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Research on 3D Wireless Sensor Networks ISC-EAR Routing Algorithm

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Abstract: In order to improve the performance of 3D wireless sensor networks, an Iterative Split Clustering Energy Angle Routing (ISC-EAR) Algorithm is proposed. The design idea is discussed theoretically, and the design idea is as follows: on the basis of the link bandwidth and other meeting user QoS requirements, all nodes within the node perception radius or communication radius are regarded as next hop candidates. Select the next hop node according to the total energy consumption of the node (including sending and receiving energy consumption), and try to ensure that the farthest transmission distance consumes the least energy. Select the current node, the destination node and the next hop node, the space vector with the current node as the vertex has the smallest angle, that is, the candidate node closest to the destination node as the next hop node. In order to verify the performance of the algorithm, use C/C++ for programming simulation. Through three different topological structures of mine topology, average topology and random topology, the performance evaluation is carried out using four indicators: the number of alive nodes, network lifetime, network energy consumption and average energy of node. Through simulation calculation, the ISC-EAR routing algorithm has good technical performance advantages compared with the benchmark routing algorithm IGreedy, which can increase the survival time of nodes, reduce network energy consumption, and prolong the survival time of the network. It has better advancement.

Keywords: 3D WSN, ISC-EAR, Routing Algorithm, Clustering, Energy Saving

1. Introduction

In recent years, 3D wireless sensor network technology in underground sensor network [1], underwater sensor network [2], space sensor network [3-4], smart home [5] and the field of structural health monitoring [6] etc has been widely applied. Main research interests include: network coverage [7-8], localization algorithm [9], data aggregation [10], and routing algorithm [11-13], etc. This paper mainly research on 3D wireless sensor network routing algorithm.

In 3D wireless sensor network routing algorithm research there has been a lot of research results. The routing algorithm in 3D wireless sensor network (3D WSN), the main research focus is the routing algorithm based on clustering. Its objective is to minimize the power consumption, improve the use time of the network. The algorithm GFG (Greedy Face Greedy) [14] is a classical wireless sensor network Routing algorithm, the algorithm used at the beginning of the Routing Greedy Routing algorithm choose destination node nearest neighbor node as the next hop, when Routing hole (Local Minimum), use Face Routing algorithm make the data along the area of line segments in the plane of the mobile, when faced with a closer than their own away from the destination node, continue to use the Greedy Routing algorithm for data delivery. In order to overcome the shortage of GFG algorithm, reference [15] presented for local geography routing algorithm GRG (Greedy Random Greedy), the algorithm application of RW (Random Walks) algorithm recovery mechanism to avoid the local minimum. The reference [16] is proposed based on a tiny space location information of 3D routing algorithm EGF3D (Efficient Subminimal Ellipsoid Geographical Greedy Face 3D Routing). The algorithm is based on the Greedy Routing and Face Routing algorithm is proposed, and applied to the forwarding node and destination node and destination node distance minimum angle of the conviction of neighbor nodes within the ellipse. Reference [17] is proposed a mathematical model is proposed to find out the energy consumption rate and to distribute the optimum number of sensor node in each corona according to energy consumption rate. An algorithm is proposed to distribute the optimum number of sensor nodes in corona-based networks. Reference [18] is proposed a cooperative group-based network reduces the number of the messages transmitted inside the network, which reduction of energy consumed by the whole network, and increase of the network lifetime. The simulations will show how the number of groups improves the network performance.

This paper proposes a Iterative Split Clustering Energy Angle Routing (ISC-EAR) algorithm, which reduction of energy consumed by the whole network, and increase of the network lifetime. Using the simulation calculation under different topology, ISC-EAR routing algorithm with the international benchmark IGreedy [19] compared various technical indicators have very good performance, has good advancement and research value.

2. Iterative Split Clustering Energy Angle Routing, ISC-EAR

2.1. ISC - EAR Design Idea

Based on 3D wireless sensor network routing design and energy saving goal, the basic idea of the algorithm is first radius from the node sensation all neighbor nodes are selected to satisfy the user bandwidth demand candidate set of nodes, then according to the node and the distance to the neighbor node sends the ratio of the energy consumption, at the same time, considering the current node and destination node and neighbor node space angle of choice of the next-hop node, and set different weight of these two factors, to ensure that the selected node sends furthest distance and minimum energy consumption, deviating from the destination node angle factors to prevent the node too far.

2.2. ISC-EAR Operation Rules

The ISC-EAR algorithm main operation includes the following seven parts:

2.2.1. The Determination of Candidate Set of Nodes

Node sensing radius or communication radius can directly communicate node called the neighbor node, the node and link bandwidth between neighbor nodes is greater than the bandwidth needed for the user, the neighbor nodes can be used as candidates for the next-hop node, all can communicate directly with the current node and meet the demand of the user bandwidth under the nodes of a candidate set of nodes.

2.2.2. Determine the Angle of Vector Space

Set the current node coordinates $C(x_c, y_c, z_c)$, destination node $D(x_d, y_d, z_d)$, neighbor node $N(x_n, y_n, z_n)$, the vector of the current node and destination node is expressed as:

$$\vec{a} = (x_d - x_c, y_d - y_c, z_d - z_c) \tag{1}$$

The current node of neighbor nodes and vectors as follows:

$$\vec{b} = (x_n - x_c, y_n - y_c, z_n - z_c) \tag{2}$$

The current node and destination node and neighbor nodes based on the current node space of the vertex Angle cosine value:

$$\cos\beta = \frac{(x_d - x_c)(x_n - x_c) + (y_d - y_c)(y_n - y_c) + (z_d - z_c)(z_n - z_c)}{\sqrt{(x_d - x_c)^2 + (y_d - y_c)^2 + (z_d - z_c)^2} \times \sqrt{(x_n - x_c)^2 + (y_n - y_c)^2 + (z_n - z_c)^2}}$$

By the cosine function space Angle beta for

$$\beta = \arccos(\cos\beta) \tag{3}$$

2.2.3 The Compute Nodes Sending Energy Consumption

According to the model, the energy consumption of nodes sending energy consumption E_{TX}

$$\begin{aligned} E_{Tx}(k,d) &= E_{Tx-elec}(k,d) + E_{Tx-amp}(k,d) \\ &= E_{elec} * k + \varepsilon_{amp} * k * d^{\alpha} \\ &= \begin{cases} E_{elec} * k + \varepsilon_{fs} * k * d^2, d < d_0 \\ E_{elec} * k + \varepsilon_{mp} * k * d^4, d \ge d_0 \end{cases} \end{aligned} \tag{4}$$

E_{elec} as the energy consumption of transmitting and receiving circuit, k as the packet size, ε_{amp} for energy consumption of power amplifier, when the transmission distance is less than d_0, then α=2， by using the free space model, namely the $\varepsilon_{amp}=\varepsilon_{fs}$. When the transmission distance is greater than d_0, then α=4, using the multipath fading model, namely the $\varepsilon_{amp}= \varepsilon_{mp}$。

2.2.4. Determine the Next-hop Node

Node energy consumption of total energy consumption includes sending and receiving, sending energy consumption in total energy consumption accounts for a large proportion, and energy consumption of nodes sending related to the distance, in order to decrease the total energy consumption of node, choose as far as possible when the next hop node so the most distant way in the guarantee send consumes the least energy consumption. In addition, in order to prevent the next hop node deviating from the destination node, should choose the current node and destination node and the next-hop node of the current node as the vertex of the space vector Angle of the smallest, namely the closest to the destination node candidate nodes as the next hop node. Considering the above two factors, and set the different weights, from the candidate set of nodes and reasonable the next hop node is selected.

Select Nexthop (NT) according to the expression:

$$NT = w_1 * \frac{d}{E_{TX}} + w_2 * \frac{1}{\beta} \quad (5)$$

Here *w1* and *w2* are the sum of the two weights, and both are 1, d for the current node to the neighbor node distance, E_{TX} for launch to the next hop node energy, β neighbors for the current node and destination node space of the vertex Angle for the current node.

To sum up, the greater, the d/E so the most distant way in the shows the least energy consumption; $1/\beta$ the greater the space Angle is smaller, the more close to the destination node, so the NT value is bigger, the better, that is from the current node NT of the candidate set of the next-hop node as the next-hop node of maximum value.

2.2.5 Forming Path

Each selected the next-hop node stored in the *Rout* path set in turn. In order to prevent the loop, set the selected node *Selectednodes* set, each node in the process of find a way can only be selected once, once the node is selected, after choosing the next-hop the node loses the qualification of the selected. In addition, if the current node can't find meet the requirements of the next-hop node, from the current node, pops up in Rout path set to choose NT value times bigger as the next-hop node, and mark the current node state = 0, said the node, no next time choose the path when it no longer choose this node as the next-hop node.

2.2.6. Update Nodes Remaining Energy

According to the formula (6) the residual energy of each node is calculated, update the residual energy of nodes and run the ISCA algorithm to select cluster head. Update nodes remaining energy formula is:

$$E_R = E - E_{Tx} - E_{Rx} \quad (6)$$

Here E_R refers to the residual energy of nodes, the current energy E for the node, E_{Tx} for energy consumption of nodes to send data calculated by formula 4, E_{Rx} for receiving data node energy consumption calculated by the formula 7.

$$E_{Rx}(k) = E_{Tx-elec}(k) = k * E_{elec} \quad (7)$$

2.2.7. Data Fusion

Numerous nodes in wireless sensor network data, there may be redundant data collected from different nodes information, and these redundant data information in the process of transmission will be unnecessary energy waste, so need to cluster of cluster nodes in data fusion processing, to achieve the purpose of reducing energy consumption data transmission. Each cluster head of data fusion rate was 70% [10], calculation formula:

$$D_{after} = D \times 70\% \quad (8)$$

3. The Simulation Analysis

To measure the design in this paper the performance of 3D wireless sensor network routing algorithm, this article using the C/C++ language to realize the simulation calculation algorithm, and compared with the international the benchmark algorithm IGreedy contrast.

3.1. The Benchmark Algorithm

Greedy algorithm is a classic of 3D wireless sensor network routing algorithm, the reference [19] based on greedy algorithm proposed IGreedy-PAGR (Power adjusted greedy algorithm with optimal transmission range and threshold) based on the optimal transmission radius and adjustable threshold energy greedy routing algorithm.

In the routing algorithm that does not consider the energy consumption factor, the node uses a constant transmission radius to find neighbors and next hops, resulting in a lot of energy wasted when sending data. The IGreedy algorithm uses an adaptively adjusted transmission radius instead of the traditional constant transmission radius. The transmission radius of the node further reduces the energy consumption of transmitting data to achieve the purpose of energy saving.

IGreedy algorithm of initial setting node Transmission radius for the Optimal Transmission radius OR (Optimal Transmission Range), using the greedy routing algorithm for data forwarding path, known as the OR model; When meet local cavity, in order to find the next hop node, the Transmission radius increases to MR (Minimum Transmission Range), continue to use the greedy routing algorithm for path, called MR mode. In order to accurately determine when to use the OR and MR mode, algorithm to set a threshold parameter DR = 4 node degree, initial use OR neighbor nodes, pattern choice when the node degrees down to less than the threshold value of DR, use MR mode, when the node degrees rebounded more than the threshold, in return for the OR model, so repeatedly, until you find destination node failure OR cannot find a neighbor node algorithm.

3.2. Topology Case

In order to test the performance of the routing algorithm for the 3D wireless sensor network designed in this paper, the routing algorithm was run under random topology, average topology and actual application underground mine topology, and comparative analysis was made.

Random topology means that 100 nodes are randomly deployed in a cube with a side length of 100m, and the three-dimensional coordinates of the nodes are randomly generated by the system.

Average topology means that 100 nodes are approximately evenly distributed in a cube with a side length of 100m. First, the cube is evenly divided into 64 small cubes, and the nodes are placed in the center of each small cube, and the remaining 36 nodes Deployed on the six surfaces of the cube, with six on each surface, the three-dimensional coordinates of these 100 nodes can be calculated by mathematical formulas.

Mine topology using the underground tunnel topology, the length and width is 5 m, the height is 100 m, base station is located in the surface coordinates of (0m, 0m, 0m). As close to the benchmark station node than from base stations transmit more data and to consume more energy, so that the nodes near the benchmark station will die prematurely because of energy depletion, affects the survival time of the entire network. In order to reduce the average node Energy consumption and prolong network life time, this paper adopts reference [20] Energy efficient sensor node deployment algorithm EESP (Energy efficient sensor placement), the algorithm based on node Energy consumption model, deduced the formula of the distance between the nodes di, as shown in formula (9).

$$d_i = \frac{L}{\sqrt[3]{i} \times \sum_{i=1}^{n} \sqrt[3]{\frac{1}{i}}} \tag{9}$$

L is the height of the network topology area, n is the number of sensor nodes in network topology, d_i for the node v_{i+1} and the distance between the v_i.

3.3. Performance Evaluation

In order to measure the performance of the ISE-EAR routing algorithm proposed in this paper, under the same simulation conditions, it is calculated with the benchmark routing algorithm IGreedy to compare its performance. Simulate calculations on mine (tunnel) topology, average topology and random topology. The performance of the algorithm is evaluated from four indicators: the number of effective surviving nodes, network survival time, network energy consumption and average node energy consumption.

3.3.1. Effective Number of Surviving Nodes

The number of effectively surviving nodes in the network refers to the number of nodes that have enough energy to send data from the source to the base station. The more effectively the number of surviving nodes, the more complete the information obtained, and the better the network integrity. If there are few effective nodes remaining, the user cannot obtain the complete data information of the network, and the meaning of network monitoring is lost.

Under the three network topologies of mine topology, average topology and random topology, the number of effective surviving nodes at different times of the ISC-EAR routing algorithm and the benchmark algorithm IGreedy are simulated and calculated, as shown in Table 1.

Table 1. *Number of alive nodes.*

Routing algorithm	Simulation time (sec)	1000	2000	3000	4000
ISC-EAR	Mine topology	98	81	65	41
	Average topology	98	76	60	37
	Random topology	98	73	46	27
IGreedy	Mine topology	95	75	55	27
	Average topology	97	69	49	13
	Random topology	96	66	27	0

It can be seen from Table 1 that as the simulation time increases, the number of effective surviving nodes under the three network topologies shows a downward trend; the comparison of different topologies at the same simulation time shows that the number of effective surviving nodes is the largest under the mine topology; the same topology Compared with the same simulation time, the routing algorithms proposed in this paper have more effective surviving nodes than the benchmark algorithm. When the simulation time is 4000 seconds, all the nodes of the benchmark algorithm under the random topology have died, while the ISC-EAR algorithm under the mine topology has 41 nodes alive, which greatly extends the network survival time.

3.3.2. Network Lifetime

The network survival time refers to the time from when the network starts to transmit data to the time it cannot provide users with information about the monitoring environment. This article uses the first nodes death time, half nodes death time and all nodes death time in the network to represent. The death time of the first node in the network can explain the balance of the routing algorithm, ensuring that the energy of each node is more balanced; half of the node death time is used to illustrate the effectiveness of the routing algorithm, and the longer the time, the longer the network service time. Long; the death time of all nodes is the longest survival time of the network, which directly determines the longest survival time of the network.

Under the three network topologies of mine topology, average topology and random topology, the results of the network survival time of the ISC-EAR routing algorithm and the benchmark routing algorithm IGreedy proposed in this paper are simulated and calculated as shown in Table 2.

Table 2. *Network lifetime.*

Routing algorithm	Simulation time (sec)	first nodes death time	Half nodes death time	All nodes death time
ISC-EAR	Mine topology	633	3886	6856
	Average topology	556	3145	5728
	Random topology	565	3454	5935
IGreedy	Mine topology	524	2856	4622
	Average topology	511	2865	5453
	Random topology	505	2488	3956

It can be seen from Table 2 that under the same simulation conditions, the death time of the first node, the death time of half of the nodes, and the death time of all nodes of the ISC-EAR routing algorithm are much later than the benchmark algorithm IGreedy; under different topologies It can be seen from the comparison that the mine topology is later than the death time of the first node, the death time of half of the nodes, and the death time of all nodes under the random topology and the average topology. In the mine topology, half of the node death time of the ISC-EAR algorithm is increased by 24% compared with the benchmark algorithm IGreedy, and the death time of all nodes is increased by 20%. This shows that the routing algorithm designed in this paper extends the network survival time and has a good balance.

3.3.3. Network Energy Consumption

Network energy consumption is defined as the total energy consumption of all data transmission paths in the network during a period of time. The energy consumption of each path is defined as the sum of the energy consumption of each node on the path. The energy consumption of each node can be calculated according to the energy consumption model. Network energy consumption is an important indicator to measure the effectiveness of routing algorithms. The greater the network energy consumption, the shorter the survival time, and vice versa. However, the network energy consumption cannot reflect the energy consumption of each node. The network energy consumption needs to be used in conjunction with the average energy consumption of the nodes to jointly measure the performance of a routing algorithm.

Table 3 shows the random topology, average topology and mine (tunnel) topology under three kinds of network topology, ISC-EAR routing algorithm and the benchmark routing algorithm IGreedy test results for network energy consumption.

Table 3. *Network energy consumption.*

Routing algorithm	Simulation time (sec)	1000	2000	3000
ISC-EAR	Mine topology	28	115	227
	Average topology	30	131	251
	Random topology	30	170	291
IGreedy	Mine topology	35	138	286
	Average topology	38	160	315
	Random topology	33	205	395

It can be seen from Table 3 that the energy consumption of the proposed algorithm ESC-EAR is lower than the benchmark algorithm IGreedy at the same simulation time with different topologies; compared with the same simulation time under the same topology, the ISC-EAR routing algorithm is better than the benchmark routing algorithm IGreedy. Energy consumption is significantly reduced. For example, when the simulation time is 1000 seconds in the mine topology, the energy consumption is 25% lower than the benchmark algorithm, and when the simulation time is 3000 seconds, the energy consumption is 26% lower than the benchmark algorithm. Other topologies and simulation times have similar rules. It can be seen from this index that the routing algorithm proposed in this article has better energy-saving effects.

3.3.4. Average Energy of Node

Average energy of node is defined as the network energy consumption within a certain time and the ratio of the amount of data transferred, reflects the network node load balance, load is balanced, the longer the network survival time.

Under the three network topologies of random topology, average topology and mine topology, the ISC-EAR routing algorithm and the benchmark algorithm were tested respectively, and the average energy consumption of nodes obtained is shown in Table 4.

Table 4. *Average energy of node.*

Routing algorithm	Simulation time (sec)	1000	2000	3000
ISC-EAR	Mine topology	2.81	3.11	3.49
	Average topology	2.92	3.21	3.59
	Random topology	2.95	3.35	3.79
IGreedy	Mine topology	3.01	3.39	3.89
	Average topology	3.06	3.42	4.02
	Random topology	3.18	3.6	4.36

It can be seen from the results in Table 4 that under different topologies, the ISC-EAR algorithm proposed in this paper has lower average energy consumption than the benchmark algorithm IGreedy at the same simulation time. For example, at 3000 seconds, the average energy consumption of nodes in the mine topology proposed by the ISC-EAR algorithm is 10% lower than the benchmark algorithm, and the random topology is 25% lower than the benchmark algorithm. This shows that the algorithm proposed in this paper also has better performance in terms of node energy consumption indicators, better energy-saving effects, and can better extend network life.

4. Conclusion

In summary, the ISC-EAR routing algorithm proposed in this paper is based on the minimum energy consumption model to obtain the optimal distance from the node to the next hop. In order to prevent the next hop node from deviating from the destination node, it ensures that the current node is between the source node and the destination node. The vertical distance between the connections is the smallest to ensure the least energy consumption of the entire path. In terms of performance evaluation, three topological structures of mine topology, average topology and random topology of the 3D wireless sensor network and four technical indicators of the number of alive nodes, network lifetime, network energy consumption and average energy of node are used for simulation realization. The benchmark routing algorithm IGreedy has obvious advantages. This routing algorithm has good advancement and research value, and can be popularized and applied in various 3D wireless sensor networks.

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