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A Multi-hop Routing Algorithm based on Integrated Metrics for Wireless Sensor Networks

Fengjun Shang

College of Computer Science and Technology, Chongqing University of Posts and Telecommunications, Chongqing 400065, China

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Abstract: In this paper, a multi-hop routing algorithm based on integrated metrics (MRIM) was proposed for wireless sensor networks by research current routing algorithms. The core of MRIM has two parts as following. Firstly, a clustering algorithm based on time delay (CATD) was presented. By simulation it has verified the CATD clustering algorithm having more obviously improvement on the network performance, comparing with the algorithm for LEACH and the based on the timer of clustering algorithm for TB-LEACH. Secondly, the algorithm of the CATD is improved in cluster data transmission phase after the cluster heads are selected, called MRIM, which can be used in large scale. In the algorithm, it makes the equal distributed cluster-heads of the network into constructing a routing tree by means of the multi-hop transmission way so that this may reduce the number of cluster head nodes, when it communicates directly the base station (BS). Furthermore it reduces the network energy and cost. Meanwhile, the algorithm also limits the distance of the shortest forwarding multi-hop routing so as to reduce the overhead of intermediate nodes in the circuit and the number of multi-hop forwarding of data, save the network energy consumption, weaken the "hot spot problem" of the network. Simulation results demonstrate that MRIM can save energy and balance the network load and obvious improve the network lifetime.

Keywords: Wireless sensor network, Energy efficient, Integrated metrics, Cluster-head selection, Multi-hop.

1. Introduction

The rapid developments and technological advances in M-EMS(Micro Electromechanical System) and wireless communication, has made possible the development and deployment of large scale wireless sensor networks. Wireless sensor network consists of hundreds to several thousands of small sensor nodes scattered throughout an area of interest. The potential applications of sensor networks are highly varied, such as environmental monitoring, target tracking, and battlefield surveillance [1]. Sensors in such a network are equipped with sensing, data processing and radio transmission units. Distinguished from traditional wireless networks, sensor networks are characterized by severe power, computation, and memory constraints. Due to the strict energy constraints, energy efficiency for extending network lifetime is one of the most important topics. Sensor nodes are likely to be battery powered, and it is often very difficult to change or recharge batteries for these nodes. Prolonging network lifetime for these nodes is a critical issue. Therefore, all aspects of the node, from hardware to the protocols, must be designed to be extremely energy efficient.

Wireless sensor networking is a broad research area, and many researchers have done research in the area of power efficiency to extend network lifetime. In order to achieve high energy efficiency and increase the network scalability, sensor nodes can be organized into clusters [2]. The high density of the network may lead to multiple adjacent sensors generating redundant sensed data, thus data aggregation can be used to eliminate the data redundancy and reduce the communication load. Hierarchical protocols aim at clustering the nodes so that cluster heads can do some aggregation and reduction of data in order to save energy.

The paper is organized as follows. In Section 2, CATD algorithm is discussed. Section 3, describes our proposed data transmission algorithm. In section 4, simulation results are presented while Section 5 concludes the paper.

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* Corresponding author e-mail: shangfj@cqupt.edu.cn

2. The CATD Algorithm

Owning to constraining the resource of sensor node, clustering algorithm aiming at ad hoc networking can not be used directly, especially, the energy of WSN is limited, so new clustering algorithm must be researched. In [3], a timer-based distributed clustering algorithm is presented. By adaptively adjusting the wakeup rate of the exponential distributiona node with higher residual energy is more likely to be elected cluster-head. Moreover, the algorithm is able to ensure that cluster-heads are well scattered, but the distribution of cluster-heads is not always even. In [4], a Time-based cluster-head selection algorithm for LEACH is presented. This new protocol is called TB-LEACH. In this paper, it states the principle of TB-LEACH and gives the main flowchart and pseudo codes realizing TB-LEACH. Simulation results show that our algorithm outperforms original LEACH by about 20% to 30% in terms of system lifetime. In TB-LEACH, it has the fixed number of cluster-heads, but the location of cluster-heads is not even.

This paper improves the mechanism of time delay so that a node with higher residual energy is more likely to be elected cluster-head. At the same time, the optimum radius and number of cluster-head are introduced. The less is energy consumption, the longer is lifetime.

2.1. Radio Energy Model

We use a simplified model shown in figure 1 for the radio hardware energy dissipation. Both the free space (d^2 power loss) and the multi-path fading (d^4 power loss) channel models are used in the model, depending on the distance between the transmitter and receiver. Transmission (E_{Tx}) and receiving costs (E_{Rx}) can be calculated. Thus, to transmit an l-bit message a distance d, the radio expends as follows [5]:

$$E_{Tx}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs}d^2, d < d_o \\ lE_{elec} + l\varepsilon_{mp}d^4, d > d_o \end{cases} \tag{1}$$

Where d is the distance between the transmitter and the receiver. The electronics energy, E_{elec} depends on factors such as the digital coding, modulation, and filtering of signal before it is sent to the transmit amplifier. The parameters ε_{fs} and ε_{mp} will depend on the required receive sensitivity and the receiver noise figure, as the transmit power needs to be adjusted so that the power at the receiver is above a certain threshold $d_0 = \frac{\varepsilon_{fs}}{\varepsilon_{mp}}$.

To receive this message, the energy used by the radio can be expressed following:

$$E_{Rx}(l) = E_{elec}l \tag{2}$$

with l as the length of the message in bits, d as the distance between transmitter and receiver node. A sensor node also consumes E_{DA} (nJ/bit/signal) amount of energy for data aggregation. It is also assumed that the sensed information is highly correlated, thus the cluster-head can always aggregate the data gathered from its members into a single fixed length packet.

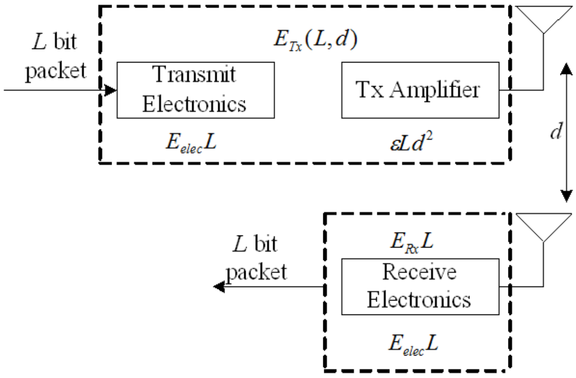


Figure 1: Radio Energy Dissipation Model

2.2. Selecting Cluster-head

Let us consider a sensor network consisting of N sensor nodes uniformly deployed over a vast field to continuously monitor the environment. We denote the i^{th} sensor by s_i and the corresponding sensor node set $Node = \{n_1, n_2, ..., n_N\}$, where $|Node| = N$. We make some assumptions about the sensor nodes and the underlying network model:

1) There is a base-station ($i.e.$, data sink) located far away from the square sensing field. Sensors and the base-station are all stationary after deployment.

2) All nodes are homogeneous and have the same capabilities. Each node is assigned a unique identifier (ID).

3) Nodes have no location information.

4) All nodes are able to reach BS in one hop.

5) Nodes can use power control to vary the amount of transmission power which depends on the distance to the receiver.

6) Links are symmetric. A node can compute the approximate distance to another node based on the received signal strength, if the transmitting power is given.

Selecting cluster-head is the basis for creating clusters. After deployment, each sensor sets a random waiting timer. If the timer expires, then the sensor declares itself to be a cluster-head, a focal point of a new cluster. However, events may intervene that cause a sensor to shorten or cancel its timer. For example, whenever the sensor detects a new neighbor, it shortens the timer. On the other hand, if a neighbor declares itself to be a cluster-head, the sensor cancels its own timer and joins the neighbor's new cluster. Because LEACH does not consider residual energy and distance of nodes, an average energy factor for CATD and make the node with the highest level of energy to be first cluster-head. The key parameter is as follows.

$$\lambda_i = \frac{E(i)_{residual}}{\overline{E(r)}} \tag{3}$$

where $E(i)_{residual}$ is the residual energy of the *i-th* node, $\overline{E(r)}$ is the average energy of the node and $r$is the current round number.

Definition 1 The number of rounds from first round to round which first node dies is called ***lifetime***.

Every node i maintains a variablex_i, which is assigned a random value from 0 to 1, namely, x_i =*random*(0, 1). Obviously, x_i is a random variable with uniform distribution on the interval [0, 1]. Each node i waits for a initiator timer according to an exponential random distribution i.e.

$$x_i = e^{-\lambda_i t_i} + rand(0, \alpha] \tag{4}$$

where $\alpha = 0.1$.

Formula (4) explains that t_i is inversely proportional to $E(i)_{residual}$. Formula (4) may be written by

$$t_i = -\frac{\ln(x_i)}{\lambda_i} \tag{5}$$

Substituting (3) into formula (5) and $\overline{E(r)}$ is invariant in that round, so Formula (5) is written by

$$t_i = -\frac{\ln(x_i)}{E(i)_{residual}} \tag{6}$$

We can find the relation between t_i and $E(i)_{residual}$ by setting the derivative t_i with respect to $E(i)_{residual}$.

$$\frac{dt_i}{dE(i)_{residual}} = \frac{\ln(x_i)}{E(i)^2_{residual}} \tag{7}$$

$\because \quad 1 \le x_i \le 1$

$\therefore \quad \frac{dt_i}{dE(i)_{residual}} < 0$, that is, t_i is inversely proportional to $E(i)_{residual}$.

From above analysis, we select short time as cluster-head, that is, we select high energy as cluster-head, so it is beneficial to prolong lifetime of network. After sensors are deployed, each sensor sets a random waiting timer. If the timer expires, then the sensor declares itself to be a cluster-head, a focal point of a new cluster.

2.3. Estimating Average Energy

It is important to estimate the average energy, but the disadvantage of this approach is that each node has to estimate the aggregate remaining energy in the network since this requires additional communication with the base-station and other nodes. In order to improve the approach, the average energy must be estimated.

In CATD, we assume that there are N nodes distributed uniformly in a MxM region. If there are k clusters, there are on average $\frac{N}{k}$ nodes per cluster (one cluster head and $\frac{N}{k} - 1$ non-cluster head nodes). Each cluster head dissipates energy receiving signals from the nodes, aggregating the signals, and transmitting the aggregate signal to the BS. Since the BS is far from the nodes, we can assume that the energy dissipation follows the multi-path model (d^4 power loss). Each non-cluster head node only needs to transmit its data to the cluster head once during a round. We can also assume that the distance to the cluster head is small, so the energy dissipation follows the free-space model (d^2 power loss). Hence, the total energy consumed during a single round can be estimated as:

$$E_{round} = E_{CH} + E_{non-CH} \tag{8}$$

where E_{CH} is the cluster-head consumption energy, E_{non-CH} is cluster member consumption energy. For the cluster-headE_{CH}, the single round energy consumption is as follows.

$$\begin{aligned} E_{CH} = LE_{elec} + L\varepsilon_{mp} d^4_{toBS} + \tfrac{N}{k} \times LE_{DF} \\ +(\tfrac{N}{k} - 1) \times LE_{elec} \end{aligned} \tag{9}$$

For cluster member E_{non-CH}, the single round consumption energy is as follows.

$$E_{non-CH} = LE_{elec} + L\varepsilon_{fs} d^2_{toCH} \tag{10}$$

where l is the number of bits in each data message, d_{toBS} is the distance from the cluster head node to the BS, d_{toCH} is the distance from the node to the cluster head, and we have assumed perfect data aggregation.

If we knowE_{round}, we may estimate the average energy

$$\overline{E_r} = \frac{E_{total} - rE_{round}}{N} \tag{11}$$

where $E_{total} = \sum_{i=1}^{N} E_i$ is the initial energy of all the nodes, E_i is i^{th} node energy, E_{round} is single round energy consumed. Furthermore, let single round energy consumed to be uniform. On above condition, we may estimate $\overline{E_r}$ as follows.

In Ref. 6, the two parameters k and d_{toCH} are given by:

$$k = \sqrt{\frac{N}{2\pi}} \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \frac{M}{d^2_{toBS}} \tag{12}$$

$$d_{toCH} = \frac{M}{\sqrt{2\pi k}} \tag{13}$$

From Ref. 7, we may find the parameters d_{toBS} to be equal to:

$$d_{toBS} = 0.765\frac{M}{2} \tag{14}$$

Substituting (9), (10), (12), (13), and (14), into (8) allows for estimation of E_{round}. Furthermore, we may estimate equation (11) and avoid additional communication between cluster-head and BS.

2.4. Number of Cluster-heads in CATD

We assume that there are N_1 nodes distributed uniformly in a r_1 region. If there are h_1 clusters, there are on average $\frac{N_1}{h_1}$ nodes per cluster (one cluster head and $\frac{N_1}{k_1} - 1$ non-cluster head nodes). Each cluster head dissipates energy receiving signals from the nodes, aggregating the signals, and transmitting the aggregate signal to the BS. Since the BS is far from the nodes, we can assume that the energy dissipation follows the multi-path model (d^4 power loss). Each non-cluster head node only needs to transmit its data to the cluster head once during a round. We can also assume that the distance to the cluster head is small, so the energy dissipation follows the free-space model (d^2 power loss). Hence, the energy consumed of cluster-head during a single round can be estimated as:

$$E_{CH} = lE_{elec}(\tfrac{N_1}{h_1} - 1) + lE_{DA}\tfrac{N_1}{h_1} + \\ lE_{elec} + l\varepsilon_{fs}D(CH_i, CH_{i+1})^2 \tag{15}$$

with l as the length of the message in bits and $D(CH_i, CH_{i+1})$ is the transmission distance between two sequential cluster head nodes CH_i and CH_{i+1}. A sensor node also consumes E_{DA} amount of energy for data aggregation.

Assumed d is distance from non-cluster head to cluster-head, if d<d$_0$, the energy consumed of non-cluster head during a single round can be estimated as:

$$E_{non-CH} = lE_{elec} + \varepsilon_{fs}d^2_{toCH} \tag{16}$$

d_{toCH} is the distance from non-cluster head to cluster-head. Given the area of per cluster-head is $\frac{\pi r_1^2}{h_1}$ and density is $\rho(x, y)$. If the center of region is the cluster-head, the square of the distance can be estimated as:

$$dtoCH^2 = \iint (x^2 + y^2)\rho(x, y)dxdy$$

$$= \iint r^2\rho(r, \theta)rdrd\theta$$

$$= \rho \int_{\theta=0}^{2\pi} \int_{r_1=0}^{\sqrt{\frac{r_1^2}{h_1}}} r^3(r, \theta)drd\theta = \rho\pi\frac{r_1^4}{2h_1^2} \tag{17}$$

If the nodes distribution is even, that is, $\rho = \frac{N_1}{\pi r_1^2}$ and $d^2_{toCH} = \frac{N_1 r_1^2}{2h_1^2}$, the formula (16) can be written as

$$E_{non-CH} = lE_{elec} + \varepsilon_{fs}\frac{N_1 r_1^2}{2h_1^2} \tag{18}$$

Hence, the total energy consumed of the cluster-head during a single round can be estimated as:

$$E_{cluster} = E_{CH}(\frac{N_1}{h_1} - 1)E_{non-CH}$$

$$= lE_{elec}\tfrac{N_1}{h_1} + lE_{DA}\tfrac{N_1}{h_1} + l\varepsilon_{fs}D^2 + \\ (\tfrac{N_1}{h_1} - 1)lE_{elec} + (\tfrac{N_1}{h_1} - 1)l\varepsilon_{fs}\tfrac{N_1 r_1^2}{2h_1^2}$$

$$\approx lE_{elec}\tfrac{N_1}{h_1} + lE_{DA}\tfrac{N_1}{h_1} + l\varepsilon_{fs}D^2 + \\ \tfrac{N_1}{h_1}lE_{elec} + \tfrac{N_1}{h_1}l\varepsilon_{fs}\tfrac{N_1 r_1^2}{2h_1^2} \tag{19}$$

Hence, the total energy consumed of the cluster-head during a single round can be estimated as:

$$E_{total} = h_1 E_{cluster}$$

$$= 2N_1 lE_{elec} + N_1 lE_{DA} + h_1 l\varepsilon_{fs}D^2 + \varepsilon_{fs}\frac{N_1^2 r_1^2}{2h_1^2} \tag{20}$$

E_{total} derivative of the h_1 is equal to zero, the optimum number of cluster-head h_1 can be computed as

$$h_1 = \sqrt[3]{\frac{N_1^2 r_1^2}{D^2}} \tag{21}$$

This h_1 can be seen as a reference value, we use it according to actual application.

3. Data Transmit in MRIM

In order to reduce energy consumption, there are many multi-hop routing algorithm based on clustering. In [8], it researched the energy consumption in single hop and multi-hop mode of communication. A systematic cost-based analysis of both the modes is presented, and provided results that could serve as guidelines to decide which mode should be used for given settings. In [9], it presents a novel uneven cluster-based routing protocol for wireless sensor networks. Its core is an Energy-Efficient Uneven Clustering (EEUC) algorithm for network topology organization, in which tentative cluster heads use uneven competition ranges to construct clusters of uneven sizes. The clusters closer to the sink have smaller sizes than those farther away from the sink, thus the cluster heads closer to the sink can preserve some energy for the inter-cluster data forwarding. Simulation results show that the routing protocol effectively balances the energy consumption among cluster heads and achieves an obvious improvement on the network lifetime. In [10], a ring based multi-hop clustering routing algorithm (RBMC) for wireless sensor networks was proposed. The main task of RBMC was to prolong the lifetime of the network, balance energy consumption between nodes. The main idea of RBMC was to divide the WSN field into concentric rings and build unequal size of clusters in different rings. From the objective of minimum energy consumption in first ring and balance of it between first ring and other rings, the optimum choice of cluster numbers for each ring was deduced. Via adoption of different algorithms for cluster head election, RBMC could be applied to homogeneous and heterogeneous energy settings. In [11], based on shortest path tree, ratio weight (Ratio-W) and sum weight (Sum-W) routing algorithms are proposed, in which both remaining energy of nods and energy consumption for delivering packets on wireless links are considered. In [15], a novel routing protocol based on integrated metrics is proposed for Infrastructure/Backbone wireless mesh networks. The new protocol greatly optimized routing performance by making use of a brand-new routing metric, which takes into account two factors in route selection: link length and link communication efficiency. The simulation results show that the proposed routing protocol improves the packet delivery ratio, reduces the end-to-end delay, and achieves load balance in the route selection process. In [16], it propose a new energy-efficient LEACH-based protocol that employed cluster member threshold and merged the tiny cluster to avoid the great cluster and small cluster existing at the same time; estimated cluster head's energy to reduce unnecessary energy consumption. In [17], it proposes an optimal number of cluster-heads based on multi-hop routing in wireless sensor networks. It can be observed that a local cluster made by a cluster-head influences the energy consumption of sensor nodes. It determined an equation for the number of packets to send and relay, and calculated the energy consumption of sensor networks using it. Through the process of calculating the energy consumption, it can obtain the optimal number of cluster-heads in wireless sensor networks. In [18], it surveys the novel approach of using the large scale federated WSN resources in a sensor virtualization environment. The focus in that paper is to introduce a few design goals, the challenges and opportunities of research in the field of sensor network virtualization as well as to illustrate a current status of research in this field. That paper also presents a wide array of state-of-the art projects related to sensor network virtualization.

But in above algorithm, there are some shortcomings to need research. Firstly, when transmit distance is close, the transmit nodes will consume too much energy. Secondly, the overhead in exchange of information between cluster-head and next cluster-head is high, when the cluster-head selects next hop. Thirdly, energy balance among cluster-heads need be improved. So, CATD algorithm based on multi-hop is presented, called MRIM. It generates a routing tree based on distance energy cost. When it selects next hop, it considers the distance of transmit, residual energy and distance from base station so that it can select reasonably next hop and number of hop. MRIM can extend lifetime of network and be easy to implement.

When the scope of WSN gets larger, the diversity of energy consumption among cluster-heads of LEACH as well gets larger.

Let's suppose that there are cluster-heads $S(i)$ which is r far from the BS and$S(j)$ which is $3r$ far from the BS.

When $r \geq d_0$, the energy consumption of $S(i)$ is listed as

$$E_{Tx}(k,r) = kE_{elec} + k\varepsilon_{mp}r^4 \tag{22}$$

The energy consumption of $S(j)$ is written as

$$E_{Tx}(k,r) = kE_{elec} + 81k\varepsilon_{mp}r^4 \tag{23}$$

In the formula, when the circuit consumption is the same, the energy consumed by transmit amplifier of $S(i)$ is 81 times as much as that of $S(j)$, so WSNs in large scope should adopt multiple-hop routing protocols.

3.1. Selecting optimum Transmitting Node

The data collected by myriad sensors flow to a small number of BS, which leads to the energy of sensors which near to basic be used up quickly and leads to the break of networks, so the question existing in many-to-one networks is viewed as the hot spot [12]. Meanwhile, only considering the shortest route will result in the geographic superiority of individual sensor embodied in the multiple routes, and this is proved in LEACH-M. Besides, multiple-hops routing cuts down the communication consumption, but increases the circuit energy consumption. In order to go on the research, let's suppose that there is a linear network model, as shown in Figure 2.

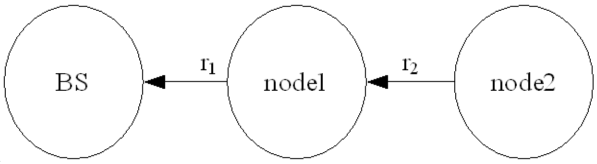


Figure 2: Relay node network model

Where $r_1 < d_0$ is the distance between BS and node1, $d_0 < r_2 < 2d_0$ is distance between node2 and node1, r is distance between BS and node2. We select node1 to transit data, when node2 transmit data to BS. From figure 2, we have

$$r_2 = r - r_1 \tag{24}$$

When node2 transmits data to node1, the energy consumption is written as

$$E_{node1} = k\varepsilon_{fs}r_1^2 + kE_{elec}$$

$$E_{node2} = k\varepsilon_{fs}(r_1^2 + r_2^2) + 2kE_{elec}$$

The total energy consumption is as follows

$$E_{tot} = 2k\varepsilon_{fs}(r_1^2 + r_2^2) + 3kE_{elec} \tag{25}$$

We replace (24) into (34),

$$E_{tot} = 2k\varepsilon_{fs}((r - r_2)^2 + r_2^2) + 3kE_{elec}$$

And the optimum node position is computed as below:

$$r_2 = \frac{r}{2} \tag{26}$$

In a similar way, when $r_{31} = \frac{r}{3}$ and $r_{32} = \frac{2r}{3}$, the energy consumption is minimum, etc.

According to above computation, optimum transmitting distance is

$$d_{opt} = \frac{d}{\beta_{opt}} \times (\beta_{opt} - 1) \tag{27}$$

Given coordinate of $S(i)$ be $(x,\ y)$, optimum node coordinate is listed as

$$\begin{cases} x_{opt} = \frac{x}{\beta_{opt}} \times (\beta_{opt} - 1) \\ y_{opt} = \frac{y}{\beta_{opt}} \times (\beta_{opt} - 1) \end{cases} \tag{28}$$

3.2. Estimating Hop-counts

The communication between the cluster-heads and the BS should adopt Collision Avoidance when the network becomes large and the number of sensors increase, or it will give rise to the occurrence of conflicts when the cluster-heads are sending data. Therefore, sensor networks in large scope should adopt certain strategies to reduce the occurrence of conflicts.

CHs can send their data via just one (high-energy) transmit of data to the base station or via a multi-hop scheme where each data message must go through n(low energy) transmits and $n$receives. Depending on the relative costs of the transmit amplifier and the radio electronics, the total energy expended in the system might actually be greater using multi-hop routing than direct transmission to the base station.

To illustrate this point, consider the linear network shown in Figure 2, where the distance between the nodes is r. If we consider the energy expended transmitting a single l-bit message from a node located a distance nr from the base station using the direct communication approach via one hop, we have:

$$E_{Tx} = l\varepsilon_{fs}(\frac{n-1}{\beta}r)^2 + lE_{elec} \tag{29}$$

Where β is the number of hops. Thus, the total energy is written as

$$Etot = \beta E_{TX} + \beta E_{RX}$$

$$= 2l\beta E_{elec} + l\varepsilon_{fs}\frac{(n-1)^2 r^2}{\beta} \tag{30}$$

And the optimum number of hops is computed as below:

$$\begin{cases} \frac{dE_{tot}}{d\beta} = 2kE_{elec} - k\varepsilon_{fs}\frac{d^2}{\beta_{opt}^2} = 0 \\ \frac{d}{\beta_{opt}} \leq d_0 \end{cases} \Rightarrow \beta_{opt} = \left\lceil \frac{d}{d_0} \right\rceil \tag{31}$$

This shows that, when transmission energy is on the same order as receive energy, which occurs when transmission distance is short, direct transmission is more energy-efficient than multi-hop routing. Thus we use direct transmission communication among CHs and the base station.

3.3. Routing among Cluster-heads

After the network finished deployment, the base station broadcasts a Sink_ADV using the fixed transmit power and then the nodes compute the distance from node to BS according to the signal strength.

We introduce a threshold $Restriction\_dis\tan ce$, if the distance from base station to cluster-head is less than $Restriction\_dis\tan ce$, the cluster-head communicate direct to base station, or else, the muti-hop routing is used. When the cluster is formed, the broadcast radius of each cluster-head is $2r_c$ and then it broadcasts a NODE_STATE _MSG, which includes ID, distance, residual energy. The message structure is shown in figure 3.

DPT	ID	DBS	EN

Figure 3: Structure of Broadcast Packet

Where DPT means the type of message, ID denotes identification of message, DBS denotes the distance from node to base station, EN means the current energy of node.

When the i^{th} cluster-head receives the broadcast message of the j^{th} cluster-head, it may compute the distance. Each cluster-heads saves the information table of neighbor cluster-head. When $d(i, BS) > Restriction\_dis\tan ce$, the i^{th} cluster- head selects route method as follows.

Definition 2 When k bits data are transmitted from node i to node j consume energy is called Communication energy consumption and it is written as $e_{ij}(k, d_{ij})$. Both the free space (d^2 power loss) and the multi-path fading (d^4 power loss) channel models are used in the model, depending on the distance between the transmitter and receiver.

$$e_{ij}(k, d_{ij}) = \begin{cases} kE_{elec} + k\varepsilon_{fs}d^2, d < d_o \\ kE_{elec} + k\varepsilon_{mp}d^4, d > d_o \end{cases} \tag{32}$$

Where $d$is the distance between the transmitter and the receiver.

Assumed node i and node *j,k,. . . ,n* are clusters shown on figure 4, where L_{itoBS}denotes the distance from node i to BS, L_{ij}denotes the distance from node i to node j, L_{jtoBS}denotes the distance from node j to BS, L denotes the distance by using RSSI[9].

Definition 3 The clingy degree of interlinking $L_i = \frac{L_{ij}}{L_{itoBS}}$ and $L_j = \frac{L_{jtoBS}}{L_{itoBS}}$.

Theorem 1 When the clingy degree of link is higher or balanced, the value of $\frac{\sqrt{L_i^2+L_j^2}}{L_iL_j}$ is less.

Proof: Assumed there be two interlinking are respective $(n_p$,$n_q)$ and $(n_m$,$n_n)$, where $U_{pq} = \frac{\sqrt{L_p^2+L_q^2}}{L_pL_q}$ and $U_{mn} = \frac{\sqrt{L_m^2+L_n^2}}{L_mL_n}$.

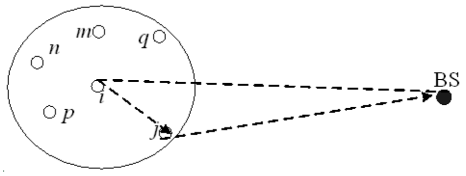


Figure 4: The illustration node i to node j

(1) Given $(L_p + L_q) \geq (L_m + L_n)$, $|L_p - L_q| = |L_m - L_n|$ and $|L_p - L_q| = |L_m - L_n| = \Delta$

$$\therefore 4L_pL_q = (L_p + L_q)^2 - (L_p - L_q)^2$$

$$= (L_p + L_q)^2 - \Delta^2 \geq (L_m + L_n)^2 - \Delta^2 = 4L_mL_n$$

$$\therefore L_pL_q \geq L_mL_n$$

Given $e = L_pL_q$, $e \in [0, +\infty)$

So $\sqrt{L_i^2 + L_j^2}/L_iL_j$ can be replaced by

$f_1(e) = \sqrt{\Delta^2 + 2e}/e$

$\because$The derivative of $f_1(e)$ is negative number,

$$\therefore U_{pq} \leq U_{mn}$$

So the clingy degree of link is higher or balanced, the value of $\frac{\sqrt{L_i^2+L_j^2}}{L_iL_j}$ is less.

(2) Given $(L_p + L_q) = (L_m + L_n)$ and $|L_p - L_q| \leq |L_m - L_n|$, $(L_p + L_q) = (L_m + L_n) = \Delta$

$$\therefore 4L_pL_q = (L_p + L_q)^2 - (L_p - L_q)^2$$

$$= \Delta^2 - (L_p - L_q)^2 \geq \Delta^2 - (L_m - L_n)^2 = 4L_mL_n$$

$$\therefore \Delta^2/4 \geq L_pL_q \geq L_mL_n$$

Given $e = L_pL_q$, $e \in \left[0, +\Delta^2\right)$

So $\sqrt{L_i^2 + L_j^2}/L_iL_j$ can be replaced by

$f_1(e) = \sqrt{\Delta^2 - 2e}/e$

$\because$The derivative of $f_1(e)$ is negative number,

$$\therefore U_{pq} \leq U_{mn}$$

So the clingy degree of link is higher or balanced, the value of $\frac{\sqrt{L_i^2+L_j^2}}{L_iL_j}$ is less.

Definition 4 The energy intensity is the energy divided by distance, called Energy Intensity Factor and it is written as EIF_{ij}:

$$EIF_{ij} = \frac{e_{ij}}{L_i} \tag{33}$$

Definition 5 The integrated metrics is the total cost from node i to node j, called Integrated Metrics Cost and it is written as *IM*(i,j).

$$IM(i,j) = \frac{EIF_{ij}}{E^j_{residual}} / \frac{\sqrt{L_i^2 + L_j^2}}{L_iL_j} \tag{34}$$

Toward any path $P = n_1, n_2, ..., n_k$, the integrated metrics is written as:

$$IM_P = \sum_{i=0}^{k-1} IM_{i+1} \tag{35}$$

According to the total integrated metrics, we select the minimum integrated metrics as the next hop in all routes R, that is

$$NF = \min_{P \in R}(IM_P) \tag{36}$$

According to the above strategy, the routing is selected. It is a tree, which the root is the base station. The data transmit from cluster-head to the base station.

3.4. Analysis of MRIM

We design the MRIM algorithm. The Pseudo-code is as follows.

```
;Selecting Cluster-head
FOR $i$ =1:1:NodeNumber
    $Timer(i) = e^{-\lambda_i t_i} + rand(0, \alpha]$
END

IF a certain node $i$ is expire after $T_{timer}(i)$ seconds
    Calculate $Ttimer$ for each node;
    The smallest delay node broadcasts a CH_ADV;
END IF

IF be$Ttimer(i)$expires==false
    IF Node$i$receives CH_ADV;
      Send CH_ADV to$S_{CH}(i)$;
    END IF
END IF

WHILE be$T_{timer}(i)$ expires==true
    IF $|S_{CH}(i)| < K$ then
        IF $d(i, S_{CH}(i)) > r_c$
          Broadcasts CH_ADV;
          Be_CH_Head=True;
        ELSE
          Become a CM node;
        END IF
    ELSE
      EXIT;
    END IF
END
```

Produced number of CHs is k: $\{CH_{i1}, CH_{i2}, \ldots, CH_{ik}, k \Leftarrow K\}$;

```
;Data Transmit from cluster-head to base station
FOR $i$ =1: 1: k
    IF $d$(CH$_i$, BS)≤ Restriction_distance
      Transmit data from CH$_i$ to base station
    ELSE
```

```
      CH$_i$ Broadcast SELECT_NEXT_HOP_MSG;
      IF Node $j == min(IM_P)$
         Node $j$ broadcast JOIN_ClusterHead_MSG;
      END IF
   END IF
END
```

In this algorithm, each node broadcast information using same power, in order to save energy, this broadcasting radius is r_c. Firstly, according to waiting timer, if the timer expires, the cluster-heads are produced. Secondly, the cluster-heads broadcast the number of receiving node. Thirdly, it produces the final cluster-head according to the optimum radius and distance. Furthermore, each cluster-head broadcasts CH_ADV information. According to receiving information, nodes add the shortest distance cluster-heads. Lastly, nodes send *JOIN_ClusterHead_MSG* information and tell that cluster-head.

After cluster-head is selected, according to distance, nodes add themselves to the cluster-head. Furthermore, during the data transmission phase, the cluster-head structures a *TDMA-based* schedule, which determines when each cluster member can communicate with the cluster-head.

According to Algorithm 1, the cluster head selection process is message driven, thus we must discuss its message complexity.

Theorem 2 The message complexity of the cluster formation algorithm is $O(N)$.

Proof:At the beginning of the cluster head selection phase, BS broadcasts a *BS_MSG*, $\frac{Area}{\pi r_c^2}$(*Area* is selected that area of scenario) cluster-heads broadcast *CH_ADV* and cluster members broadcast N-$\frac{Area}{\pi r_c^2}$ *JOIN_MSG*. Next step, the cluster heads are produced and each of them broadcasts a *COMPETE_HEAD_MSG*. Then each of them makes a decision by broadcasting a *RECEIVE_NODE_MSG* to calculate the total number of node adding that cluster-head. Furthermore each of them makes a decision by broadcasting a *CH_ADV* to act as a final cluster head, or a *QUIT_MSG* to act as an ordinary node. Suppose $k$cluster heads are selected, they send out k *HEAD_MSG*, and then $(N-k)$ ordinary nodes transmit $(N-k)$ *JOIN_ClsterHead_MSG*. Thus the messages add up to $N \times \frac{Area}{\pi r_c^2} + N \times (1 - \frac{Area}{\pi r_c^2}) + 3N \times \frac{Area}{\pi r_c^2} + k + N - k + 1 = (3\times \frac{Area}{\pi r_c^2} + 2) \times N + 1$ in the cluster formation stage per round, $i.e.$, $O(N)$.

The theorem 2 shows the message overhead of MRIM is small. In HEED [13], the upper-bound of message complexity is $N_{iter}\times N$ where N_{iter} is the number of iterations. Because we have avoided message iteration in the cluster-head selection algorithm, the control message overhead in MRIM is much lower than that in HEED. EECS algorithm [14] is also $O(N)$, but when it select cluster-head, it does not consider the cost of each node and cluster-head. The theorem 3 shows the selective path is loop-less route.

4. Simulations and Analysis

This paper makes Matlab as experiment platform, and goes on simulation in two scenes respectively. The parameters of simulation experiments see the following table 1, in which the first ten parameters are same to the document.

Table 1: Simulation Parameters

parameter	scene1	scene2
The scope	100×100m^2	200×200m^2
Number of sensors	100	400
Location of BS	(50,175)	(100,275)
Initial energy	0.5J	0.5J
Length of packets	4000bits	4000bits
E$_{elec}$	5×10^{-8}J	5×10^{-8}J
ε_{fs}	10^{-11}J	10^{-11}J
ε_{mp}	1.3×10^{-15}J	1.3×10^{-15}J
E$_{DA}$	5×10^{-9}J	5×10^{-9}J
r_c	25m	25m
d_0	87m	87m

4.1. Number of Cluster-head and Distribution

The number of cluster-head is stable in MRIM. A stable clustering algorithm can produce the stable number of cluster-head so as to save energy consumption. 1000 rounds of simulation are selected in selected algorithm and distribution of cluster-heads can be known from figure 5. In LEACH, it uses random numbers and threshold to select cluster-head, so the fluctuation of cluster-head number is high and the fluctuation of cluster-head number is high in each round. In TB-LEACH and MRIM, number of cluster-head is stable because it selects cluster-heads in the whole network according to information aggregation of cluster-heads and control number of cluster-heads.

Energy consumption is related both number of cluster-heads and location distribution of cluster-heads. It may save energy, when cluster-heads location is even. Figure 6(a) is shown location of cluster-heads in TB-LEACH. Figure 6(b) is shown location of cluster-heads in MRIM. Location of cluster-heads in TB-LEACH is not even and this leads to extra energy consumption owning to retransmit data. At the same time, it also can product isolated cluster-head so that it communicates directly base station and consumes too

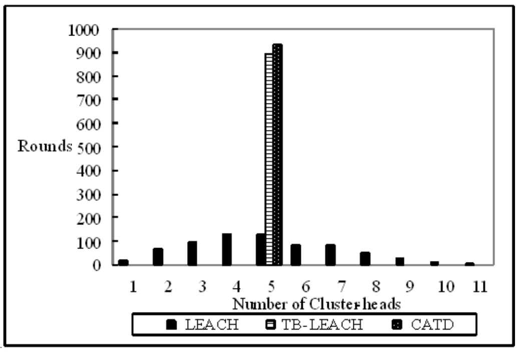
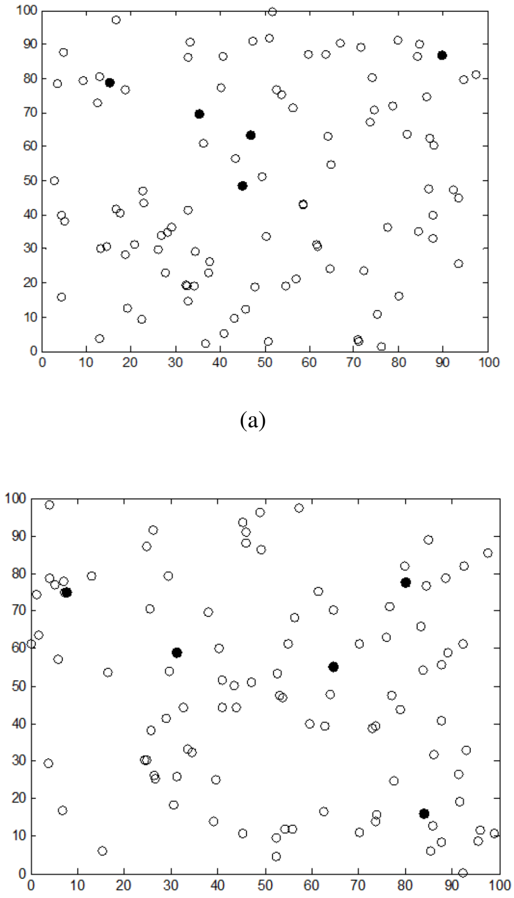


Figure 5: Comparing numbers of cluster-heads between TB-LEACH and MRIM



(a)

(b)

Figure 6: (*a*) Location of cluster-heads in TB-LEACH, (*b*) Location of cluster-heads in MRIM

much energy. But location of cluster-heads in MRIM is even by means of the optimum broadcast radius so that it reduces energy consumption and extends network lifetime.

4.2. Lifetime

Figure 7 is the network's lifetime in 100×100m^2 scenes. In the scene 1, the Fist Node Death time (**FND**) of MRIM is 1.35 times more than that of LEACH, and the Half Nodes Death (**HND**) time of MRIM is about 1.15 times more than that of LEACH. This demonstrates that MRIM algorithm makes energy consumption be evenly distributed all nodes so that each node will dies owning to consuming too much energy. The FND and HND in MRIM is 1.1 times more than that of TB-LEACH and CATD, because MRIM introduces the optimum hop and reduces energy consumption of network.

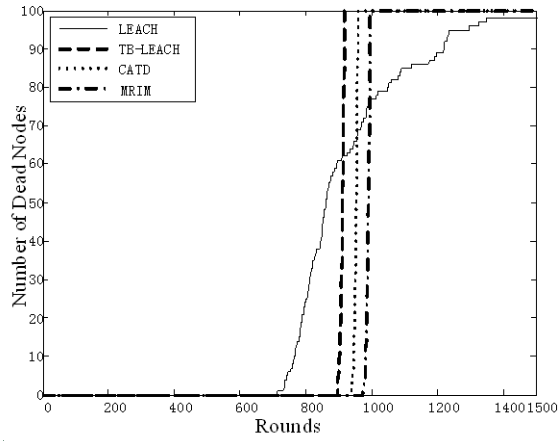


Figure 7: Relation between dead nodes and number of round in 100×100m^2

Figure 8 is the network lifetime in 200×200m^2 scenes. In the scene 2, MRIM's FND and HND are 3.1 times and 1.25 times as much as that of LEACH. MRIM's FND is 1.8 times and 1.25 times as much as that of TB-LEACH and CATD. MRIM's HND is 1.2 times as much as that of TB-LEACH and CATD. Because the distance in other three algorithms is bigger than MRIM so that communication energy consumption of cluster-head is higher than MRIM in big scope scene. But in MRIM communication between cluster-head and base station selects the cluster-head, which is the less energy consumption and the closer distance from base station, so communication energy consumption of each cluster-head in single round is not increased with increasing distance and then this can balance energy consumption. It is known that span of time of FND and HND can balance energy consumption of node. The less span is, the higher

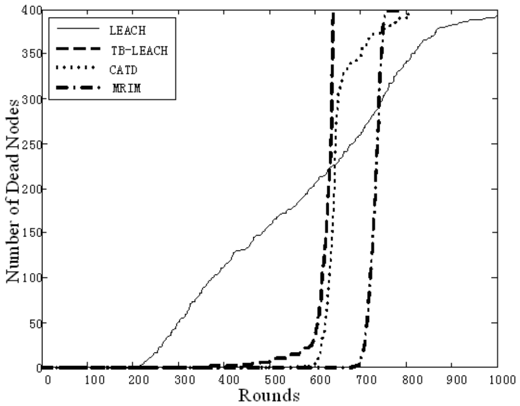


Figure 8: Relation between dead nodes and number of round in 200× 200m^2

energy-efficiency is. MRIM both extend network lifetime and reduce span of time. In beginning phase of MRIM, The coverage area is the biggest among LEACH, TB-LEACH and CATD. In some time point, nodes of network in MRIM begin dying, so in later phase, the number of alive nodes is reduced. The some ratio of dead nodes is in all nodes of WSNs and then it is dead network. So this can not effect on network lifetime in WSN.

It is known from figure 7 and figure 8 that it can save energy consumption by using multi-hop. MRIM can balance energy consumption of cluster-head in different location and reduce communication energy load of cluster. Meanwhile, the algorithm also limits the distance of the shortest forwarding multi-hop routing, and reduces the overhead of intermediate nodes in the circuit and the number of multi-hop forwarding of data, also saves the network energy consumption, weakening the network ”hot spot problem.” Through the above research, a complete set of algorithms form the cluster head selection to data transmission design completed, gives a distributed energy efficient communication protocol was presented, its core is a clustering hierarchy arithmetic based on time delay.

4.3. Received Number of Packets

Figure 9 is the sum of data packets which is the cluster-heads sending to the BS in 100×100m^2 scene. In the scene 1, before HND, the sum of data packets transmitted by MRIM is 1.2 times as much as that of LEACH and 1.1 times as much as that of TB-LEACH and CATD. Because MRIM rationally selects multi-hop and then this effectively resolves routing overhead of network and energy consumption so that load of nodes is minimum among three algorithms and extends lifetime of network. Furthermore, CATD can save energy consumption of network and improve energy-efficiency of network.

Figure 10 is the sum of data packets which is the cluster-heads sending to the BS in 200×200m^2 scene. In the scene 1, before HND, the sum of data packets transmitted by MRIM is 1.5 times as much as that of LEACH and 1.1 times as much as that of TB-LEACH and CATD. From Figure 10, it is known that MRIM can extend lifetime of network. When half number of nodes is dead, most nodes in LEACH, TB-LEACH and CATD have be dead so that some areas are covered, so MRIM is better than LEACH, TB-LEACH, CATD.

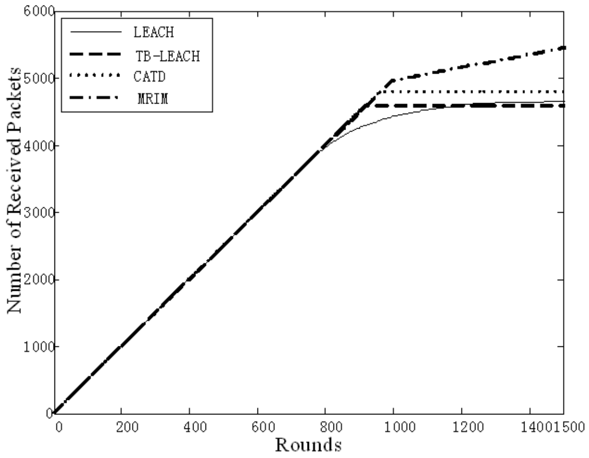


Figure 9: Received packets over rounds in 100×100m^2

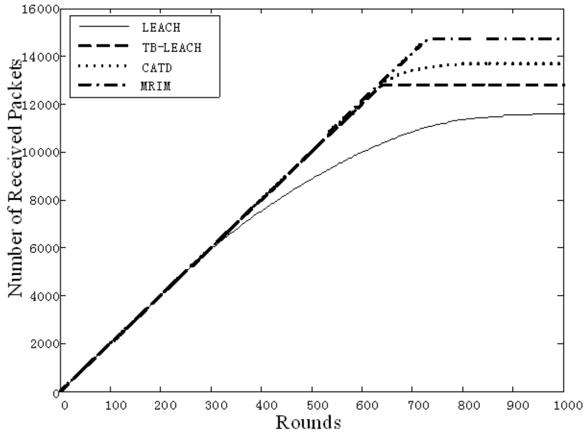


Figure 10: Received packets over rounds in 200×200m^2

From Figure 9 and figure 10, it is known that MRIM can extend lifetime of network and increase sum of packets. If the area is increasing, it is evident that this algorithm has the clear superiority.

4.4. Energy Consumption

Figure 11 is relation between energy consumption and round among LEACH, TB-LEACH, CATD and MRIM in 100× 100m^2 scene. From figure 11, it is known that MRIM can save energy consumption of network when MRIM is compared with LEACH, TB-LEACH and CATD. After a while, it saves energy in LEACH and MRIM is better than LEACH, TB-LEACH and CATD. In about the 800th round, total energy consumption of network in MRIM is more than LEACH, TB-LEACH and CATD, because some nodes in LEACH, TB-LEACH and CATD are dead with time going.

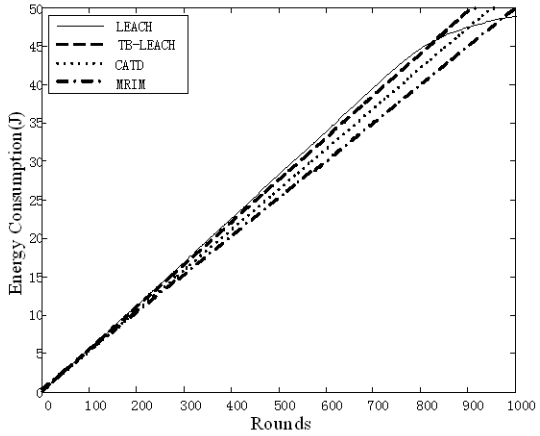


Figure 11: Energy consumption of LEACH, TB-LEACH, CATD, MRIM in 100× 100m^2

If the area is increasing, MRIM is evident that this algorithm has the clear superiority. Figure 12 is relation between energy consumption and round among LEACH, TB-LEACH, CATD and MRIM in 200×200m^2 scene. From figure 12, it is known that MRIM can save energy consumption of network when MRIM is compared with LEACH, TB-LEACH and CATD. In about the 300th round, total energy consumption of network in MRIM saves 50% energy consumption when MRIM is compared with LEACH, TB-LEACH and CATD, because some nodes in LEACH, TB-LEACH and CATD are dead with time going.

From Figure 11 and figure 12, it is known that MRIM can extend lifetime of network by using mlti-hop strategy when it is compared with LEACH, TB-LEACH and CATD. If the area is increasing, it is evident that this algorithm has the clear superiority.

4.5. Load Balance

Balance load of network is one of network performance evaluation for wireless sensor network. For convenience of research, this paper classify the sensor nodes for two areas according to distance from base station. For convenience of description, the nodes of first area, which is close from base station and half number, overlay first region. Thus the nodes of second area, which is far from base station and half number, overlay second region. Figure 13 is the relation between energy consumption and round for LEACH in 100×100m^2 scene. From figure, it is known that 50 nodes of area1, which is close from base station, consume the less energy than that of area2, but 50 nodes of area2 which is far from base station, consume the more energy than that of area1. This will make load of network be uneven so that nodes, which is far from base station, consume the more energy and die earlier.

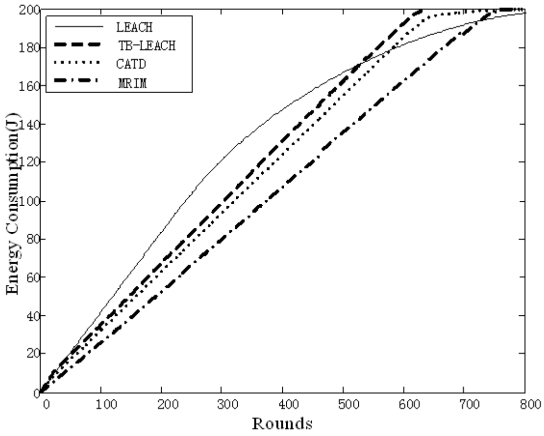


Figure 12: Energy consumption of LEACH, TB-LEACH, CATD, MRIM in 200× 200m^2

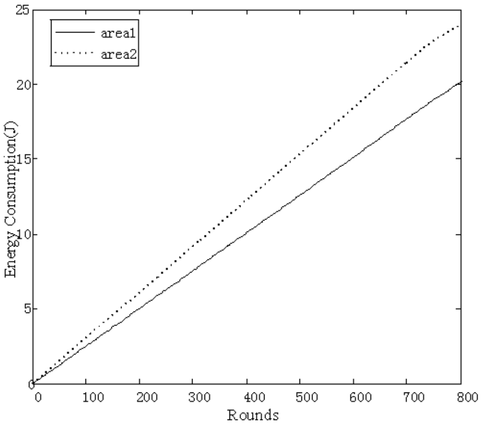


Figure 13: Relation between energy consumption and round for LEACH in 100×100m^2 scene

Figure 14 is the relation between energy consumption and round for LEACH in 200×200m^2 scene. From figure, it is evident that load imbalance has highlighted. In worst things, 200 nodes of area2, which is far from base station, consume 2 times as much as that of area1.

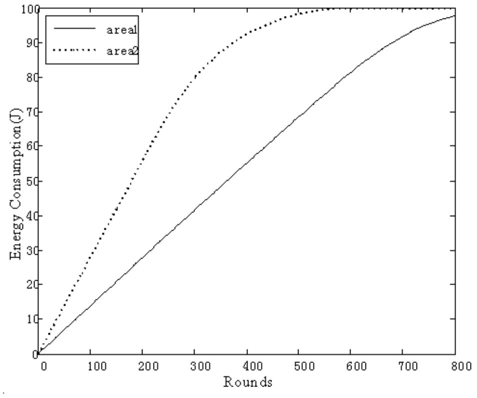


Figure 14: Relation between energy consumption and round for LEACH in 200×200m^2 scene

From Figure 13 and figure 14, it is known that these nodes, which are far from base station, in single hop clustering algorithm like LEACH, consume the more energy with increasing area so that load imbalance has highlighted, so these algorithm can not be use big scope scene.

Figure 15 is the relation between energy consumption and round for MRIM in different area in 100×100m^2 scene. From figure, it is evident that energy of two areas is balanced so that it extend lifetime of network.

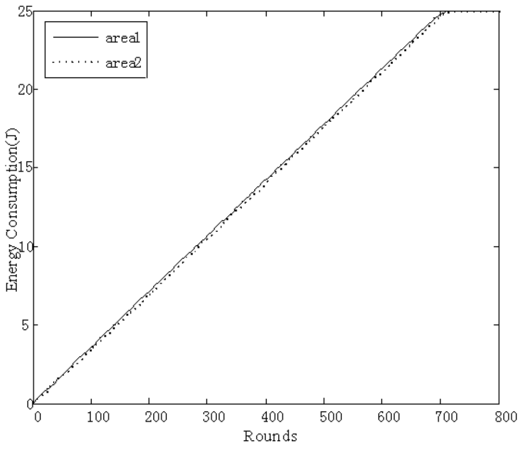


Figure 15: Relation between energy consumption and round for MRIM in 100×100m^2 scene

Figure 16 is the relation between energy consumption and round for MRIM in different area in 200×200m^2 scene. From figure, it is evident that energy of two areas is balanced so that it extend lifetime of network. If the area is increasing, it is evident that MRIM algorithm has the clear superiority.

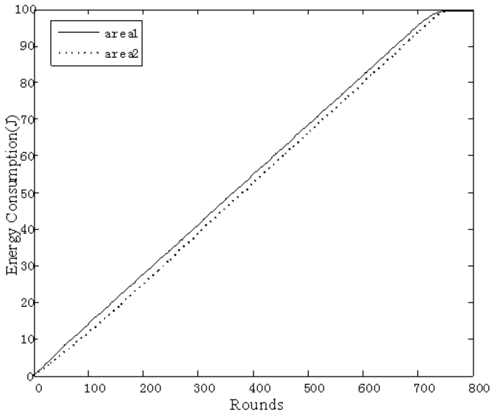


Figure 16: Relation between energy consumption and round for MRIM in 200×200m^2 scene

In conclusion, MRIM can extend lifetime of network and increase sum of packets and save energy consumption of network and balance energy load of network and improve CATD Clustering algorithm by simulating MRIM algorithm.

5. Conclusions

In this paper, it summarizes the main research thoughts in the cluster-based sensor network routing. The main contents of this dissertation are as following: (1) this paper presents a clustering algorithm based on time delay (CATD). By simulation it has verified the CATD clustering algorithm having more obviously improvement on the network performance, comparing with the algorithm for LEACH and the based on the timer of clustering algorithm for TB-LEACH. (2) this paper improves the algorithm of the CATD and design of a cluster-based routing algorithm, called MRIM, which can be used in large scale. In the algorithm, it makes the equal distributed cluster-heads of the network into constructing a routing tree by means of the multi-hop transmission way so that this may reduce the number of cluster head nodes to communicate directly the base station. Furthermore it can reduce the network energy and cost. Meanwhile, the algorithm also limits the distance of the shortest forwarding multi-hop routing so as to reduce the overhead of intermediate nodes in the circuit and the number of multi-hop forwarding of data, save the network energy consumption, weaken the ”hot spot problem” of the network. Simulation results demonstrate that MRIM can save energy and balance the network load and obvious improve the network lifetime.

In future research, we will consider NS2 simulation platform using event-driven mechanism to simulate performance of the MRIM algorithm. In LEACH, TB-LEACH, CATD and MRIM, we assume that data are transmitted at any moment, but for event-driven network, in no events, nodes do not consume energy and keep sleeping status. Once there is an event, the node is waked to collect data and communicate, so this can improve energy-efficient of sensor network so that this make MRIM is better to apply in real condition.

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FENGJUN SHANG (1972), male, received the Diploma degree in Intelligent Instrument at Chengdu University of Technology, China, in 2001. He finished his Ph.D. degrees in Instrument Science and Technology at the College of Opto- electronic Engineering, Chongqing University, China, in 2005. Since then he works as a professor with the Institute of Computer Network Engineer in Chongqing University of Posts and Telecommunications, China. He was a visiting scholar in Telecommunications and IT Research Institute (TITR), University of Wollongong, Australia, from November 2007 to November 2008. His research interests include sensor network, traffic engineer, network optimization and WiMAX.
Email: shangfj@cqupt.edu.cn. Tel: +86 13752871911
Dr. Shang has authored/co- authored one book (research monograph) and over 40 scientific papers (22 indexed by SCI/EI Compendex). His Research Interests include sensor network, traffic engineer, network optimization and WiMAX.