varepsilon(N) + h(N) \quad (13)$$

$$\{f_\varepsilon^s(N)\}_{\max} = g_\varepsilon^2(S) + g_\varepsilon(N) + h(N) \quad (14)$$

$$\{f_\varepsilon^p(N)\}_{\min} = g_\varepsilon^1(P) + g_\varepsilon(N) + h(N) \quad (15)$$

$$\{f_\varepsilon^p(N)\}_{\max} = g_\varepsilon^2(P) + g_\varepsilon(N) + h(N) \quad (16)$$

From the above derivation, the cost function can be calculated.

$$f_{\min} = \min\{\{f_\varepsilon^s(N)\}_{\max}, \{f_\varepsilon^p(N)\}_{\max}\} \quad (17)$$

$$f_{\max} = \min\{\{f_\varepsilon^s(N)\}_{\min}, \{f_\varepsilon^p(N)\}_{\min}\} \quad (18)$$

According to solve minimal value to the maximal extent and maximal value to the minimal extent, it is sure that we can solve a minimal energy consumption route as the optimal route of LEACH-A*.

2.3. Leach-A* Algorithm Pseudocode

Pseudocode of LEACH-A* algorithm is as follows:

```
Best_Search_Leach( )
{
  Openlist=[Start_Node];
  Closed=[ ];
  While (Open!=NULL) {
    //Get a node X from linked list Open,
    //and delete from Open at first
    If (X==Goal_node) {
      Calculate PATH;
      Return PATH;
    }
    If (X_Node->next==Y_Node) {
      If (Y_Node!= Open[]||Y_Node!= Closed[]){
        //estimated cost of node Y
        Calculate Y_Node_Eval;
        Open=[Y_Node];
```

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```
        }
        Else if (Y_Node== Open[ ]) {
          //Sort linked list Open again
          If (Y_Node_Eval<Open[i]. Eval)
              //update estimated cost of Open
              Update Open[i]. Eval
          } Else {
              //Put node Y to linked list Closed;
              // Sort linked list Open according to
cost;
              If (Y_Node_Eval<Closed[i]. Eval)
                 Update Closed[i]. Eval;
              Delete Closed[i]= Y_Node;
              Put Open[i]= Y_Node;
        }//end if
      }//end for
   }//end while
}//end function
```

2.4. Example Of Leach-A* Algorithm

Figure 1 is an exemplary state diagram of clustered sensor nodes. Seen from figure 1, there are 19 cluster-head nodes in the formation phase of clusters, and every cluster-head node has a estimated value $f(n)$. The specific algorithm process is as follows:

1) Initializing linked list:
OPENLIST=[CH_1];
CLOSEDLIST=[ ];

2) Searching and estimating cost functions of eight directions of node CH_1, putting the successor node of CH_1 into linked list OPENLIST, and putting CH_1 into linked list CLOSEDLIST.
OPENLIST=[CH_7,CH_3,CH_2,CH_4],
CLOSEDLIST=[CH_1];

3) Searching and estimating cost functions of eight directions of node CH_7, putting the successor node of CH_7 into linked list OPENLIST, and putting CH_7 into linked list CLOSEDLIST.
OPENLIST=[CH_5,CH_6,CH_8,CH_10,
CH_3,CH_2,CH_4],
CLOSEDLIST=[CH_7, CH_1];

4) Searching and estimating cost functions of eight directions of node CH_5, putting the successor node of CH_5 into linked list OPENLIST, and putting CH_5 into linked list CLOSEDLIST.
OPENLIST=[CH_14,CH_17,CH_16,CH_15,
CH_6,CH_8,CH_10,CH_3,
CH_2,CH_4],
CLOSEDLIST=[CH_5,CH_7, CH_1];

5) Searching and estimating cost functions of eight directions of node CH_14, putting the successor node of CH_14 into linked list OPENLIST, and putting CH_14 into linked list CLOSEDLIST.
OPENLIST=[CH_18,CH_13,CH_11,CH_17,
CH_16,CH_15,CH_6,CH_8,
CH_10,CH_3,CH_2,CH_4],
CLOSEDLIST=[CH_14,CH_5,CH_7, CH_1];

6) Searching and estimating cost functions of eight directions of node CH_18, putting the successor node of CH_18 into linked list OPENLIST, and putting CH_18 into linked list CLOSEDLIST.
OPENLIST=[BS,CH_19,CH_12,CH_13,
CH_11,CH_17,CH_16,CH_15,
CH_6,CH_8,CH_10,CH_3,
CH_2,CH_4],
CLOSEDLIST=[CH_18,CH_14,CH_5,CH_7,
CH_1];

7) Estimating BS, and putting BS into linke list CLOSEDLIST.
CLOSEDLIST=[BS,CH_18,CH_14,CH_5,
CH_7, CH_1];

In figure 1, we can solve an optimal routing path [CH_1,CH_7,CH_5,CH_14, CH_18, BS] according to LEACH-A* algorithm (solid arrow line) .

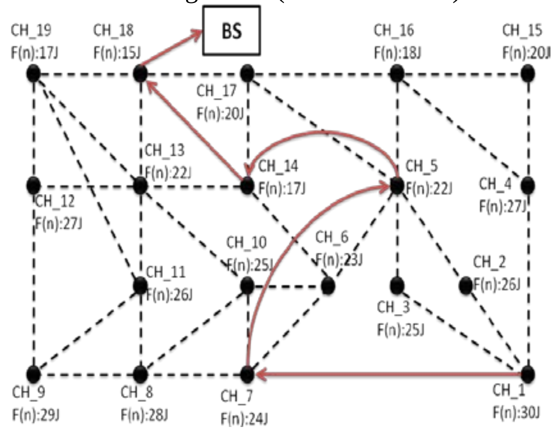

Figure 1. A Exemplary State Diagram Of Clustered Sensor Nodes

3. SIMULATION & RESULTS ANALYSIS

LEACH-A* algorithm is implemented and simulated based on LEACH protocol in the network simulation platform. LEACH, LEACH-C and LEACH-A* is contrasted and analyzed from aspects of energy consumption and network performance in this paper.

Figure 2 is the comparison of simulation result of network survival time among three algorithms. X-axis represents running time of network, and Y-axis represents the number of survival nodes for a

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period of running time. Network life cycle can be judged by three factors: death time of the first node, death time of the first node, and death time of the last node in the network. Seen from figure 2, performance of the network lifetime of LEACH-A* algorithm is superior to that of LEACH and LEACH-C, and performance of the network lifetime of LEACH is inferior to that of LEACH-C. Figure 2 indicates that the wireless sensor network has formed a multi-hop spanning tree by means of LEACH-A* algorithm. Because it promotes high-efficient data transmission in wireless sensor network, LEACH-A* algorithm balances energy consumption and saves energy of the whole network. Although LEACH-C algorithm takes into account of location information and residual energy of nodes, it still adopt single hop mode to transmit data. In the stage of stable data transmission, nodes may die out of energy in advance.

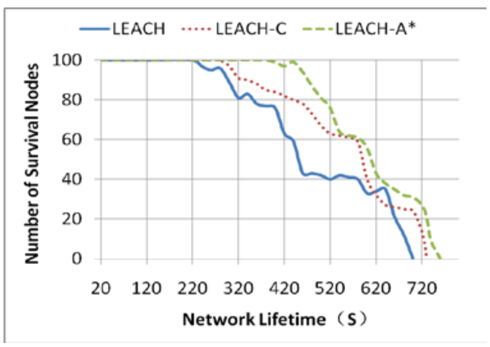

Figure 2. Contrast Of Network Lifetime

Figure 3 shows the comparison of simulation result of energy consumption of nodes among three algorithms. Seen from figure 3, the energy consumption of nodes through LEACH-A* is lower than LEACH and LEACH-C.

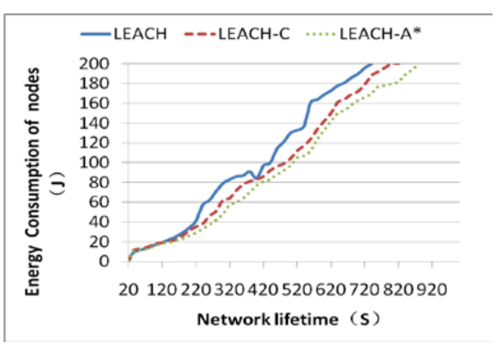

Figure 3. Contrast Of Network Energy Consumption

Figure 4 shows the comparison of simulation result of received data from the base station among three algorithms. Seen from figure 4, the amount of received data through LEACH-A* is higher than the other two algorithms.

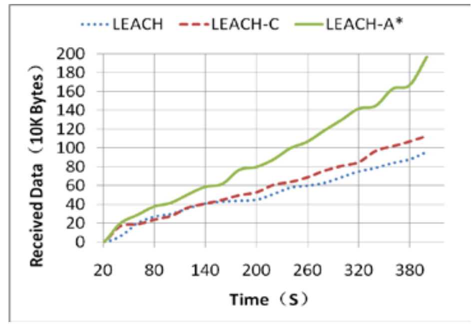

Figure 4. Contrast Of Data Reception Of BS

4. CONCLUSIONS

An energy-aware routing algorithm LEACH-A* based on the heuristic searching algorithm A* in wireless sensor networks is presented in this paper, which utilizes the distance among cluster-head nodes and their corresponding energy and combines with the heuristic searching algorithm to provide the multi-hop communication mode. It can avoid earlier death of some cluster-head nodes, and shift the energy consumption burden from cluster-head nodes to the whole sensor network, thus to prolong the life cycle of the network and improve the transmission quality. The simulation results on NS2 platform show that network performance of LEACH-A* algorithm such as network lifetime, network energy consumption and data transmission from the base station are superior to that of LEACH and LEACH-C.

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