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A Novel Routing Protocol for Wireless Sensor Networks Based on Clustering Algorithm

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Abstract—**This paper designs a novel routing protocol of wireless sensor networks (WSN). Using sub-cluster theory based on linear programming, the protocol deals with the problem of excessive energy consumption in transportation among nodes in WSN. In order to satisfy the purpose that every sensor node has equal energy consumption as the head node, a more simplified head node rotation mechanism is proposed to avoid fast consumption of a single node's energy. And a failure restore mechanism is designed to ensure the robustness of protocol. Finally, through comparing with traditional clustering routing protocols such as LEACH and TTDD, some improvement of the new protocol was proved by large number simulations with OMNet++ Software.**

Index Terms—**routing-protocol, cell, clustering, path-weight**

I. Introduction

WIRELESS Sensor Networks (WSN) prevails in information technology. A typical WSN consists of a number of cheap, low-power consumption sensor nodes in monitor areas. These sensor nodes often carry one or several kinds of sensors in order to collect interesting physical or chemical environment information and send them to central nodes by wireless communication. Central nodes also connect and interchange data and information with console by internet or satellite link. Clients can use the console to look over data collected by sensor nodes and use the central nodes to send inquiries and control instructions to sensor nodes [1].

As one of the most important technology in WSN, many distinctive types of routing protocols have emerged since the rise of WSN because of its importance. Through analysis of existing routing protocols, we found that routing protocols in WSN are mainly based on four following technology [2][3]:

(1) Routing protocol based on flooding.
(2) Routing protocol based on converse path.
(3) Routing protocol based on energy cost.
(4) Routing protocol based on clustering structure.

Being compared with previous protocols, because of its special logical structure, the protocols based on clustering structure can better support data fusion, security, and so on. In addition, as protocols based on clustering structure have better energy efficiency, they increasingly gain attention recently. At the same time, many of these protocols are also applied to topology control in WSN [4]. By referring to latest material for WSN, this paper proposes a novel protocol unlike traditional clustering strategies to improve the performance of routing protocol based on clustering.

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II. Fixed Cell Directional Jump Routing Protocol

A. Meshing and establishment of the grids

We will mesh the wireless sensor network when deployed. It shows in [5] that complete covering the region requires the least sensor nodes through cellular layout. In order to ensure that each selected head node in cluster can forward data to neighboring head nodes, effective radio-radii of the sensor nodes must be greater than the maximum distance between two adjacent cells. Suppose that there are two nodes at position B and position C respectively as shown in Fig. 1 where $BC \le R$, and R is the radius of the node's transmission.

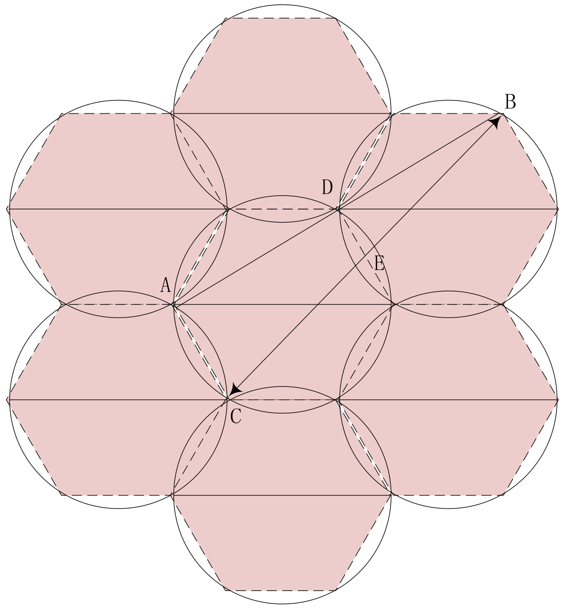

Fig. 1: the sketch map of grids

For $AD = DB$;

$AC \,//\, DA$,

so $AC = 2DE$,

and for $AD = \sqrt{3}AC$,

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so $DB = \sqrt{3}AC = 2\sqrt{3}DE$.

For $BE = EC = \dfrac{1}{2}R$;

$$DB^2 + DE^2 = BE^2,$$

so $DE = \dfrac{R}{2\sqrt{13}}$,

$$r = AC = 2DE = \frac{R}{\sqrt{13}}.$$

A region whose area is M_{area} is divided into several identical cells with the same radius r. The number of nodes required to cover the area is k, that is $k = 2M_{area} / \sqrt{27}r^2 = 26M_{area} / \sqrt{27}R^2$. After the WSN is deployed completely, each hexagon cell becomes a cluster. And the clusters will never change in life cycle of the sensors. The fixed meshing of a region can solve the unideal problem caused by concentrated distribution of cluster head in LEACH protocol, and can also avoid the repeated cost needed to build grids in TTDD protocol once an event is detected[6].

The specific process of establishing the grid is described as follow. First, the central node sends a broadcast message including the location (x_c, y_c) of the central node to all common nodes. When every common node with coordinates $(x_p - y_p)$ receives the message, we will calculate its relative position (x, y) to the central node, where $x = x_p - x_c$; $y = y_p - y_c$, and determine the possible values of k by the formula:

$$k - 1 < \frac{-\sqrt{3}x/3 - y}{r} \le k + 1$$

Then using the formula (1)-(3), the values of l, n, m can also be calculated. Finally, the nodes with the same values of k, l, n, m form a cluster (Fig. 2).

When $k = 3p, (p \in N)$

$$\begin{cases} k-1 < \dfrac{-\sqrt{3}x/3-y}{r} \le k+1 \\ 3l-1 < \dfrac{\sqrt{3}x/3-y}{r} \le 3l+1 \\ 2n-1 < \dfrac{2x}{\sqrt{3}r} \le 2n+1 \\ 3m-1 < \dfrac{y}{r} \le 3m+1 \end{cases} \text{ or } \begin{cases} k-1 < \dfrac{-\sqrt{3}x/3-y}{r} \le k+1 \\ 3l-1 < \dfrac{\sqrt{3}x/3-y}{r} \le 3l+1 \\ 2n < \dfrac{2x}{\sqrt{3}r} \le 2n+2 \\ 3m+\dfrac{1}{2} < \dfrac{y}{r} \le 3m+\dfrac{5}{2} \end{cases} \tag{1}$$

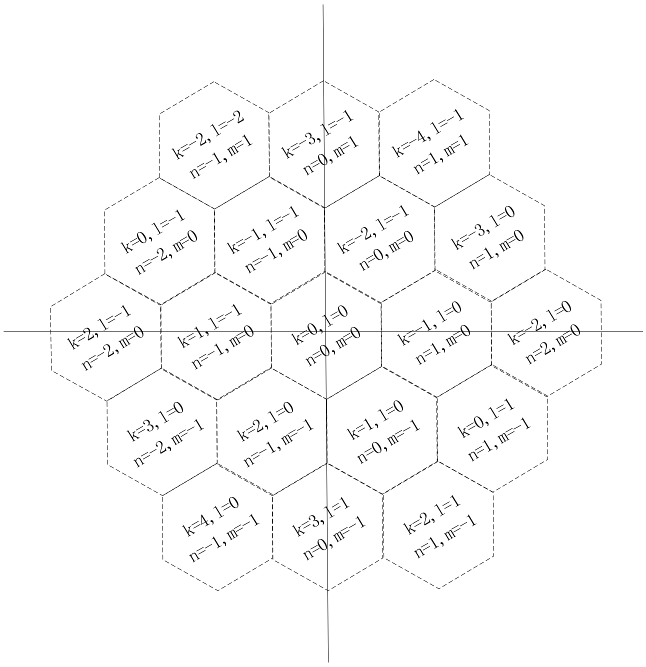

Fig. 2 : the sketch map of weights of grids

When $k = 3p - 1, (p \in N)$

$$\begin{cases} k-1 < \dfrac{-\sqrt{3}x/3-y}{r} \le k+1 \\ 3l < \dfrac{\sqrt{3}x/3-y}{r} \le 3l+2 \\ 2n-1 < \dfrac{2x}{\sqrt{3}r} \le 2n+1 \\ 3m-1 < \dfrac{y}{r} \le 3m+1 \end{cases} \text{ or } \begin{cases} k-1 < \dfrac{-\sqrt{3}x/3-y}{r} \le k+1 \\ 3l < \dfrac{\sqrt{3}x/3-y}{r} \le 3l+2 \\ 2n < \dfrac{2x}{\sqrt{3}r} \le 2n+2 \\ 3m+\dfrac{1}{2} < \dfrac{y}{r} \le 3m+\dfrac{5}{2} \end{cases} \tag{2}$$

When $k = 3p - 2, (p \in N)$

$$\begin{cases} k-1 < \dfrac{-\sqrt{3}x/3-y}{r} \le k+1 \\ 3l+1 < \dfrac{\sqrt{3}x/3-y}{r} \le 3l+3 \\ 2n-1 < \dfrac{2x}{\sqrt{3}r} \le 2n+1 \\ 3m-1 < \dfrac{y}{r} \le 3m+1 \end{cases} \text{ or } \begin{cases} k-1 < \dfrac{-\sqrt{3}x/3-y}{r} \le k+1 \\ 3l+1 < \dfrac{\sqrt{3}x/3-y}{r} \le 3l+3 \\ 2n < \dfrac{2x}{\sqrt{3}r} \le 2n+2 \\ 3m+\dfrac{1}{2} < \dfrac{y}{r} \le 3m+\dfrac{5}{2} \end{cases} \tag{3}$$

where $k, l, n, m \in N$

B. Calculation of path weight N of the cluster

The nodes use the parameters k, l, m, n and the formula (4)-(6) to calculate the coordinates (x_i, y_i) of its cluster's center:

When $k = 3p, (p \in N)$:

$$\begin{cases} x_i = \dfrac{\sqrt{3}(3lr - kr)}{2} \\ y_i = -\dfrac{kr + 3lr}{2} \end{cases} \quad (4)$$

When $k = 3p - 1,\ (p \in N)$:

$$\begin{cases} x_i = \dfrac{\sqrt{3}(3lr + r - kr)}{2} \\ y_i = -\dfrac{kr + 3lr + r}{2} \end{cases} \quad (5)$$

When $k = 3p - 2, (p \in N)$:

$$\begin{cases} x_i = \dfrac{\sqrt{3}(3lr + 2r - kr)}{2} \\ y_i = -\dfrac{kr + 3lr + 2r}{2} \end{cases} \quad (6)$$

where r is the cellular radius.

After calculating the center of the cluster, every common node will then use the formula (7) to solve the weights N of the path and store them.

$$\begin{cases} N = \left|\dfrac{2}{3r} y_i\right| \ when\ x_i \in (-\dfrac{\sqrt{3}}{3} y_i, \dfrac{\sqrt{3}}{3} y_i] \\ N = \dfrac{y_i + \sqrt{3}x_i}{3r} \ when\ x_i, y_i > 0, x_i \in (\dfrac{\sqrt{3}y_i + 3x_i}{6}, \dfrac{\sqrt{3}y_i + 3x_i}{3}] \\ N = \dfrac{-y_i - \sqrt{3}x_i}{3r} \ when\ x_i, y_i < 0, x_i \in (\dfrac{\sqrt{3}y_i + 3x_i}{3}, \dfrac{\sqrt{3}y_i + 3x_i}{6}] \\ N = \dfrac{y_i - \sqrt{3}x_i}{3r} \ when\ x_i < 0, y_i > 0, x_i \in (\dfrac{-\sqrt{3}y_i + 3x_i}{3}, \dfrac{-\sqrt{3}y_i + 3x_i}{6}] \\ N = \dfrac{-y_i + \sqrt{3}x_i}{3r} \ when\ x_i > 0, y_i < 0, x_i \in (\dfrac{-\sqrt{3}y_i + 3x_i}{6}, \dfrac{-\sqrt{3}y_i + 3x_i}{3}] \end{cases} \quad (7)$$

C. Selection and rotation of the cluster head node

To average the cluster head nodes cost, the time period in the protocol is designed as *t* and the sensor nodes within the cluster become head nodes in rotation. Due to the fixed grid cluster, head nodes within the cluster can be selected as follows:

First, a weight counter is set in a node and it will plus one when the node becomes a head node. In the first cycle, the protocol selects a node as the head node in the cluster randomly, and then in the end of the each cycle, the protocol appoints the node with the minimum weight as the head node for the next round.

The mechanism that nodes are selected as head nodes in turn is beneficial for sharing equal energy consumption among nodes in WSN. Comparing with TTDD protocol [6], the Fixed Cell Directional Jump Routing Protocol (FCRP) can sufficiently make use of energy of every node and therefore make WSN more stable. And through comparing with LEACH protocol [2], it is found that FCRP makes selection of the head nodes simpler by using fixed grids.

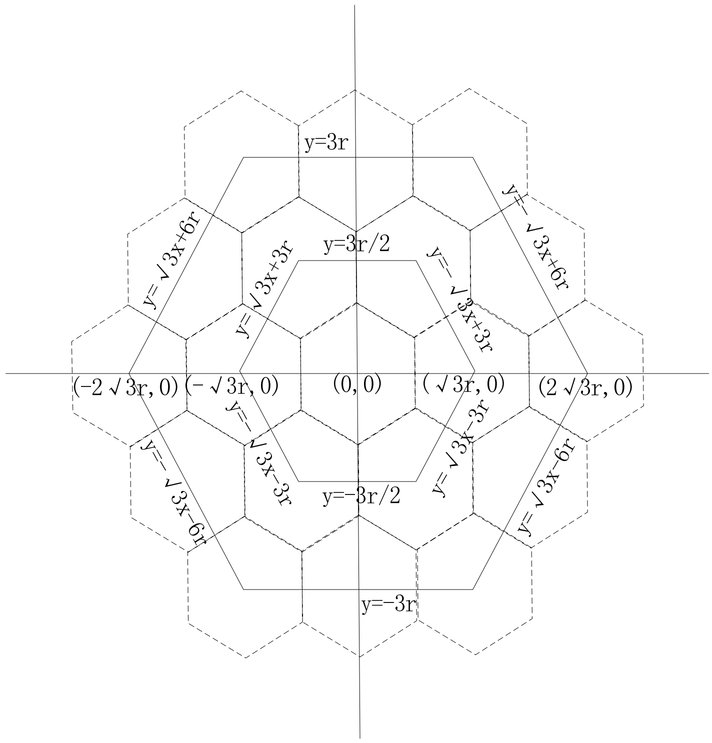

Fig. 3: weights N of the path

D. Reception and transmission of data

Reception and transmission of data mainly has two parts that are data receiving and data transmission in clusters and those processes between clusters.

The process of reception and transmission of data in clusters is that a common node will not send any data to the head node of its cluster until it detects an event happening. But the process of reception and transmission of data between clusters is more complex. During the process of data transmission of head nodes, each hop should send data to the central node in the direction where the weight N decreases.

The most significant difference between FCRP protocol and other protocols is that superposition of the same information is unavoidable in whatever flooding methods[7]. However, the problem can be effectively solved in FCRP by using fixed cell. And the FCRP can make a piece of information sent only in a defined path to the central node with much less cost than that of other algorithms.

III. PERFORMANCE ANALYSIS OF THE FCRP PROTOCOL

In this section, we use the simulation tool OMNET++ 4.0 to analyze and evaluate the performance of FCRP protocol. In the process of the simulation, we design a network with a central node just in the central position of this network. There are 9000 sensor nodes in this network, and every node has the transmission capacity to reach 1000m away. The sensor nodes are randomly distributed in the region of 10000 meters by 10000 meters. We suppose

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there are 20 events occurring every 3 seconds in the sensor network randomly, and all of the events will be received by the sensor nodes and sent to the central node.

Next, we begin to design the radii of clusters. In the above section, we have analyzed the maximum radius of a cluster can not exceed $R/\sqrt{13}$, where R is the transmission capacity of nodes, and therefore we design radius of the clusters as $r_1 = R/4$, $r_2 = R/\sqrt{13}$, $r_3 = R/3$, $r_4 = R/2$ respectively. In the following we will examine the impact of different radii of the clusters on energy consumption, the transmission delay and the success rates of the data transfer of the nodes.

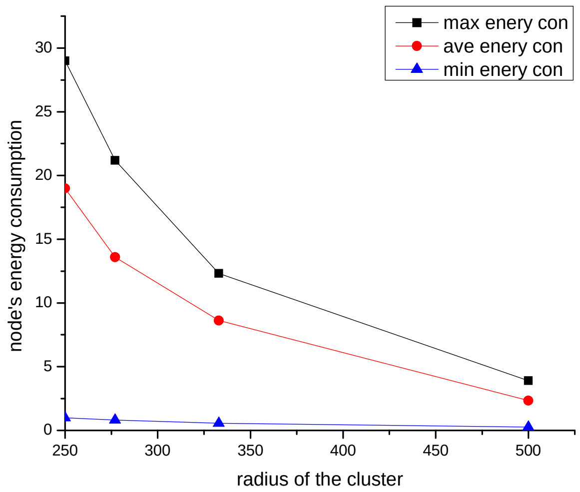

Fig. 4: The impact of different r on node's energy consumption

From Fig.4, it can be obtained obviously that the energy consumption of the sensor nodes begins to reduce as the radius r of a cluster increases. The reason is that the cluster would include more common nodes as the radius of a cluster increases. Thereby in a cluster, there are more nodes participating in the rotation of the head node, so it declines the average energy consumption of every node.

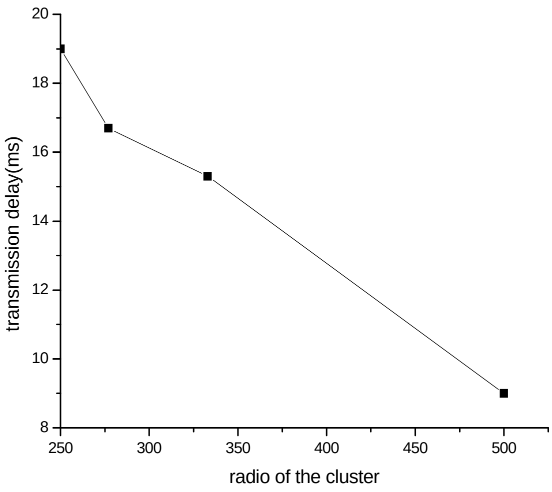

Fig. 5: The impact of different r on node's transmission delay

From Fig. 5, it can be obtained obviously that the transmission delay from a common node to the central node shortens gradually as the radius *r* of a cluster increases. The reason is that the average hops from sensor nodes to the central node reduce as the radius of a cluster increases. Thereby the time that data must be transfer reduces. So it certainly declines the transmission delay from sensor nodes to the central node.

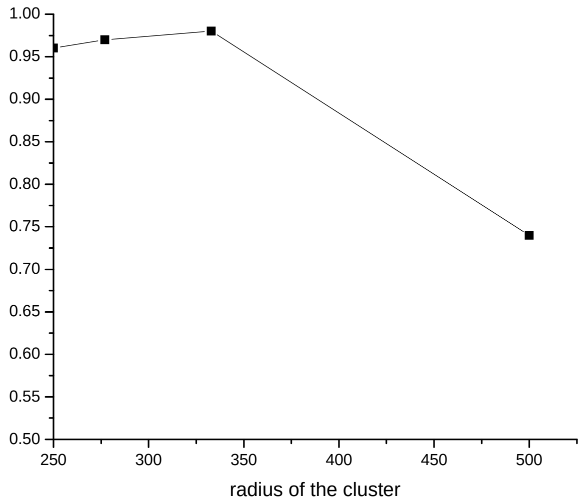

Fig. 6: The impact of different r on node's success rate of data transfer

The Fig. 6 shows impact of different radii of the clusters on nodes' success rates of data transfer. In the figure, the curve shows that the success rate of data transmission maintains at a high level and is not significantly different when the radius are $r_1 = R/4$, $r_2 = R/\sqrt{13}$, $r_3 = R/3$ respectively. However, when $r_3 = R/2$, the success rate of the data forwarding decrease sharply to 74%. The reason is that the radii of clusters are too large for the adjacent head nodes to transmit the data from one to others and so results in data loss.

By comprehensive analyses of these simulation results, it is concluded that the radii of clusters for the FCRP protocol should be neither too large nor too small, and the best choices of radius should be selected between $R/\sqrt{13}$ and $R/3$.

IV. CONCLUSION

This paper presents a novel clustering routing algorithm of wireless sensor network named as Fixed Cell Directional Jump Routing protocol (FCRP). This protocol combines the advantages of TTDD algorithms and LEACH algorithms, uses clustering and selection methods to avoid the deactivation problems of the entire network caused by that some cluster head nodes in wireless sensor network run out of energy, and propose a method based on novel line planning to achieve the path to the central node, which can significantly reduce the energy consumption caused by the process of using flood or flooding methods class node to send data to the central node. Furthermore, the new protocol does not have special requirements for wireless sensor network nodes in the term of physical strucutre.

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