Non-uniform Region Based Clustering Routing Algorithm for Wireless Sensor Networks

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***Abstract*-Considering the energy balance of nodes and "hot spots" in the non-uniform distribution wireless sensor networks in a large region, non-uniform region based clustering routing algorithm(NRBC) for wireless sensor networks is proposed. According to NRBC, the non-uniformly distributed nodes are divided into different region using the same interval concentric rings and the same angle sectors. The optimal number of head nodes in each region is calculated according the number of nodes in different region. The simulation results show that NRBC can efficient balance energy consumption of nodes, prolong the effective lifetime of the network, and this advantage is more obvious when the region of networks increase.**

Keywords: wireless sensor networks; clustering routing; region based model; effective lifetime

I. INTRODUCTION

One of the biggest characteristic of wireless sensor network(WSN) is the limited energy, how to improve the energy efficiency of WSN has been the research focus[1] [2][3], efficient routing algorithm can significantly improve the energy efficiency of WSN. LEACH algorithm [4] proposed by Heinzelman is one of the classical clustering routing algorithm of WSN. Its core idea is each node in the network act as a cluster head in turn, so that the energy consumption of nodes is balanced, but LEACH rely on random number to select cluster head, so that the number and location of cluster head per round is not stable and the energy consumption of cluster head per round is unbalanced, in addition, cluster head of LEACH algorithm communicate with base station(BS) directly, thus as the area of the network increases, the energy consumption of cluster head will rise sharply, therefore LEACH only suitable for small network.

On the "hot spots" problem, RBMC[5] proposed a method that divided the network into many region using the same interval concentric rings, and then according to the number of nodes in each region to compute the optimal number of head nodes in each region, this algorithm is a good solution to solve the problem of "hot spots", but this algorithm only suitable for uniform distribution network.

For the non-uniformly distributed network, this paper proposes non-uniform region based clustering routing algorithm (NRBC) for WSN to solve the uneven energy consumption of nodes in the non-uniformly distributed network and "hot spots" problem.

II. ALGORITHM DESCRIPTION

In the network, the nodes are divided into two types: the common nodes and the cluster head nodes. The common nodes only communicate with their own cluster head node, and the energy consumption of common nodes in different cluster is in little difference; cluster head nodes in addition to communicating with the common nodes in their own cluster, but also for fusing data, forwarding data packets of other cluster head nodes, so their energy consumption is much greater than the common nodes, in addition the cluster head nodes that closer to the Sink node need to forward more data packets, so their energy consumption is greater, in consequence balancing the energy consumption among cluster head nodes is particularly important.

To solve the above problems, according to NRBC the non-uniformly distributed network is divided into different region using the same interval concentric rings and the same angle sectors. In the same sector area, according to the number of nodes in different rings to calculate the optimal number of head nodes in each ring.

A. Network model

N nodes are non-uniformly distributed in a circular region of radius R, Sink node is located in the center of the circle, according to the actual situation, the nodes are in the isomeric energy format. As shown in Fig.1, using the evenly spaced concentric ring and fan, the network is divided into many different region, in which the ring spacing is δ (unit: m), the angle of the fan is □ (unit: rad).

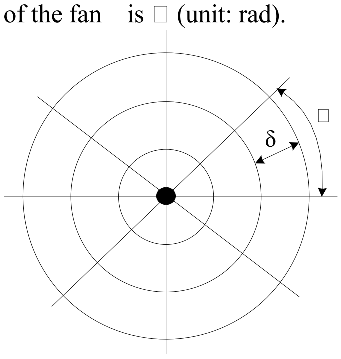

Fig.1 Subregional Network Model

Numbering outward from the Sink node ring, respectively first ring, second ring , ···,the S-th ring. Select a sector marked of first sector, then counterclockwise number, respectively second sector, ···,the K-th sector. Each region can be numbered as S（i，j） (i indicates the i-th sector, j indicates the j-th ring). Apparently R=Sδ，KΘ=2π.

B. The Optimal Number of Cluster Heads in Different Region

In the network model designed in this paper, due to the cluster head in region S(i，j)only communicate with the cluster head in region S（i，j-1）in the same sector(the forwarding path of the cluster head can be more close to a straight line, and this can effectively reduce the energy consumption of cluster head). So this paper only studies one sector, other sectors can be inferred by that logic.

According to the cluster head election method of the traditional ring network model, through building the cluster of different size in different region, to balance the energy consumption among cluster head nodes, the nearer to the inner layer, the smaller the size of the cluster will be, and the energy consumption of the intra cluster communication will be smaller[6][7].

In the network initialization phase, according to the geographic information of the nodes we can know the number of nodes in each region, marked the number of nodes in j-th ring of i-th sector as N（i，j）.

The desired square distance $\mathrm{E}\left[\mathrm{d}^2_{\mathrm{ch}S(\mathrm{i,j})}\right]$ between the cluster head in region S（i，j） and the Sink node:

$$\mathrm{E}\left[\mathrm{d}^2_{\mathrm{ch}S(\mathrm{i,j})}\right]=\int_0^{\theta}\int_{(\mathrm{j}-1)\delta}^{\mathrm{j}\delta}\frac{\mathrm{r}^3}{\frac{\theta}{2\pi}\{\pi(\mathrm{j}\delta)^2-\pi[(\mathrm{j}-1)\delta]^2\}}\mathrm{drd}\varphi=\frac{\mathrm{j}^2+(\mathrm{j}-1)^2}{2}\delta^2 \qquad (1)$$

The desired square distance between the cluster head in region S（i，j） and the cluster head in region S（i，j-1）:

$$\mathrm{E}\left[\mathrm{d}^2_{\mathrm{ch}S(\mathrm{i,j}),S(\mathrm{i,j-1})}\right]=\mathrm{E}\left[\left(\mathrm{d}_{\mathrm{ch}S(\mathrm{i,j})}-\mathrm{d}_{\mathrm{ch}S(\mathrm{i,j-1})}\right)^2\right]=\frac{42(\mathrm{j}-1)^2-17}{9(2\mathrm{j}-1)(2\mathrm{j}-3)}\delta^2 \qquad (2)$$

The energy consumption of one cluster head in region S（i，j） includes: receiving data from the common nodes in its cluster, fusing the received data, sending its own data packet and forwarding the data packets from the cluster head in region S（i, j+1）. It can be expressed as:

$$E_{\mathrm{ch}S(\mathrm{i,j})}=\ell E_{\mathrm{RX}}N_{\mathrm{ch}S(\mathrm{i,j})}+\ell E_{\mathrm{DA}}\left(N_{\mathrm{chk}S(\mathrm{i,j})}+1\right)+\ell\frac{\sum_{\mathrm{n=j+1}}^{\mathrm{S}}m_{S(\mathrm{i,n})}}{\mathrm{m}_{S(\mathrm{i,j})}}\left(E_{\mathrm{RX}}+E_{\mathrm{TX}}+\varepsilon_{\mathrm{fs}}\mathrm{E}\left[\mathrm{d}^2_{\mathrm{ch}S(\mathrm{i,j}),S(\mathrm{i,j-1})}\right]\right)+\ell\left(E_{\mathrm{TX}}+\varepsilon_{\mathrm{fs}}\mathrm{E}\left[\mathrm{d}^2_{\mathrm{ch}S(\mathrm{i,j}),S(\mathrm{i,j-1})}\right]\right) \qquad (3)$$

In equation (3), ℓ represents the length of the data packet, $N_{\mathrm{ch}S(\mathrm{i,j})}$ represents the number of nodes in one cluster of region S（i，j）.

In order to balance the energy consumption of cluster head in each region, make

$$E_{\mathrm{ch}S(\mathrm{i,1})}=E_{\mathrm{ch}S(\mathrm{i,2})}=\cdots=E_{\mathrm{ch}S(\mathrm{i,S})} \qquad (4)$$

According to equation (4), we can find the relationship of the optimal number of head nodes in different rings of one sector, so if we find the optimal number of head nodes in one region, the optimal number of head nodes in other region of one sector can inferred by that logic.

The energy consumption of one non-cluster head node in region S（i，1）can be expressed as:

$$E_{\mathrm{non-ch}S(\mathrm{i,1})}=\ell E_{\mathrm{TX}}+\ell\varepsilon_{\mathrm{fs}}\mathrm{E}\left[\mathrm{d}^2_{\mathrm{toch}S(\mathrm{i,1})}\right] \qquad (5)$$

In which,

$$\mathrm{E}\left[\mathrm{d}^2_{\mathrm{toch}S(\mathrm{i,1})}\right]=\int_0^{\theta}\int_0^{\delta\sqrt{\frac{\theta}{2\pi m_{S(\mathrm{i,1})}}}}\frac{\mathrm{r}^3}{\frac{\theta\delta^2}{2m_{S(\mathrm{i,1})}}}\mathrm{drd}\varphi=\frac{\theta^2\delta^2}{8\pi^2 m_{S(\mathrm{i,1})}} \qquad (6)$$

The total energy consumption of all nodes in region S（i，1）can be expressed as:

$$E_{\mathrm{total}S(\mathrm{i,1})}=m_{S(\mathrm{i,1})}\left[E_{\mathrm{ch}S(\mathrm{i,1})}+N_{\mathrm{ch}S(\mathrm{i,1})}E_{\mathrm{non-ch}S(\mathrm{i,1})}\right]\approx\ell(E_{\mathrm{RX}}+E_{\mathrm{DA}})N_{S(\mathrm{i,1})}+\ell m_{S(\mathrm{i,1})}\varepsilon_{\mathrm{fs}}\mathrm{E}\left[\mathrm{d}^2_{\mathrm{ch}S(\mathrm{i,1})}\right]+\ell\sum_{\mathrm{n=2}}^{\mathrm{S}}m_{S(\mathrm{i,n})}\left(E_{\mathrm{RX}}+E_{\mathrm{TX}}+\varepsilon_{\mathrm{fs}}\mathrm{E}\left[\mathrm{d}^2_{\mathrm{ch}S(\mathrm{i,1})}\right]\right)+N_{S(\mathrm{i,1})}\ell E_{\mathrm{TX}}+\frac{\ell\varepsilon_{\mathrm{fs}}\delta^2\theta^2}{8\pi^2 m_{S(\mathrm{i,1})}}N_{S(\mathrm{i,1})} \qquad (7)$$

$E_{\mathrm{total}S(\mathrm{i,1})}$ takes a derivative with $m_{S(\mathrm{i,n})}$, and makes the equal to 0.

$$\frac{\partial E_{\mathrm{total}S(\mathrm{i,1})}}{\partial m_{S(\mathrm{i,1})}}=0\quad\Rightarrow m_{\mathrm{opt}S(\mathrm{i,1})}=\frac{\theta\delta}{2\pi}\sqrt{N_{S(\mathrm{i,1})}\Big/2\mathrm{E}\left[\mathrm{d}^2_{\mathrm{ch}S(\mathrm{i,1})}\right]} \qquad (8)$$

In equation (8), $m_{\mathrm{opt}S(\mathrm{i,1})}$ represents the optimal number of head nodes in region S（i，1）.

According to equation (8), we can calculate the optimal number of head nodes in region S(i，1), and then according to equation (1),(3) and (4),we can calculate the optimal number of head nodes in different rings of one sector.

C. Cluster Heads Selection

This paper uses a method based on time delay[8] to select the cluster head of each region. At the beginning of each round, according to the residual energy each node generate a timer$T_{\mathrm{timer}}(x)$.

$$T_{\mathrm{timer}}(x)=\exp\left(1-\frac{E^x_{\mathrm{residual}}}{E_{\max}}\right)+\mathrm{rand}(0,\alpha) \qquad (9)$$

In equation (9), E^x_{residual} represents the residual energy of node, $E_{\max}$ represents the largest initial energy of the entire network.

By equation (9) we can see larger the residual energy of node is, smaller the value of the timer is, when the timer ends, the node will broadcast the message that it becomes the cluster head in the region it is located, when other common nodes in this region receive this message, they will put this node into the collection of cluster head and calculate the distance to this cluster head, if the distance is less than $\mathrm{r}=2\sqrt{A(\mathrm{i,j})/\pi m_{S(\mathrm{i,j})}}$ (A（i，j）represents the area of region

S（i，j），$m_{S(i,j)}$represents the optimal number of head nodes in region S（i，j）), the node closes its timer. When the number of head nodes in the collection reaches the optimal number of head nodes of this region, the nodes which have not timed out close their timer, the common nodes select a closest cluster head in the collection to communicate with. Regional cluster heads selection phase is completed, and then entering the next stage of data transmission.

The advantage of this method: the head nodes only broadcast a message in the region once in the entire cluster head selection phase, while the common nodes only send a request message to the closest cluster head once. It can reduce the energy consumption of cluster head selection in this way. Because of introduction of competitive radius r, the head nodes are more evenly distributed in the region.

III. SIMULATION

A. Simulation Description

The algorithms of simulation include LEACH, RBMCand NRBC proposed by this paper, and the simulation environment uses MATLAB. The main purpose of the simulation is to validate the effect of NRBC in the non-uniformly distributed network, and to compare with the effect of LEACH and RBMC. Table 1 shows the main simulation parameters used in the simulation.

N nodes are non-uniformly distributed in a circular region of radius R in the simulation, the Sink node is located in the center of the circular region. When simulate the RBMC algorithm, the ring interval is δ; and when simulate the NRBC algorithm, the sector angle is ϴ, the ring interval is δ. According to the actual situation, the nodes are in the isomeric energy format.

TABLE 1 MAIN PARAMETERS OF THE SIMULATION ENVIRONMENT

Parameter	Parameter Values
E_{RX}	50×10^{-9}J/bit
E_{TX}	50×10^{-9}J/bit
E_{DA}	5nJ/bit/signal
ε_{fs}	10pJ/bit/m^2
Data Packet Length	4000b
Control Packet Length	100b

Simulation one:

Table 2 shows the parameters of simulation one, Fig.2 shows the initial distributed nodes in simulation one.

TABLE 2 THE PARAMETERS OF SIMULATION ONE

N	*R*	□	δ
800	240m	π/4 rad	60m

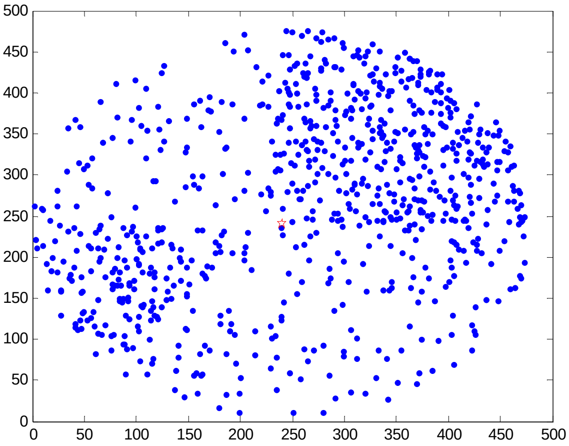

Fig.2 The Initial Distributed Nodes in Simulation One

Simulation two:

In order to verify the effectiveness of NRBC algorithm in a larger region, increasing the radius R of the region, while increasing the number the nodes, the nodes are non-uniformly distributed in a circular region of radius R. Table 3 shows the parameters of simulation two.

TABLE 3 THE PARAMETERS OF SIMULATION TWO

N	*R*	□	δ
1200	350m	π/6 rad	70m

B. Definition of Effective Network Lifetime

As the running time passes, some nodes in the network may die, in many cases what we concerned is not the time when the last node die, but how many nodes still alive in a certain period of time. The more nodes alive in a certain period of time, the more efficiently data the Sink node will receive. Set R_a as the network lifetime, set $N_{live}(i)$ as the number of survival nodes of the network in the i-th round, set N as the total number of nodes in the network.

Define the number of effective nodes in the network as: $N_v = {\sum_{i=1}^{R_a} N_{live}(i)} / {R_a}$

Define the effective network lifetime as:

$$R_v = {R_a N_v}/{N} = {\sum_{i=1}^{R_a} N_{live}(i)}/{N} \quad (12)$$

C. Simulation Results and Analysis

Simulation one:

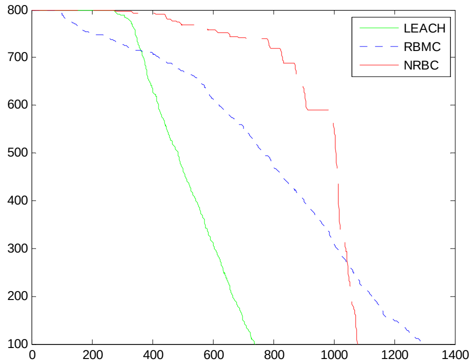

Fig.3 The Network Lifetime Comparison Chart of Different Algorithms

As can be seen from Fig.3, the number of survival nodes of NRBC algorithm is greater than LEACH algorithm's and RBMC algorithm's each round in a certain time, but the total lifetime of NRBC algorithm is slightly shorter than RBMC algorithm's.

According to equation (12) we can compute the effective lifetime of different algorithms.

TABLE 4 THE EFFECTIVE LIFETIME COMPARISON OF DIFFERENT ALGORITHMS

	LEACH	RBMC	NRBC
Effective Lifetime	543	853	967
Lifetime	740	1299	1078

As can be seen form Table 4, although the lifetime of NRBC algorithm is not longer than RBMC algorithm's, but the effective lifetime of NRBC algorithm is longer than RBMC algorithm's, which indicates that the energy consumption among nodes is more balanced, the nodes are with higher effective utilization rate, the Sink node will receive more valid data in a certain time.

Simulation two:

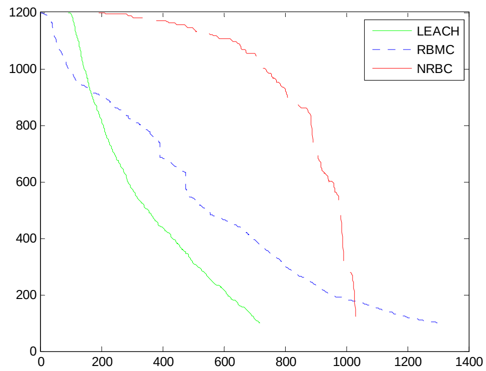

Fig.4 The Network Lifetime Comparison Chart of Different Algorithms

As can be seen from Fig.4, in a larger region of the non-uniformly distribution network, the advantage of survival nodes each round of NRBC algorithm in a certain time is more obvious.

According to equation (12) we can compute the effective lifetime of different algorithms.

TABLE 5 THE EFFECTIVE LIFETIME COMPARISON OF DIFFERENT ALGORITHMS

	LEACH	RBMC	NRBC
Effective Lifecycle	351	540	885
Lifetime	717	1299	1033

As can be seen from Table 5, in a larger region of the non-uniformly distributed network, the advantage of effective lifetime of NRBC algorithm is more obvious, which validates the effectiveness of NRBC algorithm in a lager non-uniformly distributed network.

Because RBMC algorithm is for uniformly distributed network, its cluster head nodes are randomly distributed in the network, so the energy consumption of cluster head in non-uniformly distributed network is not balanced, there will be some nodes premature death. NRBC algorithm is for non-uniformly distributed network, according to the number of nodes in different region to compute the optimal number of head nodes, the energy consumption of cluster head is balanced. As can be seen from the simulation results, NRBC algorithm works better than RBMC algorithm in the lager non-uniformly distributed network.

IV. CONCLUSION

Considering the application limitation of RBMC algorithm, NRBC algorithm is proposed. NRBC algorithm divides the network into many region, the optimal number of head nodes of each region is calculated according the number of nodes in different region, so that the energy consumption of cluster head is balanced in the non-uniformly distributed network, prolong the effective lifetime of the network. The follow-up work will be the evenly distribution of forwarding problem among the cluster head.

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