A Coverage and Connectivity Approach to Node Optimum Clustering in Wireless Sensor Networks

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ABSTRACT

There is always an important topic to extend the whole lifetime in wireless network environment. The paper has to struggle the following design and consideration. How to make use of the consumption of the limited energy in the sensor nodes? How to obtain the sensor node number of the optimum cluster? How to upgrade the efficiency and quality of the information transmission? This paper proposes an optimum node number on clustering-based routing protocol called CCOC (Coverage and Connectivity approach to node Optimum Clustering), which utilizes a node of optimum coverage and connectivity to transmit another node and calculated a optimum cluster of nodes number.

In this article, the CCOC, which distributes the energy dissipation evenly among all sensor nodes improves network lifetime and average energy savings. The performance of CCOC is then compared to clustering-based schemes such as Low-Energy Adaptive Clustering Hierarchy (LEACH). Simulation results show that CCOC improves network lifetime and reduces whole average of energy consumption.

1：Introduction

Recently, wireless sensor network[1] is a popular topic and instrument. It applies to the inhuman handling work, such as detect the temperature and humidity and collect data in the mountain area, monitor and data aggregation[2,3] in dangerous area, monitor the condition in the building and monitor the enemy direction in the battleground, etc. By way of the development in microprocessor technology, communication technology and battery technology, the sensor node has interaction wireless communication and information handle ability.

However, to restrict within operating by the energy of the sensor nodes, the distance of the wireless communication transmission is only from several meters and hundred meters. Therefore, for saving the energy consumption in transmission and solving the distance problem, if the sensor is far away from the base station, the sensor nodes need to use multiple-hop relay to set up the network routing. The data is formed and aggregated by many sensor nodes and transmitted to sink by way of wireless transmission or to base station by way of route.

These sensor nodes could not only react and detect the change of the object in this environment, but also deal with the collected data. It is very difficult to manage the network because the number of the node in the sensor network could be from hundreds to thousands of thousands. In addition, the energy control is almost the main struggle faced by sensor design and network manager under the impossibility of replacement and the limited electric power. Furthermore, since the monitor scope is wider, the demand quantity of the sensor facility is larger. That is to say, the sensor facility has to be cheaper and the malfunction opportunity is relatively raised. Therefore, the fault tolerant function is essential to wireless sensor network design and management.

For solving the limited energy of the sensor node, these aimed at the effective coverage of the sensor node. Combining the cluster concept and the wireless sensor routing protocol to set up the wireless network. The combination could find out the effective coverage of the sensor node and solve this problem. Then, these conditions can infer the optimum cluster group. Under routing protocol in the wireless network, it helps to solve the limited energy of the sensor nodes.

The remainder of the paper is organized as follows: In this paper, we first discuss related work in Section 2. We then present our routing protocol algorithm in Section 3, which followed by a coverage and connectivity technique with a optimum cluster. Section 4 discusses the simulations performed, the metrics used and obtained results. Finally, we conclude the paper after presenting the simulation results.

2：Related Work

2.1：LEACH

'Cluster', the LEACH[4](Low Energy Adaptive Clustering Hierarchy) will be divided all the sensor nodes into several clusters. The sensor nodes in the same cluster can communicate each other, but the sensor nodes in the different cluster can't. However, each cluster has a header, called 'cluster header', which is charge for transmitting the data to the other cluster or directly to sink node. Among the clusters, they transmit the information through the cluster header. They choose a node of the cluster randomly to be the cluster header and this node consume larger electric power. The nodes in each cluster can share the energy consumption and extend the lifetime of the sensor network.

LEACH chooses the sensor node by the following function to be the cluster header. The routing protocol is a very good and common protocol.

2.2：Coverage and Connectivity

- ***Coverage:*** Each sensor has their induction plane to operate. A effective node can represent the relative information in the induction plane.
- ***Connectivity:*** Each sensor node has the largest and direct communication plane to confirm the connection.

Therefore, the sensor nodes only monitor and collect the information in the providing coverage and connectivity[5]. That is to say, the sensor nodes cannot monitor and collect the information outside the coverage and connectivity. The only way that the sensor nodes monitor and collect the information outside the coverage and connectivity, which is a multi-hop mode.

3：Coverage with Connectivity：Necessary and Sufficient Conditions

To design the saving energy consumption of the sensor is an important struggle in wireless sensor network because it can upgrade the lifetime in the wireless network. The cost of the sensor is down so we can randomly and effectively operate many sensor nodes in the wireless network. Therefore, the sensor nodes use the high-density network to solve the problem of the lifetime in wireless network. However, the sensor nodes of the high-density network also cause information overlapping in wireless network and more energy consumption of each sensor node. So, it needs to calculate the effective coverage in the high-density wireless network by way of the sensor nodes. In the meantime, we divide the sensor node into the several clusters by taking the cluster concept. The communication within the clusters is by operating cluster header to lower the consumption energy of the sensor nodes. It also upgrades the lifetime of the wireless network.

For solving the management of the high-density sensor nodes in wireless network and lower the overlapping plane of the sensor nodes, we propose the solution.

First of all, we propose a method of sensor node coverage by way of the coverage density. This method can lower the overlapping coverage[6] and solve the overlapping node located in nodes. Therefore, we research in the density of the sensor node scattering and also calculate the optimum sensor node number from here. For managing effectively the sensor node and the transmission quality, the cluster header is selected from each cluster group under combining the sensor node. After the sensor node in the same cluster collect the data, it can transmit the data by way of the cluster header.

From the above mode, we can save the limited energy of the sensor node and lower the collision in the flooding communication and broadcast communication of the wireless node information transmission. Besides, since the sensor node is no need to transmit the data direct to the sink or the base station, it can enormously lower the high-speed consumption of the node energy. Therefore, the cluster group can manage the wireless sensor node and extend the lifetime of the wireless network.

Finally, we propose a routing protocol of the wireless sensor network. By this protocol, the sensor node can efficiently complete information transmission and keep up the transmission quality under the cluster group.

3.1：Grid Structure

The paper is going to use grid structure to design. Also, the range covered with 2 nodes is best with the radius of node in Figure 3.1.1 shows the nodes in the coverage of the grid structure area.

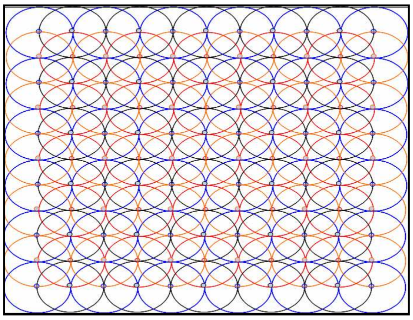

Figure 3.1.1 Grid Structure

3.2：Coverage Region

There are four phases of the coverage region[7] in the nodes:

- *Phase1: CADB area occurring intersection simultaneously in two nodes.*

Phase 1 will discuss the minimum coverage in two nodes. (See Figure 3.2.1) We calculate the intersection area in two nodes as follows:

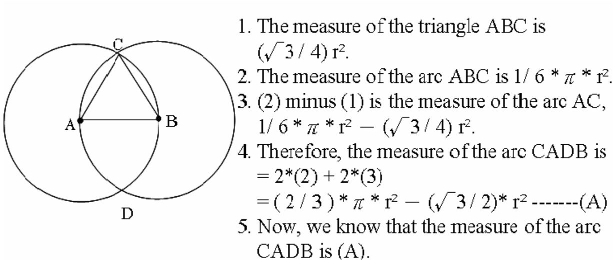

Figure 3.1.1 Phase1

- *Phase2: The measure of the arc in four nodes*

Phase 2 will discuss the arc area among of the four nodes, like Figure 3.1.2 and calculate the BDFE area as follows:

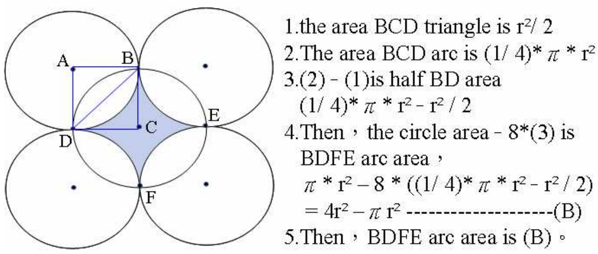

Figure 3.1.2 Phase2

- *Phase3: The arc area among three nodes*

Phase 3 will discuss the arc area among three nodes shown in Figure 3.1.3 and calculate the arc ACG area as follows:

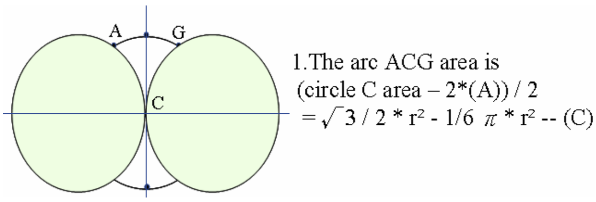

Figure 3.1.3 Phase3

- *Phase4: The arc area outside intersection with three nodes*

Phase 4 discusses the white arc FEB area outside intersection wit three nodes shown in Figure 3.1.4 and calculate the arc area as follows:

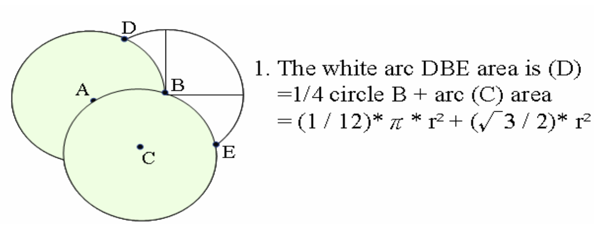

Figure 3.1.4 Phase4

3.3：The nodes of density in grid area

We discuss the above nodes coverage with grid area. We use the different color to represent the node group and calculate the coverage (minus the overlapping area). Then, we calculate the area covering from all nodes among grid area.

3.3.1：The first part of coverage on grid area

1. The blue nodes in D x D area as Figure 3.1.1：
   a. The calculation in vertical side each 2r distance has a node so each vertical side has $\frac{D}{2r}$ nodes.
   b. The calculation in horizontal side each 2r distance has a node so each horizontal side has $\frac{D}{2r}$ nodes.
2. There are $(\frac{D}{2r})^2$ nodes.
3. Each coverage of node is πr^2.
4. The measure of area is $\frac{1}{4}\pi D^2$. ---------- (E)

3.3.2：The second part of coverage on grid area

1. The red nodes in D x D area as Figure 3.1.1：
   a. The calculation in vertical side each 2r distance has a node so each vertical side has $(\frac{D}{2r})-1$ nodes.
   b. The calculation in horizontal side each 2r distance has a node so each horizontal side has $(\frac{D}{2r})-1$ nodes.
2. There are $((\frac{D}{2r})-1)^2$ nodes.
3. Each coverage of node is πr^2.
   a. A minus the intersection overlapping area of the blue node.(arc area is $4r^2 - \pi r^2$)
4. The measure of area:

$$D^2 - 4Dr - \frac{1}{4}D^2\pi + D\pi r + 4r^2 - \pi r^2 \quad \text{-------- (F)}$$

3.3.3：The third part of coverage on grid area

1. The black nodes in D x D area as Figure 3.1.1：
   a. The calculation in vertical side each 2r distance has a node so each horizontal side has $\frac{D}{2r}$ nodes.
   b. The calculation in horizontal side each 2r distance has a node so each horizontal side has $\frac{D}{2r}$ nodes.

2. The measure area of the black nodes：

a. The arc area intersection between the upper column, blue nodes and the lower column, black nodes is

$$\{ 2 * [(\frac{D}{2r} - 1) * (\frac{\sqrt{3}}{2} r^2 - \frac{1}{6} \pi r^2)]\}$$

b. The most right arc area intersection excluding the upper and lower nodes is

$$\{ ((\frac{D}{2r}) - 2) * (\frac{\sqrt{3}}{2} r^2 - \frac{1}{6} \pi r^2)\}$$

c. The most right arc area intersection of the upper and lower nodes is

$$\{ 2 * (\frac{1}{12} \pi r^2 + \frac{\sqrt{3}}{2} r^2) \}$$

3. The measure of area is

$$(\frac{\sqrt{3}}{2})Dr - \sqrt{3} r^2 - \frac{1}{6} D \pi r + \frac{1}{3} \pi r^2 \quad \text{---- (G)}$$

3.3.4：The forth part of coverage on grid area

1. The orange nodes in D x D area as Figure 3.1.1

a. The calculation in vertical side(the leftest side) each 2r distance has a node so each horizontal side has $\frac{D}{2r}$ nodes.

2. The measure of area in orange nodes is

$$\frac{\sqrt{3}}{2} Dr - \sqrt{3} r^2 - \frac{1}{6} D\pi r + \frac{1}{3} \pi r^2 \quad \text{------------ (H)}$$

Therefore, the result from the total coverage of four parts is as follows:

The total coverage (I) is : (E) + (F) + (G) + (H) =

$$D^2 + (\sqrt{3} - 4)Dr - \frac{1}{3} D\pi r + (4 - 2\sqrt{3}) r^2 - \frac{1}{3} \pi r^2$$

3.3.5：The density in grid area

Then the density of grid area d = (I) / D^2 =

$$1 + \frac{(\sqrt{3}-4)r}{D} + \frac{r}{3D} \pi + \frac{4 - 2\sqrt{3}}{D^2} r^2 - \frac{r^2}{3D^2} \pi \quad \text{----- (J)}$$

3.3.6：The optimum cluster of formula

The area of each cluster is $Z = d\pi c^2$

- Z : is cluster of area
- d : coverage range of nodes density in the D x D of area
- c : connected range of node

Therefore the sensor node number of the optimum cluster number of nodes[8] is

$$N = (\frac{D}{2r})^2 / (d\pi c^2) = (\frac{D}{2r})^2 / (\pi c^2) * (J)$$

So, (K) = N =

$$\frac{D^4}{(D^2 - 2.268 Dr + 0.536 r^2 - \frac{1}{3} D\pi r - \frac{1}{3} \pi r^2) \pi c^2 r^2}$$

3.4：Calculation of the optimum nodes of cluster

In this section, we study required and sufficient conditions for the grid network to node covering the unit area. Before presenting details of the proposed optimum cluster of formula (K), we will express an example for this section. When the edge of grid network is D = 100(m), each node of cover radius is r = 2(m). So we will obtain the best node quantity of the cluster for the value into this formula. At the same time, we discuss the different coverage and connectivity. The following example r represents covering radius of the node, c is connecting range of the node and N is the number of the node.

- When c = r , then N = 213.22 (nodes)
- When c = $\sqrt{2}$ r , then N = 106.61 (nodes)
- When c = $\sqrt{3}$ r , then N = 71.07 (nodes)
- When c = 2 r , then N = 53.31 (nodes)
- When c = 3 r , then N = 23.69 (nodes)
- When c = 4 r , then N = 13.33 (nodes)
- When c = 5 r , then N = 8.53 (nodes) ………

Moreover related cluster topology uses the regard equilateral triangle of characteristic to show the cluster group in WSN. The regard equilateral triangle have equal than edges and the distance of max is edge length._So, when the edge length of the equilateral triangle is 2, it shows that there can be the distances of length of radius 3 nodes. Therefore, depending on the regard equilateral triangle rule, we can receive the quantity of the following nodes.

- When the regard equilateral triangle of edge is 2, then N = 3 (nodes)
- When the regard equilateral triangle of edge is 3, then N = 6 (nodes)
- When the regard equilateral triangle of edge is 4, then N = 10 (nodes)
- When the regard equilateral triangle of edge is 5, then N = 15 (nodes)

- When the regard equilateral triangle of edge is 6, then N = 21 (nodes) ………..

Regarding the above results, we find that the nodes number is 213.22 upon condition that the c is equal to r. However, the edge length of the equilateral triangle is 1 then non-correspond of nodes number.

While $c = \sqrt{2}$ r, $c = \sqrt{3}$ r, c = 2r and c = 3r, the node number does not correspond the triangular type of nodes number. Until the c = 4r, it needs 13.33 nodes. Then corresponds the equilateral triangle length of edge is 5, the suitable for nodes quantity is 15. And other need node quantities, the disparity has been bigger. Therefore, we may obtain the node number from this example which best cluster needs it.

3.5：CCOC of Algorithm

About the CCOC of algorithm will divide into 3 parts to prove. At first, it builds about the cluster topology. It is utilized the formula to make optimal node number. The cluster topology uses the characteristic of the regard equilateral triangle to institute the formation. Furthermore, we will discuss the 2nd part that the routing protocol transmit to sink of messages from nodes of gathers or events. Nodes dispersed in WSN environment will make the topography or the limited energy cause to fault. For this fault tolerance will be discussed in the last part.

3.5.1：Building a Cluster Topology

First of all, we will build up the cluster topology with the sensor nodes on the WSN. The way to set up this cluster topology is as follows(Figure 3.5.1.1)：

- To building the cluster by regard equilateral triangle, which an edge length is 4 (namely the cluster of regard equilateral triangle there is 5 nodes and it has 15 nodes).
  - The first step is to set up the upper right 1st node of the initial value =1.
  - Accumulating serial number value to the left down to every node value from right top in order.
- To divide the equal nodes to each cluster.
  - Each cluster is at most 15 nodes.
- The rest nodes are fewer than 15 nodes and still become one cluster.
- Reset the serial number for nodes in each one cluster again.
  - From right to left
  - From top to down

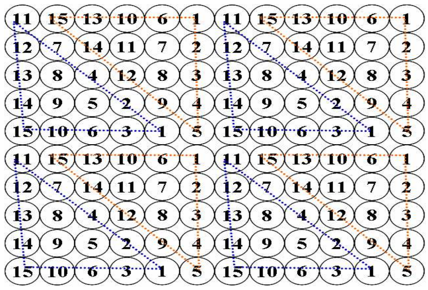

Figure 3.5.1.1 Building a Cluster Topology

3.5.2：Routing Protocol

The main goal of this section is to show that a wireless sensor network has been routing and data fusion. The messages are transmitted to each cluster head. These cluster heads were elected by serial number of nodes. In the previous section, the cluster was built by the serial number nodes. Therefore, we describe the algorithm of routing protocol. It explains as follows to mainly divide into 5 steps. The first step is that the initial value set up each cluster of node① and elect the cluster head. The second step is transmitted messages from cluster head to next cluster head by same serial number nodes as Figure 3.5.2.1 routing protocol of path. The third step is transmitted to sink station from these cluster heads. The forth step is to elect new cluster head from next serial number node. And the final step will jump to step 2 until the energy of the nodes is used up.

1. Each cluster of node① set as cluster head for initial value.
2. Each cluster head is transmitted to the next cluster head that regarded as this cluster in accordance with the same node serial number.
3. The cluster head of the last cluster is transmitted the messages to base station.
4. Then the cluster of cluster head is selected by node serial number and accumulates 1.
5. Jump the step (2) until node energy is dissipated.

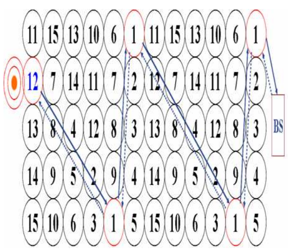

Figure 3.5.2.1 Routing

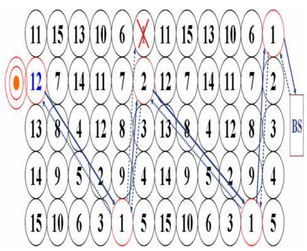

Figure 3.5.3.1 Fault Tolerance

3.5.3：Fault Tolerance

Unable to effect corresponding the same serial number at the cluster head and transmitting, we start the mechanism of fault tolerance as Figure 3.5.3.1.

1. Elected as cluster head by the next serial number.
2. Elected as cluster head while transmitting to the next cluster and it is still cluster head of the original serial number.
3. Following Step (1)(2), the cluster head will be transmitted to base station.

4：Simulation Experiments

4.1：Parameter

The same set of parameters used in all experiments throughout the article as the Table1.

Table1 Simulation parameters

Parameters	Values
the total energy dissipated in the transmitter of the source node	ETx = (50 nJ/bit)
the energy cost incurred in the receiver of the destination node	ERx = (50 nJ/bit)
eFS and eTR denote transmit amplifier parameters corresponding to the free-space and the two-ray models	eFS = (10 pJ/b/m^2) eTR=(0.0013 pJ/b/m^4)
data aggregation	EDA = 5(nJ/b/message)
sensor node number	500(nodes)
each node is assigned an initial energy	2(J)
the number of data frames transmitted for each round	50(messages/round)
the data message size	500(bytes)
the length of the packet header	25 (bytes)
network topologies	100(m) × 100(m)
each node is assigned an radius	2(m)

4.2：The Radio Model

In our simulation experiments analysis, we use the radio model[9] to discussed. The transmit and receive energy costs for the transfer of a k-bit data message between two nodes separated by a distance of r meters is given by equations 1 and 2, respectively.

$$E_T(\mathrm{k}, r) = E_{Tx}\mathrm{k} + E_{amp}(r)\mathrm{k} \quad (1)$$

$$E_R(\mathrm{k}) = E_{Rx}\mathrm{k} \quad (2)$$

Given a threshold transmission distance of r_o, the free-space model is employed when $r \leqq r_o$, and the two-ray model is applied for cases where $r > r_o$. Using these two models, the energy required by the transmit amplifier $E_{amp}(r)$ is given by

$$E_{amp}(r) = \begin{cases} \varepsilon_{FS}\, r^2 , & r \leqq r_o \\ \varepsilon_{TR}\, r^4 , & r > r_o \end{cases} \quad (3)$$

Where ε_{FS} and ε_{TR} denote transmit amplifier parameters corresponding to the free-space and the two-ray models, respectively, and r_o is the threshold distance given by

$$r_o = \sqrt{\varepsilon_{FS} / \varepsilon_{TR}} \quad (4)$$

4.3：Performance Evaluation

To evaluate the performance of CCOC, we simulated the different nodes of number from cluster topology of edge length. Compared with 4 different cluster topology nodes number, namely each cluster have 15 nodes、28 nodes、45 nodes、66 nodes. To compare simultaneously 2 parts namely have the average energy dissipation and alive nodes.

The simulate result in Figure 4.3.1 and Figure 4.3.2. From result show the average energy dissipation reality when cluster5 (15 nodes) and cluster9 (45 nodes) have better then cluster7 (28 nodes) and cluster11 (66 nodes). And in cluster5, which had exhausted of energy until 200 rounds, but in cluster9 actually when 198 rounds. Therefore, cluster5 has a best from these different of cluster. At the same time, the result also conforms to in front of us inferential reasoning.

In alive of nodes part, also have same of simulated result. The Cluster5 results have better then other cluster. Simultaneously the cluster5 is show gradually to die in surplus alive nodes, but other cluster node has the phenomenon after a rounds number which the play falls.

Another we will compare CCOC and LEACH in these 2 parts. For in average energy dissipation part, which the LEACH had completed energy about 157 rounds to transmit information to base station as Figure 4.3.3. But the CCOC algorithm of cluster5 have 200 rounds to transmit information. The alive nodes of compute are also present the CCOC better then LEACH as Figure 4.3.4.

Therefore, we propose the CCOC method can save the energy and the efficiency and the fault-tolerant aspect has the good contribution.

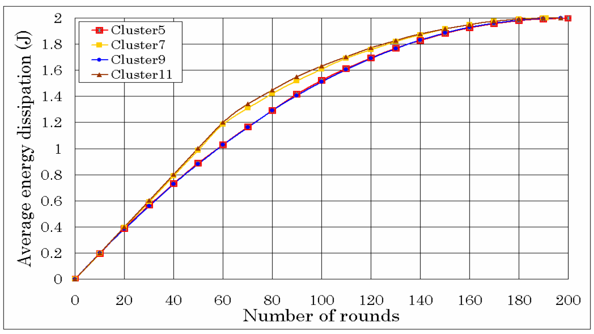

Figure 4.3.1 A comparison of CCOC's average energy dissipation with other cluster protocol

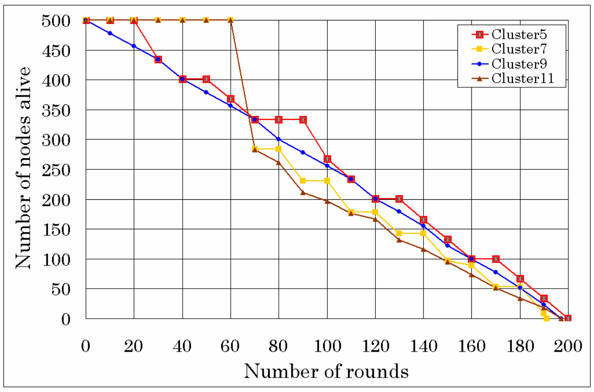

Figure 4.3.2 A comparison of CCOC's system lifetime with other cluster protocol

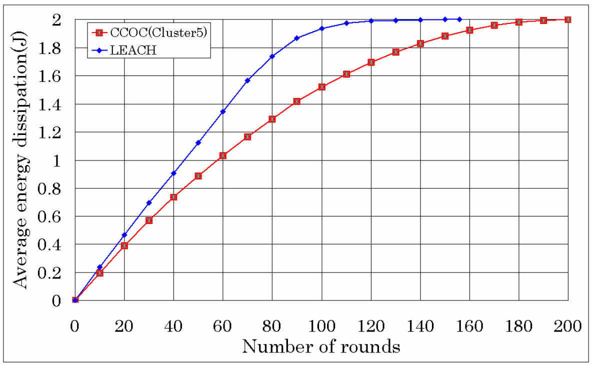

Figure 4.3.3 A comparison CCOC and LEACH of average energy dissipation

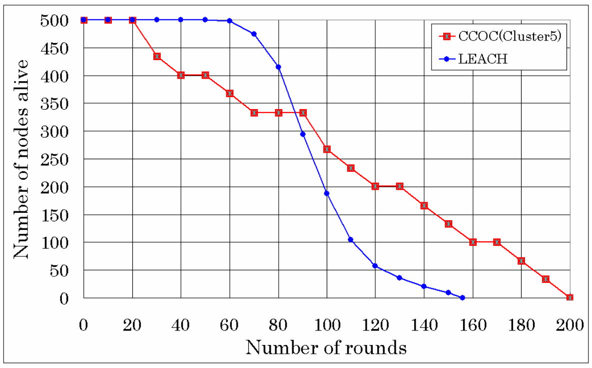

Figure 4.3.4 A comparison CCOC and LEACH of system lifetime

5：Conclusions

We propose the method for the limited energy of nodes in wireless network. For connecting the cluster concept, we discuss the effective coverage among the nodes and design the average density in the grid area. We can calculate the optimum node number from the average density and the number of the node in each cluster is same. Completing the cluster, we also consider the effective transmission distance of the sensor nodes. We select the cluster head from each cluster to be the transmission node message. We select the cluster head by the order number of the sensor node for each cluster.

Considering the QoS transmitted by the cluster head in the wireless network, we uses the routing protocol and the cluster head transmit and collect information efficiently in the wireless network. It can save the energy of the sensor nodes. The coverage of the sensor node is wide and the demand of the sensor node facility is a lot. The sensor node facility needs a cheaper facility. The opportunity of the breakdown is increasing, and then the fault tolerant is essential in the design and management in the sensor node of the wireless network.

References

[1]. Edgar H. Callaway, "Wireless Sensor Networks, Architectures and Protocols"

[2]. J. Heidemann, F. Silva, C. Intanagonwiwat, R. Govindan, D. Estrin, and D. Ganesan, "Building efficient wireless sensor networks with low-level naming," in Proceedings of the Eighteenth ACM symposium on Operating Systems Principles [21], Oct 2001, pp. 146-159.

[3]. W. Heinzelman,"Application-Specific Protocol Architectures for Wireless Networks," Ph.D. thesis, Massachusetts Institute of Technology, 2000.

[4]. Heinzelman, W.R. and Chandrakasan, A. and Balakrishnan, H. System Sciences, 2000. Proceedings of the 33rd Annual Hawaii International Conference, 4-7 Jan. 2000 Pages: 10 pp. vol.2

[5]. Rajagopal Iyengar, Koushik Kar, Suman Banerjee, "Low-coordination Topologies For Redundancy In Sensor Networks", May 2005 Proceedings of the 6th ACM international symposium on Mobile ad hoc networking and computing MobiHoc '05

[6]. Ozgur Sanli, H.; Hasan Cam;" Energy efficient differentiable coverage service protocols for wireless sensor networks" Pervasive Computing and Communications Workshops, 2005. PerCom 2005 Workshops. Third IEEE International Conference on 8-12 March 2005 Page(s):406 – 410

[7]. Rajagopal Iyengar, Koushik Kar, Suman Banerjee;"Applications: Low-coordination topologies for redundancy in sensor networks" Proceedings of the 6th ACM international symposium on Mobile ad hoc networking and computing MobiHoc '05 May 2005

[8]. Tarun Banka, Gagan Tandon, Anura P. Jayasumana: "Zonal Rumor Routing for Wireless Sensor Networks" Proceedings of the International Conference on Information Technology: Coding and Computing(ITCC'05)

[9]. Omar Moussaoui Mohamed Naïmi. " A Distributed Energy Aware Routing Protocol for Wireless Sensor Networks" October 2005 Proceedings of the 2nd ACM international workshop on Performance evaluation of wireless ad hoc, sensor, and ubiquitous networks PE-WASUN'05