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Research on a Shortest Routing Algorithm of Wave Propagation in Wireless Sensor Networks

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Abstract

The shortest routing problem is the key to the efficiency of routing in Wireless Sensor Network .This paper aimed at the problem of no obtaining the real-time shortest routing and the poor adaptability of the large-scale wireless sensor network, which is caused by considering adequately the network topology in those present shortest routing algorithms, simulating water diffusion, puts forward a shortest route algorithm of WSN. In the diffusion process, water waves gradually expand to the surrounding, and iterate over all the area, the region is treated as the network which consists of a large number of nodes and arcs. The algorithm simulates the spread of the wave movement through multiply operation, and emulates the single coverage of water wave through die operation, then simulates the motion law of the real water wave using the substitution operation, it can avoid the dead diffusion zone by overlapping operation, achieve full traversal and determine the shortest route according to the arrived wave information of each node recorded in a shortest period of time. Meanwhile, the algorithm's time complexity and space complexity are analyzed in the paper, and concluded that the time complexity of the algorithm is linear change along with the square of the node number, the space complexity is linear change along with the node number in the worst case. Experiments show that the performance of the algorithm is superior to existing shortest route algorithms in most application cases.

Keywords*: the shortest routing, Wireless Sensor Network (WSN), Wave diffusion, complexity*

1. Introduction

Wireless Sensor Networks has large scale deployment, limit energy of nodes, topology changes and other characteristics, but the routing is the key to guarantee the correct and reliable transmission of the sensing data. Determine the shortest routing is the key to improve the efficiency of routing in wireless sensor networks. The shortest path problem is a classical algorithm problem in graph theory, which has been widely used in the fields of vehicle scheduling, network communication, etc. Currently, the search of monophyletic point shortest path commonly uses algorithms including Dijkstra algorithm, A * algorithm, SPFA algorithm, the Bellman - Ford algorithm, Floyd-Warshall algorithm and Johnson algorithm [1-4].These algorithms study the shortest path problem of monophyletic undirected graph, which is composed of nodes and paths, aims to find out the shortest path between two nodes in the graph.

The Dijkstra algorithm [1, 5] is rigid, whose number of searches is fixed, both its time complexity and space complexity is $O(n^2)$. The time performance of A * algorithm [6] is the optimal in theory, but its space performance increases exponentially. Floyd algorithm [7-8] is used for the multi-source, shortest path without negative right side, the time

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complexity is $O(n^3)$. Floyd-Warshall algorithm is an algorithm which solves the shortest path between any two nodes, can handle properly the shortest path problem of directed graph or negative rights, the time complexity is $O(n^3)$, space complexity is $O(n^2)$. Bellman-Ford algorithm [9] is used for seeking the monophyletic shortest path, can judge whether negative cycle (if any, does not have the shortest path), to solve the routing problem of sparse connection network, timeliness is good, and the time complexity is $O(ne)$. The SPFA algorithm is the queue optimization of the Bellman-Ford algorithm, timeliness is relatively good, time complexity is $O(ke)$ $(k << e)$, e represents the edge, for densely connected network such as a fully connected network, $e \to n^2$, the SPFA algorithm can be used in the diagram with negative right side ,but the SPFA algorithm in time efficiency is not stable. Meanwhile, the effect of SPFA algorithm is poor in solving some grid maps [10-11].

In addition to the above algorithms, there are some intelligent search algorithms, such as genetic algorithm, ant colony algorithm [12-17], particle swarm optimization [18-19], etc. But genetic algorithm require complex coding, ant colony algorithm based on pheromone concentration has probabilistic properties, particle swarm optimization algorithm given initial solution by adding disturbance. The algorithm also has its no adaptability, which essentially belongs to the heuristic algorithm, rather than the exact algorithm. Although the efficiency of these algorithms is high, but the solution is just the optimal value of all current feasible solutions, it is difficult to guarantee that the solution is globally optimal one.

The paper is aimed at the no adaptability of the shortest routing algorithm at present, according to wave propagation laws in nature, an accurate shortest path routing algorithm is proposed in this paper.

2. Wave Propagation Algorithm

2.1. Theoretical Basis

The Dijkstra algorithm is continuously modifying the adjacency information of a mobile node, need traversing the nodes in the network for many times in order to determine the optimal solution. For a network composed of n nodes, because the algorithm doesn't go accessed is n, so need to calculate n^2 times.

The Ford and SPFA algorithm, go on the prune searching in the search region, also is a certain degree of segmentation of the search interval. If the network composed of nodes is divided into two sub search regions whose number of nodes is respectively a_1 and b_1, and $a_1 + b_1 = n$ .Meanwhile, if use the Dijkstra algorithm independently in each area, then the total number of the search is $a_1^2 + b_1^2$. Obviously, $n^2 = (a_1 + b_1)^2 = a_1^2 + b_1^2 + 2a_1 b_1 > a_1^2 + b_1^2$.

Pruning algorithm [20] usually adopts the hierarchical model or the network tree model to pruning the entire network. Therefore, prune searching reduces the difficulty of the search. For routing optimization problem, although this kind of algorithm can obtain the approximate optimal solution, but the heuristic of this segmentation method is not obvious, is not effectively deal with the boundary points of each branch.

The algorithm is proposed in this paper, the principle division of its search region is follow as:

Definition 1. The boundary is defined as the network layer which is formed by nodes are directly adjacent to the source node.

Definition 2. Wavefront is defined as the boundary consists of the adjacent nodes which divide the search area into the different search intervals.

Theorem 1. The shortest path from a source node to a destination node is specified to must pass by a node of adjacent node set between different wave fronts.

Theorem 2. The path from the boundary node to the target node is specified to must pass by the boundary composed of outer layer of adjacent nodes.

Theorem 3. These boundaries will extend layer by layer, similar to the water wave.

According to the above principle and lemma, this partitioning method effectively solves the problem of boundary point. Therefore, the obtained solution is globally optimal. For the scale of the n nodes, if two first- level sub area is further split, forming three second-level sub regions a_2, b_2, c_2, and that is

$n^2 = \left(a^2 + b^2 + c^2\right)^2 = a_2^2 + b_2^2 + c_2^2 = 2a_2b_2 + 2a_2c_2 + 2b_2c_2 > a_2^2 + b_2^2 + c_2^2$, and $a_2^2 + b_2^2 + c_2^2 \ll a_1^2 + b_1^2$.

Theorem 4. The smaller the search area is divided into, the less search times.

The algorithm in this paper, we calculate the distance values from all boundary nodes to the source node and choose the maximum value as threshold of the next partition search area in order to make the divided area dense enough. In each thin region, launch a similar Dijkstra algorithm to reduce the complexity of the algorithm.

Meanwhile, because each circle is very thin, so in the restricted search area of each circle inside, assuming that the number of nodes in a circle is k_i, then, although adopt Dijkstra algorithm similar to the operation, the nodes connected degree is greatly reduced, the actual number of search will not be equal with k_i^2, is $s \ll k_i^2$.

Theorem 5 Draws on the pheromone method of ant colony algorithm, based on the pheromone memory, greatly reducing the number of overlay operations, namely in a single thin layer, again using pruning method hierarchical model or network tree model, the search area with k_i nodes have the further subdivision. Therefore, the average number of times each node access will be greatly reduced, the search efficiency is improved greatly.

According to the above operations, the ideal division could reach $n = (1 + 1 + 1 ... + 1)$, namely n single node area, the complexity of traditional Dijkstra algorithm is $O\left(n^2\right)$, while the computational complexity of this algorithm is $(1^2 + 1^2 + 1^2 ... + 1^2) = n$.

Also, this algorithm modifies the condition of iteration termination, if encountered in Figure 8, then, the calculation times will be 1.

In view of the existing computer storage resources are limited, the space complexity is too large, the increasing node size will soon run out of memory. This paper adopts wave tree, the data structure can contribute to reduce the operation of the space complexity to $2n$, lays the foundation of solving the network routing optimization problem for large-scale node network.

2.2. Description of Algorithm

A graph $G(n, e)$, is composed of n nodes and e adjacent edges, as shown in figure 1, strives for the shortest route from the source node S to the destination node T.

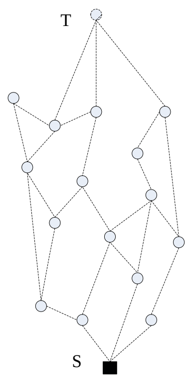


Figure 1. Node Network

The whole process simulates the wave diffusion, the search area is divided into different layers, wave started outward from the source node layer by layer, then wavefront diffusion is formed, wavefront will always be the first to arrive at the new node. The wavefront is the boundary consisting of all the leaf nodes of the wave tree diagram. Through the historical records of wavefront at a moment, these records include the current node number, the father node, corrugated layer number, the cumulative time from the source node to the current node, etc, which can obtain the shortest routing. Historical data of wavefront in each layer, is placed in the data structure called wave tree graph .Wave tree graph has a root node, that is the source node. The leaf node of wave tree graph must be located on wavefront, with the wavefront moving forward, the leaf node will change into the father node. The diffusion process of wave is given below.

At first, the wave sets out from the source node S, spreading around along the nodes network, corrugated radius increases gradually along with the search process. The diffusion paths of these water ripples eventually form a directed tree graph. The diffusion process is shown in figure 2. First of all, traversing all direct neighbor nodes of the source node, these neighbor nodes form the first circle of ripples, the maximum radius b_1 of the layer of ripple is defined by the farthest distance from the node to source node, as shown in figure 2-(a). Then perform the diffusion, prior to judgment, the father node replacement, iteration and termination. In the diffusion operation, as long as the distance from current leaf node to the source node is less than corrugated radius b_1 of the first ring, operate iterative calculation, in the iteration, the distance once is greater than the current ripple radius, terminate diffusion in this direction, and the nodes are added to wave tree graph as new leaf nodes. The wheel is calculated completely, the nodes are in the outer ring of b_1, the distance from them to the source node is greater than b_1, forming second circle ripple. Corrugated radius b_2 of the second ring is determined by the node, which is the farthest to the source node, as shown in figure 2-(b).According to wave propagation law, the third circle ripple, the fourth circle ripple, until spreading to the destination node region and covering the destination node, as shown in figure 2-(c).

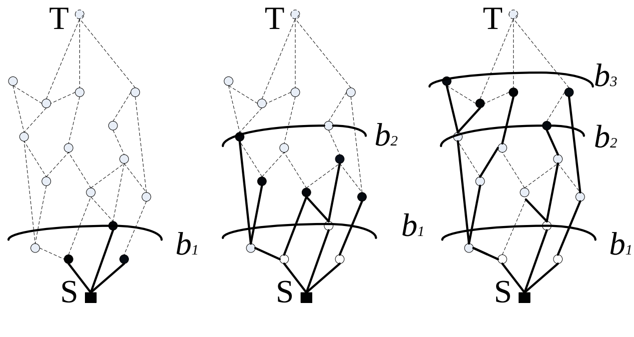


Figure 2.The Process that the Nodes on Wave Front Spread in the Node Network and Form Wave Tree Graph

To traverse each node's adjacent nodes, processing rules are as follows:

a) Multiply operation. If the wave arrives at a certain node for the first time, a new wave node object form, the relevant information will be recorded in the network nodes, and the node is added to the wave tree graph as a child node. As shown in Figure 3-a, no wave arrive at the node neighbor A of node B , therefore, the object of a new wave node is definited, and it is added to the wave tree graph. Multiply operation is the basic operation of wave diffusion, the wave tree graph grows up by breeding. Wave tree graph records the data of wave diffusion process, that is from which node, time consumption, etc. The leaf nodes on wave tree graph consist of wavefront, the whole search is over.

b) Forward control. If the adjacent node is the current node's father node, then the node is ignored, ensure that the wave does not return. As shown in figure 3-(a), the C node is adjacent to the node B, also is the father node of node B, so it no longer reverse spread. This operation can ensure the closed-loop doesn't appear.

c) Replace operation. As shown in Figure 3-(b), now operating on the node E, who has a neighbor node C, just a wave passed by it. However, if make the node C is closer to the source node from node E to node C, then the node E becomes the father node of C, and will delete the node C from child list of the node D. The operation ensures that the wave nodes only have a father node, which makes the topology of the wave tree graph well.

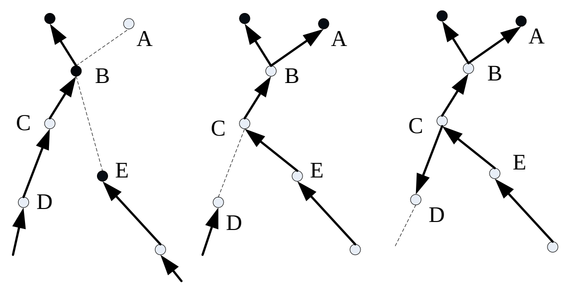


Figure 3.The Basic Operation in the Process of Wave Propagation

d) Covering operation. In the alternative operation, if the new wave comes faster than the former wave, and the distance from the node to the source node is less than the radius defined by wavefront, as shown in Figure 3-(c), and then make the node as the entrance to local iteration. So the previous wave information will be covered by the iterative operation.

e) Die operation. If a new wave passed by a node, and the new wave is slower than the existing wave, the situation will be ignored, new wave no longer diffuse, in order to reduce the search space.
f) Jumping (Ripple expansion). If all nodes within a circle of ripple are iterated, need to calculate the new ripple radius according to wavefronts of the wave tree graph. The next iteration will consider the new The next round iteration will regard the new ripple radius as the boundary. The new ripple radius is certainly greater than the last round ripple radius.
g) Calculation termination. If the destination node is between two circles ripple or in the area of the current wavefront, upstreaming the wave tree from the destination to the source node through the wave tree graph, so as to obtain the shortest routing, the search process completed.

2.3. Data Structure

Wave diffusion algorithm uses data structures, including network node, adjacency relations, wave node and wave tree graph. In order to realize the wave diffusion algorithm, this paper defines the following data structure:

The network nodes are defined as follows:

```
class Node
{
    public List<Neibor_relation> neibor_list=new List<Neibor_relation>();//Adjacency relations
    public int id;//Node number
    public double least_time;//The shortest time of wave diffuse from the source node to the current node
    public Wave w;// wave with the shortest distance coming from waves source
    public bool is_exist;//Weather the node is in the wave head node
    public Node()
 {
 least_time=0;
    is_exist=false;
 }
```

Adjacency relationship of nodes is defined as follows:

```
class Neibor_relation
{
    public int id;//Node number
    public double dist;//The distance between the nodes
    public Neibor_relation()
    {
        id=0;
        dist=0;
    }
}
```

Wave node object is defined as follows:


```
public class Wave:IComparable<Wave>
{
    public int id;//Wave number, consistent with the network node number.
    public int pid;//The primary node of the wave
    public double least_time;//The shortest time from the source node
    public Wave Parent;//Father node
    public List<Wave> ChildNodes=new List<Wave>();//The child node of wave
node
    public Wave()
{
    id=0;
    pid=0;
    least_time=0;
    candel=true;
}
}
```

Wave tree graph begins with the source node, the nodes gradually expand outward and form the tree topology. Data structures of wave tree graph are defined as follows:

```
class Wave_root
{
  public List<Wave> ChildNodes=new List<Wave>();//a number of child nodes
 }
```

At first, the wave tree graph has only a root node. Using the above data structure, this paper defines the following global objects and control variables:

```
 List<Node> node_net=new List<Node>();//the node network, reflecting the
connection relationships of network nodes
  List<Wave> wave_head_list=new List<Wave>();//Node sequence on wavefront
  Wave_root  root=new Wave_root();//Wave root, is actually wave tree graph
extending gradually from the source node
  int node_num=111111;//The total number of nodes
  int start_num=0;//The serial number of source node
  int end_num=111110;//The destination node number
  string path="";//The shortest path from the source node to the destination node
  double least_dist;//The shortest distance from the source node to the destination
node
  double max_dis=0;//The maximum radius of each new circle ripple
```

The variable *max_dis* is the longest distance that the current ripple can spread. Once a branch exceeded *max_dis* for the first time, it will halt, each circle ripple diffusion is completed, the variable *max_dis* will be recorded in *temp_max_dis* , then spread to other branches,each round diffusion is determined by *max_dis*,at the same time, updating *temp_max_dis*. And so forth, *temp_max_dis* will record the search range of the next round.

2.4. Algorithm Design

In order to complete diffusion operation, a wave node list is defined in the paper, stores the reference of wave nodes. All nodes in the list need to take part in the next round iterative operation. Also, the list will be increase or reduce during the process of iteration. The algorithm operations are mainly the judgments and assignments, the amount of calculation involved is smaller, the algorithm includes a main process and an iterative process of trans. Meanwhile, in order to simplify the code, defines a sub program of Process for updating node information. Main process of the algorithm is shown in figure 4:

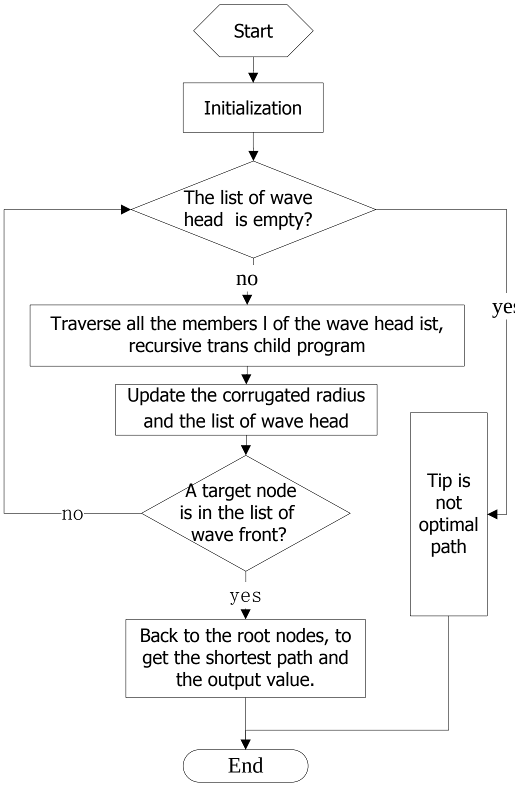


Figure 4. Main Process of Wave Propagation Algorithm

The main steps are as follows:

Step 1: Initialization network node object. Use the previously defined data structure to generate a certain number of nodes, and establish the adjacency relation between nodes. The source node is added to *wave_head_list* and root of the two objects, and find out the distance from the source node to the farthest adjacent node, will be assigned to the variable of *max_dis* , ready to enter the first round of the search.

Step 2: Diffusion operation. That is an iterative process, for the nodes of the *wave_head_list*. If the node is selected for the first time and the shortest distance to the source node is less than *max_dis*, depending on the rule 1, execute the step 2.If the node is selected many times, and the shortest distance of the source node smaller than *max_dis*, depending on the rules 3and 4, to replace the current node's father node, add the node to the tail of *wave_head_list*, checking the child nodes of the node again. If the shortest path from the current node to the source node is greater than max_dis in a search, put the distance record comparing with the variable of *temp_max_dis*, if the distance is larger, it will be recorded to the variable *temp_max_dis*, according to the rule 5 at the same time, the branch search stops immediately. After all child nodes of a node is processed, the node will be deleted from the *wave_head_list*. The rule 2 in the iteration process can ensure wave tree graph is a directed tree graph.

Step 3: Transition between layers. In the beginning of the step 2, to count *wave_head_list* members, when the members are traversed, this round of proliferation activity is done. Even the new members joined in the tail of *wave_head_lis*t, according to the rule 6, still need to deduce the next round. Before entering a new search, *temp_max_dis* needs to be recorded in the variable of *max_dis*.

Step 4: Testing *wave_head_list*. If the queue has no members, it indicates the effective path doesn't exist. Meanwhile, to test whether the target node has been hit, if has been hit (i.e., the target node has been in the wave tree graph), the search is terminated according to the rule 6.Utilizing the node of the wave tree graph back to the source node to find the shortest path, and calculate the distance value of the shortest path. If *wave_head_list* has members, then go to step 2, a new search will appear.

Figure 5 is the key to the algorithm process, contains the operations of steps 2, 3, 4 for the wave head list, data members of the wave head list will change with the extension of each lap corrugated in this link. The variable of *max_dist* records the corrugated radius, the sequence value respectively are $0, b_1, b_2, \dots, b_t$, these values constitute the search range are $(0, b_1], (b_1, b_2], \dots, (b_{t-1}, b_t]$.When the new corrugated radius updated, delete the corrugated nodes within the previous circle of corrugated radius.

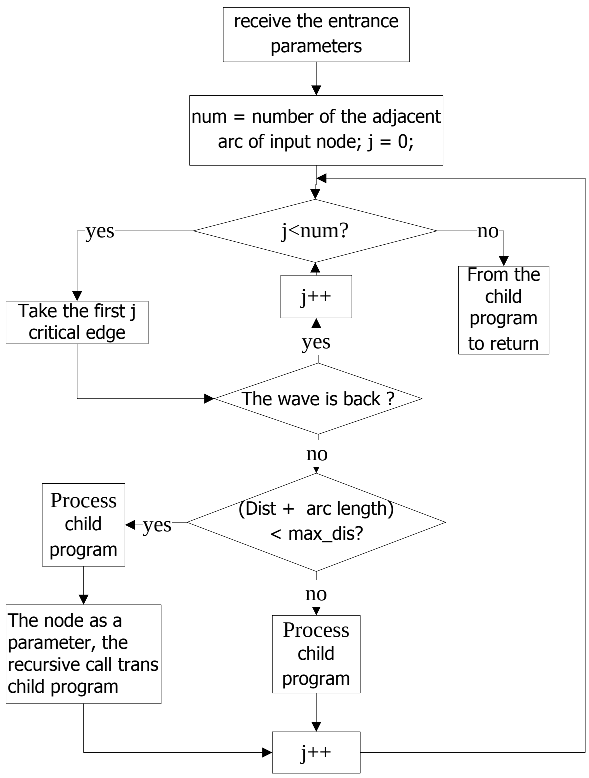


Figure 5. Wave Propagation Algorithm of Iterative Process

There is a Process program in Trans process, its code content corresponding operation is shown in figure 6.The algorithm references to principles of pheromone diffusion in ant colony algorithm. For the pheromone diffusion, the genetic algorithm uses the characteristics of concentration, the pheromone is released by the multiple ants, finally find the optimal path according to the highest pheromone concentration, is essentially a heuristic search. The pheromone concentration is fixed in the algorithm to control the process of pheromone diffusion, the area boundary that pheromone involved after diffusion is used to find the optimal path. Therefore, the algorithm simplifies the calculation process.

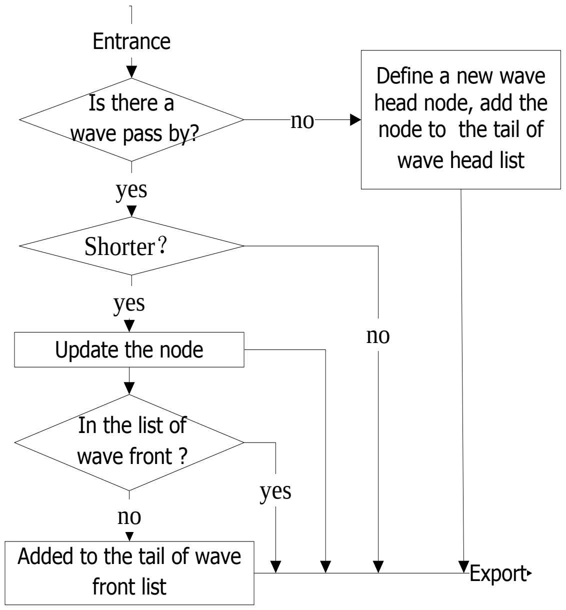


Figure 6.Process Program Flow

3. Algorithm Analysis

3.1. Time Complexity Analysis

Wave propagation algorithm based on the characteristics of water waves from the wave source gradually spread to the surrounding, to simulate the diffusion regularity of water waves. In order to ensure it expand gradually, the variable max_dist is used to define the wave diffusion between the two circles of ripples. Once the diffusion exceeds this region, iterative operation will be performed. In the search process, local iteration per round follows depth-first principle, and the whole iteration between layers of ripple takes breadth-first traversal.

In the diffusion process, for the wave arrive at a certain node, if the distance of the source node is farther than the previous wave, give up operation. Therefore, this reduces traversal to the part of nodes. If the arrival time is shorter than the previous wave, perform substitution and diffusion operation to ensure to find the optimal route value.

How is the wave propagation algorithm's time complexity proposed in the paper ? Suppose there is a process of wave diffusion, the nodes of the network is divided into several regions, as shown in figure 7.

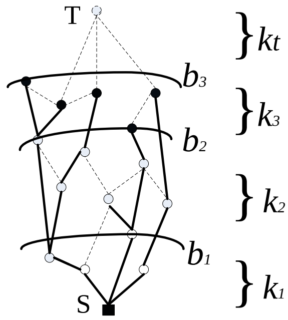


Figure 7.The Case of All Nodes are Gathered Between Two Wave Ripples

The node number between circles of ripples is respectively $k_1, k_2, k_3, \ldots k_t$, and $k_1 + k_2 + k_3 + \ldots + k_t = n$. If each node in each region traversed must conduct a comparison with all other nodes in the region, so calculation times of the algorithm is $k_1^2 + k_2^2 + k_3^2 + \ldots + k_t^2$, apparently, $k_1^2 + k_2^2 + k_3^2 + \ldots + k_t^2 \le n^2$.

If the most complicated case occurs, it has only a search region, namely $t = 1$, so the time complexity is $O(n^2)$. For another special case, as shown in Figure 8.Suppose that the destination node in the first corrugated region and it has only a valid connection, the optimal routing can be obtained by search judgment. Thus, the time complexity is $O(1)$.

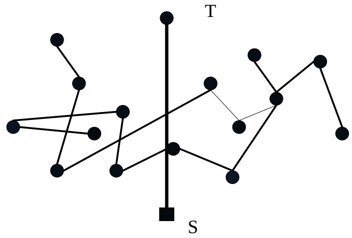


Figure 8.The Situation that Has an Only Connection between the Source Node and the Destination Node

Therefore, the time complexity of the algorithm changes with the topological map changing. The general cases as shown in Figure 7, the graph is not fully connected, but there is a measurable average node degree d . As segmentation method of the corrugated layer ensures the node number between each layer as little as possible, so as to reduce the complexity of the overlapping operation. Nodes in two each ripples, in order to obtain the optimal routing, just need a small amount of traverse, also is nd operations, the time complexity of traversing tree wave graph generated by the whole network is $O(nd)(d << n)$. As the algorithm is adaptive, when two nodes for finding the shortest path are in the area of just the same two circles ripple, need not deal with the nodes in other areas, effectively reduce the number of search. Although the location relationship of nodes is random, but the algorithm is always searching for the optimal path in the fastest way, according to the current topological structure. Therefore, the average of the actual time complexity is less than $O(nd)(d << n)$. Because the relationship between the traversal number and node size appears an approximately linear growth , so the actual execution effect of the algorithm is better than those algorithms without considering specific topological structure.

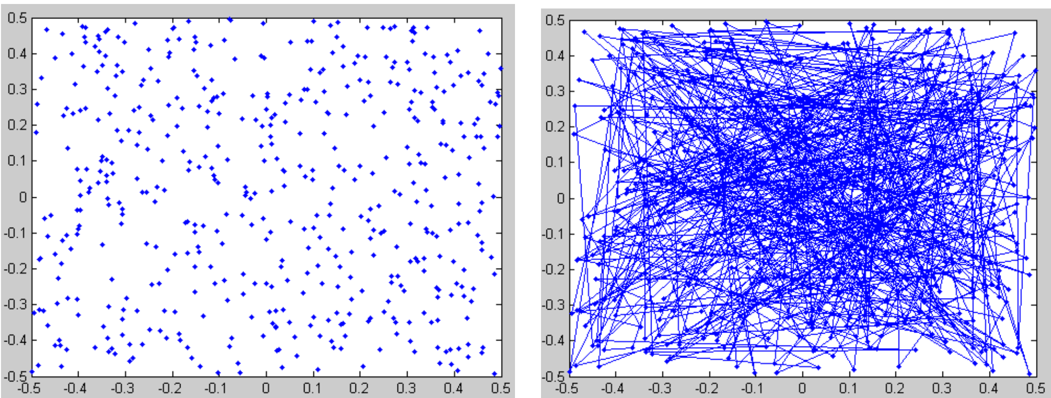
3.2. Space Complexity Analysis

This algorithm adopts the object-oriented technology, using the objects association method to express node network and data structure of wave tree graph, all the data objects involved is two lists, including node network and wave tree graph. Other objects are only the references to these objects, such as the wavefront list needn't the new storage space. Thus, the space complexity is $O(cn)$ $(c \ll n)$, c is an integer constant, it is be determined by the space that the object specific attributes take up.

For node number is 100000, even 1 million nodes consist of large-scale WSN, using the Dijkstra algorithm, the space complexity is $O(n^2)$. Using C++ requires a two dimensional array of 100000 * 100000, memory will overflow, unable to direct detect algorithm. In fact, when defining a two-dimensional double-precision array of 1000 * 1000 in C++, the memory will overflow.

4. Algorithm Implementation And Contrast

In the introduction, the performances of the classical shortest routing algorithms are analyzed in the paper, the time performance of the Dijkstra algorithm, A* algorithm, SPFA algorithm and the wave propagation algorithm proposed in the paper are tested. This paper use respectively .net and matlab platform for testing. In the test, the node number selected respectively is 100,1000,10000,100000. The average node degree is set to 10, and the adjacency relationship and the weight (distance) of nodes randomly generate .As the larger node size, visual effect is very poor. Using matlab to generate 500 nodes and the effect of node adjacency relations as shown in figure 9 (a), (b).



(a) (b)

Figure 9.Randomly Generated Node Sets and Random Adjacency Relations

Matlab can be used to check the smaller size nodes network. When the node scale reach 10000 or 100000, data structure that meet the demand of algorithm cannot be constructed, a 10000 * 10000 array, that will lead to overflow. So the traditional Dijkstra algorithm, A* algorithm and SPFA algorithm cannot be directly tested. For large-scale nodes network, because space complexity of other algorithms is too high, lead to heap overflow, can only make theoretical deduction. But this algorithm can support level of 1 million nodes network. At last, the time consumption of each algorithm is calculated on the .net platform, which as shown in figure 10:

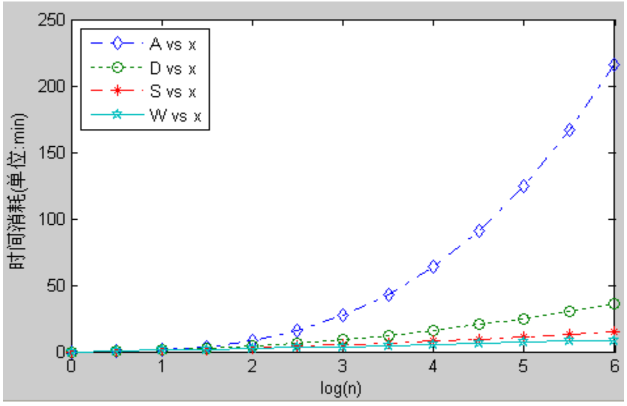


Figure 10.Time Performance Comparison of Each Algorithm

In figure 10, the thesis analyses the need time of the Dijkstra algorithm, A * algorithm, SPFA algorithm and wave propagation algorithm is proposed in this paper, under the same experimental conditions, respectively for the random number is 100,1000,10000,100000 nodes consist of network for finding the optimal path. Including the space complexity of the Dijkstra algorithm, A * algorithm and SPFA algorithm are too large, when the node size over thousands cannot be calculated directly. Thus, in the test, only using N * N multiple loop test. For the wave propagation algorithm of this paper, we constructed the real data set to calculate. The actual calculation results of the proposed algorithm depends on the network topology, so use 20 times test and get the average. As the actual search time closely relates with node topology, the case that the time complexity is $(n-2)^2$ can appear , but that is only an extreme one, in the actual nodes network, it is very difficult to meet, so the results are the average test results of 20 different randomly generated networks. Test results can be obtained by figure 10, with the number of nodes increasing , A * algorithm obviously costs more time to find the optimal path, the consume time of Dijkstra algorithm to find the optimal path is equivalent to SPFA algorithm , while wave propagation algorithm in the same experimental conditions takes the least time to find the optimal path, between two nodes, effectively reduce traversal times .The experimental results show that using wave propagation algorithm for dynamic optimal route search in large-scale WSN, is more effective than other similar algorithms.

5. Conclusions

Wave propagation algorithm, simulates the physical phenomena of nature, as the universal law of nature, it is objective. The water diffusion law is applied to finding the shortest routing algorithm in the wireless sensor network in this thesis, a new shortest routing algorithm based on the wave propagation rule is proposed. After repeated experiments, the test results show that the algorithm is superior to other similar algorithms. In fact, the algorithm considers the network scale of the nodes, the number of adjacent edges and network topology, it always find the shortest routing with the fastest speed, according to the network topology. Therefore, this algorithm has good adaptability. Therefore, the wave propagation algorithm for solving the shortest path problem has important application value.

Acknowledgments

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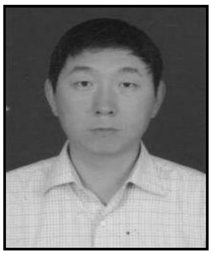

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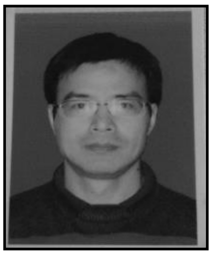

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