Energy-saving Routing Algorithm Based on Cluster in WSN

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Abstract

This paper takes the improved threshold formula and cluster radios formulas to choose cluster-heads by considering energy-saving, based on typical clustering routing protocol and optimal cluster-head selection formula. In the forming stage of cluster, the proportionality principle is used to make the distribution of cluster even more reasonable and during the sTable stage of cluster, the member nodes in cluster use TDMA to communicate with the cluster-head node, and cluster-head nodes communicate with base station BS via multi-hop interrupt communication manner. Then it proposed the realization of target tracking based on the energy- saving routing algorithm. Finally, it can be seen in the simulation results that on the behalf of the network lifetime and average energy consumption, energy-saving routing algorithm is more reasonable.

Keywords: Routing protocol, Clustering, TDMA, Target tracking

1. Introduction

The routing protocol in wireless sensor networks is intended to group the data and sent them from the sensor nodes to sink nodes, it should complete two functions: The first is to select the appropriate optimization path; the second is to transmit data along the selected path. Traditional routing protocols rarely consider node energy consumption in the selection of optimal path. However, each wireless sensor network node has limited energy, and the number of them is always huge, so nodes only get part of the topologic information to construct routing. Moreover, considering the strong applied pertinence of wireless sensor networks and data fusion, traditional routing protocols are not adapTable anymore, and it is difficult to design a general routing protocol which is appropriate for wireless sensor networks [1]. Thus extending the network's life as long as possible on the premise of performing data communication function, and avoiding the deterioration of network's connectivity, which is caused by the energy shortage of nodes, via active energy management technology has been an important goal for the design of routing protocol in wireless sensor networks.

Water resources monitoring is a kind of large-scale application of sensor networks, the nodes close to the base station may use more energy on the transmittal of data packets while the nodes on the edge of the network use primary energy on collecting data information, as a result, some of the nodes will become the energy bottlenecks of the whole network owing to the over quick energy consumption. In addition, water resources monitoring requires continuous watch, it put forward a definitely high demand on energy supply for sensor nodes, so selecting an energy-efficient communication mechanism become the key to the monitoring performing successfully[2]. In such a large-scale sensor network, the distance from each node to the base station is over the range of one hop, so a reasonable multi-hop routing mechanism is required. Since the communication energy loss is directly proportioned to square of the destination distance, comparing with other routing protocols, clustering based routing protocol has better resilience and energy efficiency. The basic idea of clustering routing is cutting down the distance and amount of data transfer via fusing and forwarding mechanism of pertinent information which is adopted by cluster-head to respond for other nodes in cluster, then reducing the communication energy consumption, and ultimately extending the lifetime of network.

In this paper, the proposed routing protocol in wireless sensor is characterized as follow:

1) Current developed routing protocols are all based on that there is no sleep scheduling mechanism, so the performance of MAC layer sleep scheduling mechanism on routing layer is propitious to the coordination of real-time performance and energy-saving performance.
2) Combining minimum energy routing protocol with hierarchical routing protocol, a clustering routing protocol with energy-aware consciousness is presented.
3) A new cluster-head selection method is presented which is aimed at solving the problem that, which is caused by the ignorance of nodes' remaining energy in cluster-head selection, some nodes with low remaining energy are chosen to be the cluster-head in the LEACH protocol, a typical clustering protocol.
4) In LEACH protocol, a typical clustering protocol, to eliminate the uneven distribution of nodes which is caused by random selection of cluster-head in each cluster, an uniform principle in clustering is presented.
5) In Leach protocol, a typical clustering protocol, all cluster-heads communicate with base station by means of single-hop mechanism , Using reasonable multi-hop communication mechanism between cluster-heads to solve the problem that over quick consumption of energy lead to the death of cluster-heads which are far from the base station.

2. Protocol description
2.1 The formation of cluster

The formation of cluster plays an important role in the protocol, and the distribution quality directly determines the lifetime of network. Focusing on unsTable count of cluster-heads, uneven distribution of cluster-heads and uneven distribution of member nodes, this paper presents the underlying mechanism for cluster-head selection [3], Flow chart as shown Figure 1.
(1) Optimal cluster-head selection formula

Supposing that N alive nodes are evenly distributed in an *axa* area, if there are *K* clusters, the average number of nodes per cluster is *N/K*, If there is only one cluster-head in each cluster, the cluster distribution comprises one cluster-head and *N/K-1* member nodes. Energy consumption of cluster-head nodes includes 4 parts:

a) E_{RX}, the energy consumed by cluster-head to receive the data from the inner nodes of cluster,
b) E_{TX1}, the energy consumed by cluster-head to send data to base station,
c) E_{DT}, the energy consumed by cluster-head to fuse data,
d) E_{TX2}, the energy consumed by cluster-head to send data to member nodes in cluster.
e) Based on the consideration of minimum network energy, optimal cluster-head selection formula can be derived:

$$K_{opt} = a\sqrt{\frac{N \cdot \mu_{fs}}{2\pi}} \sqrt{\frac{1}{E_{eRX} + E_{eTX} - \mu_{mp}a^4\left[\frac{28}{45} + C(r) + C(q) + B(r,q)\right]}} \qquad (1)$$

There into : $C(r) = r^4 - 2r^3 + 8/3r^2 - 5/3r$
$C(q) = q^4 - 2q^3 + 8/3q^2 - 5/3q$
$B(r, q) = 2r^2q^2 - 2rq^2 - 2r^2q + 2rq$

From the formula, the number of optimal cluster-heads is only determined by following factors:

a) *a*, the region size of wireless sensor networks,
b) *N,* the number of nodes,
c) μ_{fs} , propagation parameter of the wireless signal when cluster-head communicating with other cluster members,
d) μ_{mp}, propagation parameter of the wireless signal when cluster-head communicating with base station,
e) *(r, q)*, coordinates of base station,

f) E_{eRX}, the energy consumed by cluster-head to receive one bit of data from cluster members,

g) E_{eTX}, the energy consumed by cluster-head to send one bit of data to cluster members.
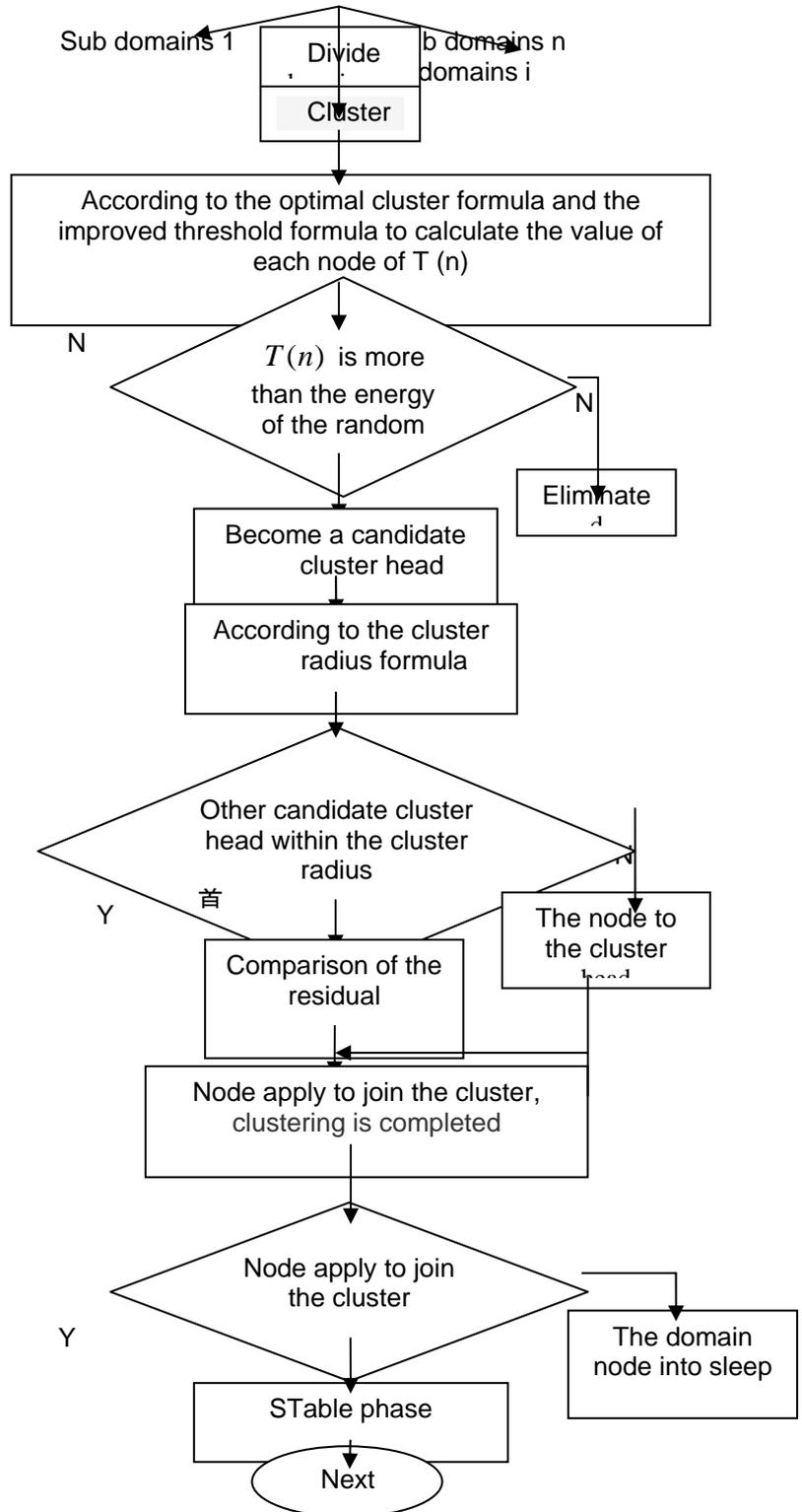
Figure 1. Cluster formation flow chart

(2)   Improvement of threshold formula

Concentrating on the uneven distribution of cluster-heads, this paper divided the entire wireless sensor network into several regions primarily, because of the round sensing range of sensor nodes, sector area can make the structure of the divided small area more uniformed, and the base station can make more efficient control of each region in the sensor networks [4]. Moreover, the sector division is convenient for the establishment of multi-hop routing mechanisms between cluster-heads, and also can optimize the topologic control of the network, while traditional rectangular partition does not have such an advantage on balancing the energy distribution.

Considering topological characteristics of the network, the minimum area which contains all sensor nodes is a circle region, the centre is base station and the radius is the distance R from base station to the farthest node. Dividing the whole sector into m parts equally and marking them from Z0 to Zm orderly, each sector is an independent region. After that, the base station broadcasts the regional information to every sensor node, and each of them registers its own, then TEEN protocol runs independently in each region.

TEEN protocol uses the same multi-clusters structure and running mode with LEACH protocol, a node ignores its current energy when competing for cluster-head [5]. So in order to avoid the node at low energy level being the cluster-head and make the energy distribution of the entire network more uniform, in this paper, we propose an energy self-adjust cluster-head selection mechanism. During each course of cluster restructure, nodes will check their remaining energy level primarily, and nodes can join the competition only when energy is abundant. Therefore, in TEEN protocol, taking average energy of network and remaining energy of nodes into account in cluster-head selection threshold formula, we can get a new threshold formula:

$$T(n) = \frac{K_{opt}}{N - K_{opt} \times [r \bmod (N/K_{opt})]} \frac{E_{res} - E_{ave}\theta}{|E_{res} - E_{ave}\theta|} \frac{E_{res}}{E_{ave}} \tag{2}$$

In the formula, in order to confirm that nodes can be selected to be the cluster-heads as many as possible, θ that ranged from 0.8 to 1.2 is defined by system and, E_{res} stands for the current remaining energy of a node, E_{ave} stands for the average energy of network.

From the new threshold formula, we can obtain that when a node competes for the cluster-head, threshold is associate with the remaining energy of the node and the average energy of network. Thus $T(n)$ is not the consistent value of all nodes. At the beginning of each course, a node gives a random number that ranged from 0 to 1, and compares it with $T(n)$, if the random number is smaller than $T(n)$, this node is selected to be the cluster-head, if not, it cannot be cluster-head.

From the formula we also can acquire that when the remaining energy E_{res} is smaller than $E_{ave}\theta$, $T(n)$ is negative or 0, and the node cannot be cluster-head whereas $T(n)$ is positive, the node may be selected. This confirms that the energy of cluster-head nodes in network is as much as possible.

Furthermore, among all the qualified nodes which can be cluster-head, we also concerned about the remaining energy of nodes, through limiting the value of $\frac{E_{res}}{E_{ave}}$, we can make remaining energy of a node more than network's average energy and as a result the node will achieve more probability to be the cluster-head, or the probability of the node will be reduced in cluster-head competition.

Through the calculation and analysis above, we can acquire the candidate nodes, which can be cluster-head, of each sector region. On the assumption that d is the distance from candidate cluster-head nodes to base station BS, according to the cluster radius formula [6],

$$R_c = [1 - c\frac{d_{\max} - d(s_i, BS)}{d_{\max} - d_{\min}}]R_c^0$$

(3)

$d_{\max}$ stands for maximum distance to the base station, $d_{\min}$ stands for minimum distance to the base station; $d(s_i, BS)$ stands for the distance from cluster-head s_i to base station BS, c is a parameter that controls value that ranged from 0 to 1. From the formula, we can conclude that the node is closer to BS, R_c will be smaller; the node is farther to BS, R_c will be greater.

After R_c is determined, each candidate node s_i broadcasts cluster-competing news to the nodes within R_{ci}, if there is no other candidate, the node will be the cluster-head and broadcast the winning message to the whole network. But if there are other candidates, comparing the remaining energy of them, the node with more energy will be the winner and then broadcast the winning massage to the whole network while others will withdraw from the competition.

Ultimately, the cluster-head of each sector region can be determined.

2.2 The forming stage of cluster

In each sector region, each node may receive messages from different cluster-heads, by comparing the first two cluster-heads, I and J, which have the highest signal strength, suppose the strength of I is greater than J, SignalI>SignalJ. NI stands for the number of member nodes in cluster I, NJ stands for the number of member nodes in cluster J. dBS(I) stands for the distance from cluster-head I to base station, dBS(J) stands for the distance from cluster-head J to base station. Depending on the proportionality principle to choose which cluster to join, and the proportionality principle is presented as follow:

Node, i, can join the cluster belonging to its region, or the cluster from a different region as well, it depends on clusters themselves, optimum conditions owner is preferred.

If $\frac{Signal_I}{Signal_J} \geq \varepsilon$, node i choose cluster I; or turn to 2.

If $|N_I - N_J| \geq \lambda$, node i choose the smaller one by comparing N_I with N_J ; or turn to 3.

If $d_{BS}(I) - d_{BS}(J) \geq 0$, node i choose cluster I, otherwise, choose cluster J, namely, choose the cluster-head which is farther from base station, ε and λ are control parameters.

After selecting all sub-domain cluster head, cluster head sends a broadcast notification message of become cluster head to other nodes, and the remaining nodes decided to join the cluster according to the principle of proportionality, and send the application message to cluster head. After the formation of a sub-domain cluster, the other sub-domain has not been completed cluster formation, then all the nodes in the sub-domain which has completed cluster formation go into hibernation, waiting for the other sub-domain cluster formation. According to the characteristics of the regional division, it can be inferred that the innermost sub-domains complete the cluster formation firstly ,and the outermost sub-domain complete the finalization. When the last one is completed, the nodes wake up in the other sub-domain and go into the sTable phase of the cluster. After a certain period of time, the next round of cluster head selection is begin.

2.3 The sTable stage of cluster

In this way, the attributive problem of the cluster-head and other nodes in each sector has been solved, the underlying nodes send their own ID, the distance from cluster-head and the remaining energy information to their cluster-heads, after cluster-head received the information of all nodes, it calculates the average remaining energy E_{ave} in cluster and use LMAC protocol of TDMA to assign control timeslots to every node, TABLE 1 is the timeslot control Table and in this Table , hard threshold and soft threshold are two parameters applied in

data fusion in TEEN protocol [7]. TDMA is a simple and mature mechanism which can realize the allocation of channel, it assigns a independent timeslot to each node for sending or receiving data, while nodes in other timeslot is sleeping, this kind of mechanism satisfies the demand of energy-saving in sensor networks, because there is no collision and retransmission problem of competitive mechanism, data transmission does not require too much control information, besides, nodes can save energy in idle timeslots, so running sleep scheduling mechanism of MAC on routing layer like this is benefit to the coordination of real-time performance and energy-saving performance.

Table 1. Time slot control of LMAC protocol

Description	Length (BYTE)
Node ID	2
Time slot occupancy information	4
The distance from cluster-head	1
Data length	1
Hard threshold	1
Soft threshold	1
Average remaining energy	11
Total	

A normal node sends a piece of news to cluster-head at the beginning of its timeslot primarily to determine whether it is necessary to collect the data of the point. If it is not necessary, close the node sender immediately, and this will further reduce the energy consumption of normal nodes [8]. After cluster-head finishes receiving all data from nodes in cluster, receiver can be turned off and data can be processed, then the processed data will be sent to the base station BS through multi-hop or single-hop manner.

The entire sector region is a multi-ringed communication region which takes the base station BS as the center, each cluster-head locates on different annuluses , the specific control algorithm is shown in Figure I, Consider the outermost annulus is k, as close to the center, there are $(k-1)$ annuluses which are numbered from $k-1$ to 1, and base station is on the annulus 0. When k is even, the data on annuluses from $k/2+1$ to k is sent dividedly to the annuluses from 1 to $k/2$, then to the base station. When k is odd, the data on annuluses from $(k+3)/2$ to k is sent separately to the annuluses from 2 to $(k+1)/2$, and then send to base station directly, the data on the annulus $(k+1)/2$ is relayed to the base station BS through annulus 1.

K=7   K=8
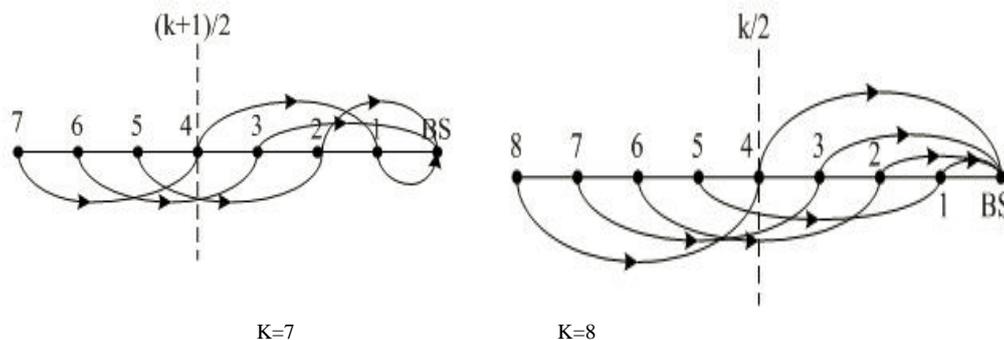
Figure 2 . Multi-hop interrupt communication manner based on dichotomy

The data processing mentioned above is mainly about that cluster-heads fuse the data from several nodes to reduce information redundancy and cut down the amount of data transmission, finally save energy. TEEN protocol, which runs in each sector region independently, is the improvement of LEACH protocol, just like the directed diffusion routing, it uses inhibition mechanism to restrain the unnecessary transmission of data; but the application of threshold setting makes the inhibition more flexible, and it can further decrease the amount of data in the course of data fusion [9]. Hard threshold is a threshold that cannot be exceeded by the monitored data, soft threshold determines the range of monitored data. During the clusters' sTable working stage, nodes constantly sense the conditions around. When monitoring the data

exceeded the hard threshold first time, open the sending and receiving unit to forward data to the cluster-head, and store the monitored data as monitoring value simultaneously. After that, only when the quantity of monitored data is greater than hard threshold and the absolute value of the difference, which is acquired by monitoring value is subtracted from the quantity of monitored data, is not smaller than soft threshold, the node will report the data to cluster-head, and store the current monitored value as monitoring value. If a new series of cluster-heads have been identified, the cluster-head nodes will reset and issue the two threshold parameters through the timeslot control Table.

After data fusing, cluster-head nodes adopt multi-hop interrupt communication manner, which is based on dichotomy, to send data to the base station BS, this can lighten the communication burden on nodes near the base station, and make the network traffic distribution more evenly, synchronously, make a combined application of binary power control algorithm and TDMA protocol to avoid the interference from near annulus, namely, only the cluster-head nodes on receiving annulus and sending annulus work in each timeslot, while others stay in dormancy [10].

3. Target tracking technology based on the energy-saving routing algorithm

The structure of tracking cluster changes when the target moves or the environment changes. The goal of dynamic clustering is to reduce the probability of the loss detection of target, maintain the continuity of detecting area. In order to achieve this goal, the strategy of tracking cluster remodeling should be taken into consideration.

The chose of cluster head should adhere to the principle of: maximum energy and shortest distance. When the target moves to the critical position of the detection area, the cluster head will notify the node with highest RSSI in the cluster to wake up the nodes within the area of a circle that takes the expected target position as centre, the distance less than the detection range as radius[11]. Notify those nodes in the wait state, when a node detects the position of the target, it will report to the cluster head. As soon as the cluster head find the members of the cluster changes, it will hand over its power, the whole cluster will be reestablished, new cluster head and new members will be selected.

 (1) The process of dynamic clustering

The specific procedures of dynamic clustering are:

Step 1: when the target enters the WSN detection area, all the nodes whose RSSI higher than the threshold R_{thread}, usually the number will be 6, begin to record the time and the signal intensity when the target enter its detecting area, and according to the optimal cluster head formula and the improved threshold value formula to chose as the cluster head. The other five nodes will be the member of the cluster.

Step 2: the members of tracking cluster will apply the method of particle filter algorithm to estimate target's state, and to predict the target's location of the next moment, the cluster head then locate the target according to the information uploaded by the cluster members, It will continue the tracking if the target still within the cluster detecting distance, Otherwise, calculate the position of all nodes that can detect the target; compare the results to the node members of the cluster right now, wake up the node with higher energy and turn the nodes into dormancy if its energy lower than R_{thread} or it is out of the detecting area.

Step 3: When the target moves to the critical position of the detection area, the cluster head will notify the node with highest RSSI in the cluster to wake up the nodes within the area of a circle that takes the expected target position as centre, the distance less than the detection range as radius. Notify those nodes in the wait state, when a close node detected the emergence of the target; it will wake up the six nodes around to detect.

Step 4: At this point, the nodes formed a new cluster, select its own cluster head and members, turn the nodes that can't detect the target into the state of dormant. Re-establish the cluster. After that, the new cluster head will summary the information of the target. The original cluster head will still be active, reporting the information monitored to the Sink node.

Step 5: The process of dynamic clustering mentioned above repeat again and again as the target moves, until it is out of the detecting area. Under the premise of ensuring the tracking accuracy, by adopting the dynamic clustering method based on sleep / wake-up mechanism, it

can efficiently reduce the redundant nodes, down the communication cost and improve the reliability of the system and extend the network life span.

(2) The implementation of algorithm

The implementation of algorithm CTTDC (Collaborative Target Tracking based Dynamic Cluster) will be as follows:

The target step into the detection region at the initial time, wake up the first cluster $(CH_1, m_1, m_2, \cdots, m_c)$ around the target according to the prior information, CH_1 denotes the head of the first cluster. There are $c+1$ members in the cluster; the cluster head CH_1 get the first set of particle $\{x_0^i, w_0^i\}$ from the initial distribution state.

4. Simulation

This article assumes that 200 nodes are randomly distributed in the 100x100 range. Matlab simulation parameter settings: node initial energy is 4*J*, the cluster head probability is 0.05. The signal strength of the two cluster head in the principle of proportionality ratio is 1.5, the margin between two members of the cluster head is 5. Each packet size is 50*bit*, energy of each node to receive or transmit data is 50*Nj/bit*.

The quality of a routing protocol algorithm in wireless sensor networks is measured by network lifetime and average energy consumption. The following is to do the simulation comparison between the most classic clustering protocol LEACH protocol and the proposed energy efficient routing protocol algorithm.

From the simulation results, it can be seen that on the behalf of the network lifetime and average energy consumption, energy efficient routing algorithm proposed in this paper are better than LEACH protocol, indicating that this algorithm is more reasonable, reducing energy consumption and balancing energy to some extent.
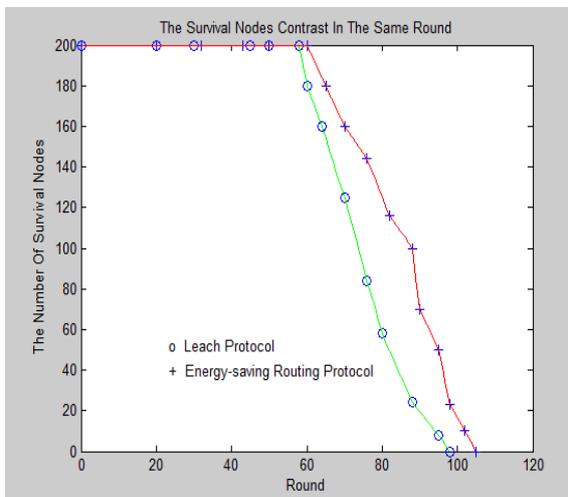
Figure 3. The survival nodes contrast in the same round
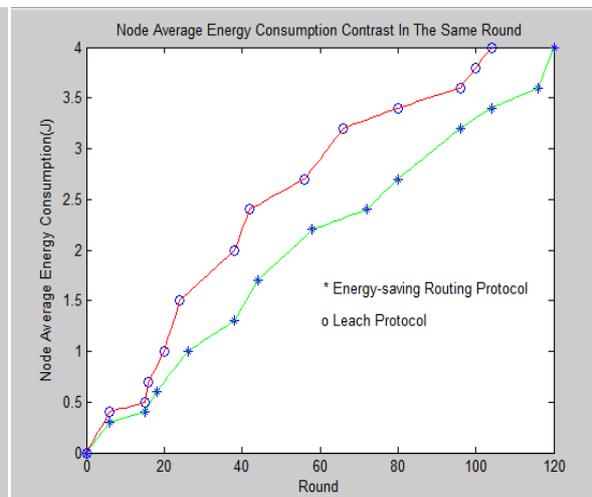
Figure 4. Node average energy consumption contrast in the same round

5. Conclusion

This paper takes energy-saving into consideration, bases on typical clustering routing protocol, combines with the optimal cluster-head selection formula, the improved threshold formula and cluster radios formulas to choose cluster-heads. What' more, the optimal cluster-head selection formula considered the energy factors of cluster-heads and cluster members, so the number of cluster-heads is steady and the distribution is more even; the improved threshold formula adds extra factors, the average energy of the network and remaining energy of nodes, to eliminate the cluster-head candidate nodes on low energy level; cluster radius formulas make the distribution of cluster-head nodes more reasonable, avoid the superposition of coverage

range of each cluster-head, apply the proportionality principle to the forming stage of cluster, make the distribution of cluster more even and reasonable; during the sTable stage of cluster, the member nodes in cluster use time sharing multiplexing to communicate with the cluster-head node, and cluster-head nodes communicate with base station BS via multi-hop interrupt communication manner which is based on dichotomy after data fusion, avoid the over burden of cluster-heads near base station with the application of single-hop communication manner.

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