World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:4, No:1, 2010

A Study of Dynamic Clustering Method to Extend the Lifetime of Wireless Sensor Network

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***Abstract*—**In recent years, the research in wireless sensor network has increased steadily, and many studies were focusing on reducing energy consumption of sensor nodes to extend their lifetimes. In this paper, the issue of energy consumption is investigated and two adaptive mechanisms are proposed to extend the network lifetime. This study uses high-energy-first scheme to determine cluster heads for data transmission. Thus, energy consumption in each cluster is balanced and network lifetime can be extended. In addition, this study uses cluster merging and dynamic routing mechanisms to further reduce energy consumption during data transmission. The simulation results show that the proposed method can effectively extend the lifetime of wireless sensor network, and it is suitable for different base station locations.

***Keywords*—**Wireless sensor network, high-energy-first scheme, adaptive mechanisms, network lifetime

I. Introduction

With the advance of microelectronic system, wireless communication, and embedded processing technology, a small electronic device can combine delicate sensors as well as computation and communication functions in one piece. This kind of device not only can detect environmental changes such as temperature and humidity but also can analyze the collected data and send them back to the base station through wireless network. There have been many applications in wireless sensor network, started from military requirement for controlling and monitoring battle fields. Now these devices can be applied to commercial applications such as factory manufacturing flow control, home appliance automation, traffic controls, and medical equipment coordination [1][2].

These applications have great potentials and prospects, but it is not without any drawbacks, which remain to be conquered. When the device was first introduced, the major concerns were cost, size, and energy consumption, and thus their computing power, memory and power capability were limited. The distance of transmission also affects the overall energy consumption, and it is another factor to be considered.

A few studies were conducted to reduce energy consumption by routing methods [3][4]. Usually, the sensor devices are scattered outdoors with limited power supply and exposed to different weather conditions, and their energy consumption depends heavily on the network interconnection topology. For example, when these devices are deployed onto a farm to monitor crops, energy consumption has become an important factor due to the large number of devices. Our research is on network topology in such environments with its lifetime in relation to energy consumption.

In general, wireless sensor data can be transmitted in two ways: direct transmission, or lowest-energy-first transmission [5]. The former sends data to base station directly for further processing, and the latter sends data by forwarding to some other nodes in the direction to base station. Each method has its merit depending on applications and structural difference of the networks. From the viewpoint of network topology, the data transmission can also be classified into general topology and cluster topology.

LEACH [6] is a classic routing protocols for clustered wireless sensor network because it can balance energy consumption within a cluster, and hence extend the network lifetime. Its operation contains two stages: initial stage and stable stage. In the initial stage, base station selects a few nodes as cluster heads based on random thresholds. All other nodes join its nearby cluster by sending out signals and discover its closest cluster head. When clusters are formed, the network goes into a stable stage. Each node starts to collect and send data to cluster head, and cluster heads forward these data to base station along with their own collected data.

PEGASIS [7] works by connecting nodes in series, starting from the farthest node to base station, to form a linked structure with its neighboring nodes. When all nodes are connected, the head of link structure will be selected, and data transmission starts towards the head. Every node will combine both received data and its own data. When all data arrive at the head, it will be forwarded to the base station.

In the clustered network with heterogeneous devices, each cluster head is better equipped than a regular node, including power supply, computing capability, memory, and even with data compression capability. Its major purpose is to reduce energy consumption of regular nodes by preventing them from sending data over long distance. This type of network is not concerned in this study because it can not tolerate the failure of cluster heads. Also it is inherently more expensive compared to a homogeneous network.

In a wireless sensor network, a small-range environment will make it easier to supply power, so there is almost no need for power saving design. Our research is for a wide range wireless network environment [8] where direct data transmission from

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regular nodes to the base station is not possible. Thus, saving power by efficient routing is of great importance.

This study is based on LEACH's network structure, improved by the high-energy-first scheme [9] to form a dynamic routing method. This study uses *data aggregation* [10] and *sleep mode* [11][12] methods to reduce energy consumption, and uses adaptive mechanisms to save energy during data transmission for extending network lifetime.

II. System Model

In this study, a wireless sensor network is divided into several clusters of the same size. Each cluster will select a cluster head to collect and forward data for the other nodes in this cluster. The high-energy-first scheme is used to determine the cluster head and its purpose is to have all nodes to play the role of cluster head in turn to balance energy consumption. When the system starts its operation, regular nodes send out collected data to the cluster head, and then the cluster head forwards data to the base station through its neighboring cluster heads using the dynamic routing mechanism to save energy (Fig. 1).

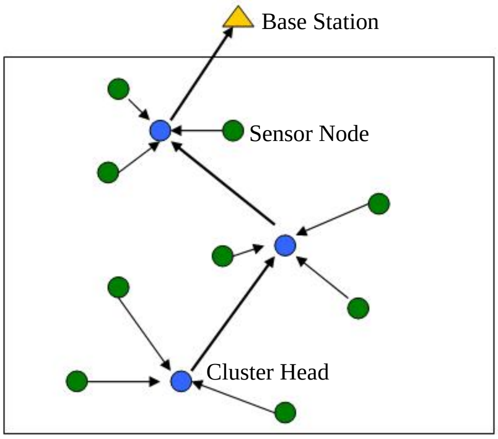

Fig. 1 A clustered wireless sensor network

In the following, the sensor devices and associated protocols for wireless sensor network are introduced. Then, the energy consumption for each regular node and cluster head is analyzed.

A. Wireless Sensor Devices

A wireless sensor network consists of sensor components, microelectronic systems and a wireless network. These devices contain four basic units: power supply unit, central processing unit, data communication unit, and sensor component (Fig. 2), altogether form an embedded system. With the advance of the microelectronics, a low-power sensor with small size has become more affordable nowadays. Therefore, it is an important issue to reduce energy consumption by the deployment of sensor devices and efficient routing protocols.

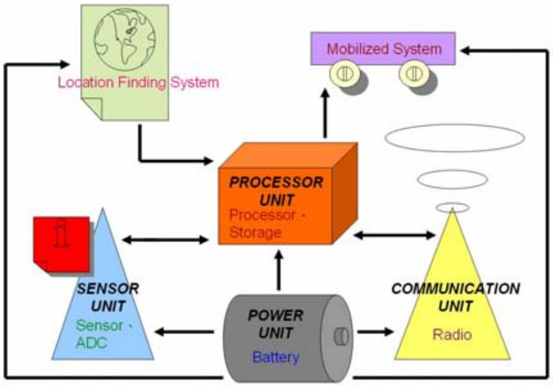

Fig 2. The basic units of a sensor device

For the selection of wireless communication protocols, the compatibility and market acceptance are the major issues for consideration. In home automation, IEEE 802.15.4 (Low-Rate Wireless Personal Area Network) combines ZigBee's standard [13] as the base for development (Fig. 3) and has become the most popular protocol for many manufacturers.

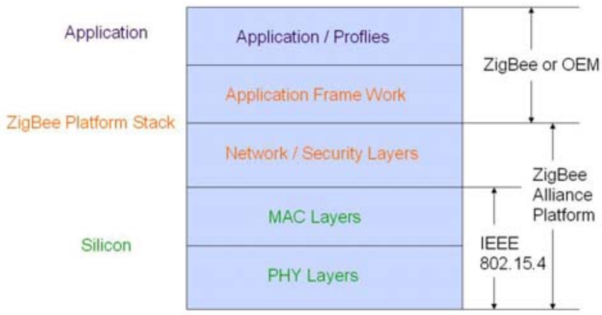

Fig 3. Combination of IEEE 802.15.4 and ZigBee protocols

B. Energy Consumption Analysis

Since routing protocols play an important role in saving the energy of wireless sensor network, the objective of this study is to extend the lifetime of wireless sensor network by using a dynamic routing mechanism. In order to evaluate the lifetime of a wireless sensor network, it is required to analyze the energy consumption of a cluster head and a regular node. The parameters related to energy consumption in sensor nodes [14] are listed in table I.

TABLE I
THE PARAMETERS OF ENERGY CONSUMPTION IN SENSOR NODES

n: number of nodes per cluster	ℓ_a : data amount after aggregation
f : data records received from neighboring clusters	E_a : Energy consumption in data aggregation
ε: amplifier consumption	d_{cc} : distance between cluster heads
E_t : energy in transmission	d_{nc} : distance between cluster head and regular node
E_r : energy in receiving	E_h : Energy consumption in deciding cluster head
ℓ : data amount	x: data records per round

In a wireless communication system, the energy loss of a signal is related to its transmission distance [15]. Equation (1) shows the energy consumed when passing through an amplifier. Using d_0 as a threshold, when transmission distance is smaller than d_0, a *free-space propagation model* is used to calculate the consumed energy, which is proportional to the square of distance; when transmission distance is greater than d_0, the *two-ray ground propagation model* is used for calculation and the consumed energy is proportional to the fourth power of distance. In that case, the consumed energy has great influence on the wireless communication system.

$$\text{Energy consumption by amplifier} = \begin{cases} \varepsilon_{fs} \times d^2, \text{ if } d \le d_0 \\ \varepsilon_{tr} \times d^4, \text{ if } d > d_0 \end{cases} \quad (1)$$

In the above equation, ε_{fs} and ε_{tr} are the parameters for the *free-space propagation model* and *two-ray ground propagation model* with their values equal to 10 pJ/bit/m^2 and 0.0013 pJ/bit/m^4, respectively; d_0, defined as $\sqrt{\varepsilon_{fs}/\varepsilon_{tr}}$, is the threshold of transmission distance and its value is about 87.7. Considering the effect of transmission distance, it is assumed that the largest area for a cluster is 70m×70m when dividing the clusters. In that case, cluster heads performing data forwarding will not consume too much energy even if they are diagonally placed, i.e., d_0 is less than 100m.

For regular nodes, the computation of consumed energy E_{sn} is simpler because the transmission distance will not exceed 100 m, as shown in equation (2). When an adaptive mechanism is applied to merge clusters, the cluster size may increase and the energy consumption will become proportional to the fourth power of transmission distance.

$$E_{sn} = (\ell \times E_t) + (\ell \times \varepsilon \times d_{nc}^{\ 2}) + E_h \quad (2)$$

The energy consumed by cluster heads consists of two portions: energy consumption for transmitting local data and energy consumption for forwarding received data from regular nodes. The energy consumed in deciding cluster heads is negligible because receiving signals from base station dose not require much energy; detecting forwarding node also requires small amount of energy and thus can be neglected. This study considers mainly the energy consumption in sending, receiving, and data aggregation of sensor device. Especially, the distance of transmission is an important factor.

Equation (3) shows the energy consumption of cluster head E_{ch}. Inside the first pair of parentheses is the energy consumption for data aggregation and forwarding; inside the remaining part is the energy consumption for a cluster head to forward x records of data for other nodes.

$$\begin{aligned} E_{ch} = &\left\{ [\ell \times E_r \times (n\text{-}1)] + [\ell \times E_t \times n] + [\ell \times \varepsilon \times n \times d_{cc}^{\ 2}] + [\ell \times E_{data} \times n] + E_h \right\} + \\ & x \times \left\{ [\ell_{data} \times E_r \times f] + [\ell_{data} \times E_t \times f] + [\ell_{data} \times \varepsilon \times f \times d_{cc}^{\ 2}] + E_h \right\} \quad (3) \end{aligned}$$

III. Routing Algorithm

In this study, the dynamic routing method consists of two stages: initialization stage and operating stage. The initialization stage includes dividing clusters and distribution of sensor nodes. The operating stage includes: data reception, collection, and transmission. Our method divides the environment into a number of smaller areas (35m×35m) for the distribution of sensor nodes. Each square area is distributed with 5 sensor nodes and their positions are determined by a pseudo random number generator to simulate real situations in deployment. During operating stage, the base station uses high-energy-first scheme to select cluster heads, and then determine neighboring nodes for transmitting data. In each cluster, our method uses *data aggregation* and *sleep mode* to reduce energy consumption. In addition, *cluster merging* and *dynamic routing* mechanisms can also be applied to save energy during data transmission. Fig. 4 shows the flowchart of each working stage.

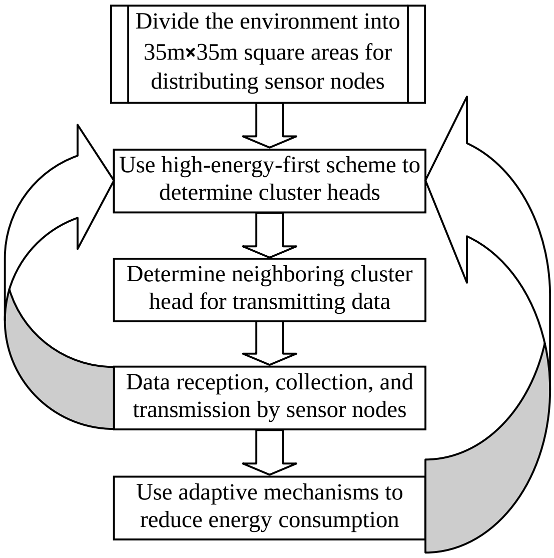

Fig. 4 The flowchart of dynamic routing method

A. High-Energy-First Scheme

In LEACH, a sensor node with a longer time as a regular node has a higher probability to be selected as the cluster head. Although this may initially seem reasonable, a recently retired cluster head still has a chance to be selected, which may lead to quick exhaustion of its electric power. Therefore, this study adopts the high-energy-first scheme to remedy this drawback. A sensor node will send out data together with the status of its remaining electric power. The base station can then decide which nodes are to be assigned as cluster heads in the next round using broadcast messages.

B. Neighbor Locating Method

In each round, a cluster head has to use neighbor locating method to determine forwarding node in neighboring clusters. The neighbor locating method is based on the angle between the directions of base station and candidate forwarding node. The neighboring cluster head with the smallest angle is chosen as the forwarding node. The purpose of this method is to choose the shortest transmission route to reduce energy consumption during data forwarding. For example, cluster head ***A*** in Fig. 5 will select node 1 as forwarding node, unless its remaining electric power is lower than the threshold value. If node 1 is not available, node 4 will be selected next. This method can avoid long-distance transmission to save electric power by choosing the shortest route for forwarding data.

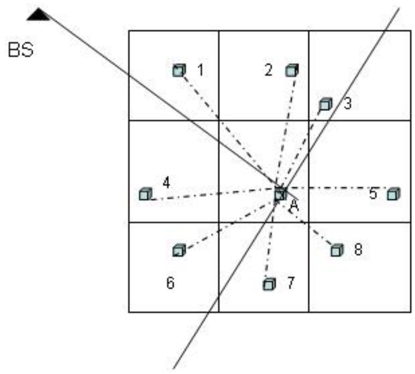

Fig. 5 Locating forwarding node in neighboring clusters

C. Data Aggregation and Sleep Mode

In wireless sensor network, the amount of data transferred can also affect the energy consumption. When a cluster head detects the same or similar data packets are being transmitted, it can use data compression method [13] to filter out similar data packets. This method can reduce the amount of data transferred, and therefore save some electric power.

Sleep mode can also achieve energy saving in wireless sensor network effectively [14][15]. In this study, a grouping method is used to divide sensor nodes into groups in a cluster. The following example (Fig. 6) shows how to divide sensor nodes into groups for the execution of sleep mode.

1. Select the cluster head (node 1).
2. Combine two nodes with the shortest distance as a group (node 3 and node 4)
3. The rest two nodes form the other group (node 1 and node 2).

In each group, the node with higher electric power is selected as the operating node, and the other node goes into sleep mode. For example, node 1 and node 3 are in operation while node 2 and node 4 are sleeping. The cluster head node 1, the only node in its cluster, is also in operation.

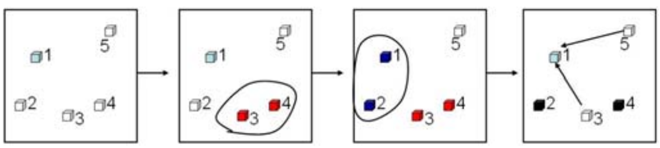

Fig. 6 The grouping method and execution of sleep mode

The main objective of grouping method is to evenly distribute operating nodes in each cluster to reduce data repetition. The purpose of sleep mode is to decrease the amount of transferred data. The ratio of sleeping nodes and group size can be adjusted according to the operating requirement.

D. Operation Flowchart

In this study, it is assumed that all sensor nodes, including cluster heads, are homogeneous, so they all have the same electric power. However, the functions of cluster heads and regular nodes are different depending on the assigned tasks, so the energy consumption can also be different. At the beginning of each round, every node will be notified of its role to play, and start to sense the environment no matter what the role is. A regular node will transfer the obtained data to its cluster head upon completion of sensing, and then go into idle state. A cluster head will send out the collected data within its cluster to the forwarding node; in the mean time, it can also receive and forward data for other cluster heads. In order to preserve partial electric power for sensing tasks, the cluster head can refuse forwarding data for other clusters if the remaining electric power is below the threshold value.

E. Adaptive Mechanisms

There are two adaptive mechanisms proposed in this study for reducing energy consumption, i.e., cluster merging and dynamic routing. The purpose of the adaptive mechanisms is to change network topology (or cluster size) and routing direction to extend network lifetime.

1. Cluster Merging

The goal of cluster merging is to increase the number of sensor nodes in a cluster to share the workload of cluster head by merging neighboring clusters into a larger cluster. When the remaining electric power of a cluster head is below the preset threshold, the cluster merging process is invoked to combine four adjacent clusters (35m×35m) into a larger cluster (70m×70m). The number of nodes in the merged cluster has increased and the network lifetime can be extended because more nodes have joined to share the workload of cluster head.

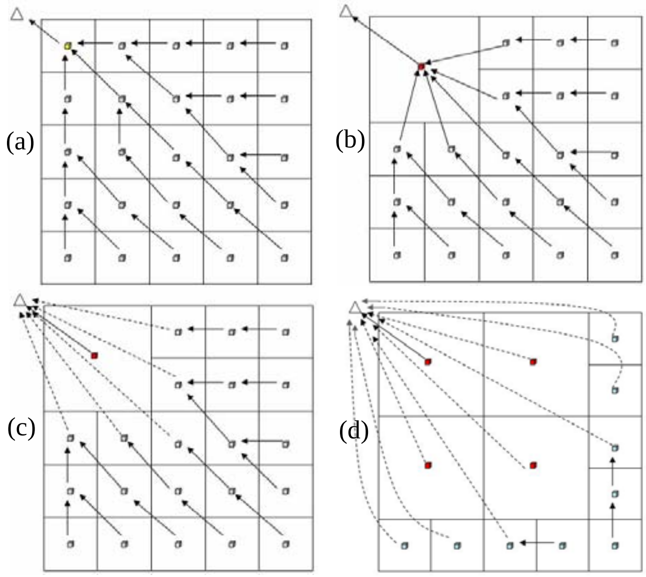

Fig. 7 The operation of cluster merging mechanism

The following example shows the cluster merging process (Fig. 7). Initially, all cluster heads have enough electric power to transmit data to the base station (Fig. 7-a). As the time progresses, the electric power of a cluster head drops below the threshold, which invokes the cluster merging process. After that, there are more nodes with sufficient electric power to share the workload of cluster head to avoid the situation of dead cluster (Fig. 7-b).

After several rounds, the electric power of sensor nodes in the merged cluster may drop below the threshold again due to its continued workload. At this point of time, the cluster head will stop forwarding data for other clusters. When the neighboring cluster heads detect this situation, they start transmitting data to base station directly if the distance is within the transmission range. The non-forwarding cluster head only need to use the remaining electric power to transmit data for its own cluster (Fig. 7-c), and thus reduce energy consumption by forwarding data for other cluster heads. The cluster merging process continues as required and the network lifetime extends as a result of balanced energy consumption (Fig. 7-d).

2. Dynamic Routing

As described earlier in this section, a cluster head decides its forwarding node by neighbor locating method, and the goal is to find the shortest route in forwarding data to reduce energy consumption. However, the neighboring cluster heads may refuse to forward data due to insufficient electric power. In that case, the cluster head initiates the *dynamic routing process* to forward data by a feasible route when its forwarding request is declined by other cluster heads.

As shown in Fig. 5, cluster head ***A*** selects node 1 as its forwarding node initially, but is declined due to low electric power; it then selects the node with the second smallest angle, i.e., node 4, but is declined again. Then, it selects the node with the third smallest angle, i.e., node 2, but still in vain. The process continues until there are no forwarding nodes in the direction of base station for selection. After that, the cluster head try to transmit data to base station directly if it is within the reachable range. Otherwise, it will turn to request nodes in the direction greater than 90 degree as a last resort.

When a cluster head has to request a forwarding node deviating from the direction of the base station, it means most nodes in the preferred direction are in low-power conditions. Instead of giving up at this moment, the cluster head tries it best by using a detoured route to send out data since the goal is to maintain a high receiving ratio by the base station.

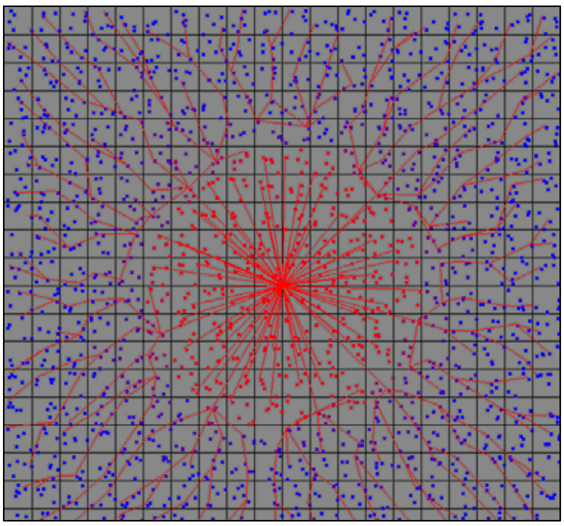

Fig. 8 The final situation of dynamic routing process

Fig. 8 shows the final situation of dynamic routing process when most inner cluster heads refuse to forward data for the outer cluster heads. The inner cluster heads still reserve some electric power which can be used to send data directly to the base station. In the mean while, the outer cluster heads try to find some alternative routes for sending data.

IV. Simulation and Experimental result

The goal of this study is to investigate the dynamic routing method for the reduction of energy consumption in wireless sensor network. This study adopts data aggregation and sleep mode for reducing data amount, and proposes cluster merging and dynamic routing mechanisms for saving energy to extend network lifetime. A simulation experiment is conducted to find out the optimal threshold values for applying cluster merging and dynamic routing mechanisms. Other related issues such as suitable locations for the base station and the proper order for applying these two adaptive mechanisms.

The simulation is performed on a VB.NET platform. The size of simulated environment is 700m×700m and there are 2000 sensor nodes distributed in this area. The environment is divided into 400 smaller areas of size 35m×35m and each smaller area contains 5 sensor nodes. The longest transmission distance for a senor node is 200m, and the transmitting and receiving energy consumption are the same, both equal to 50nJ/bit. Each data aggregation takes 5nJ/bit with compress rate equal to 70%. The parameters for transmitting amplifier is ε_{fs} =10 pJ/bit/m^2 , and ε_{tr} =0.0013 pJ/bit/m^4 , respectively. The data rate is assumed to be 160 bit/sec. When the receiving ratio by the base station is below 98% or a dead cluster occurs will result in the failure of wireless sensor network.

A. Location of Base Station

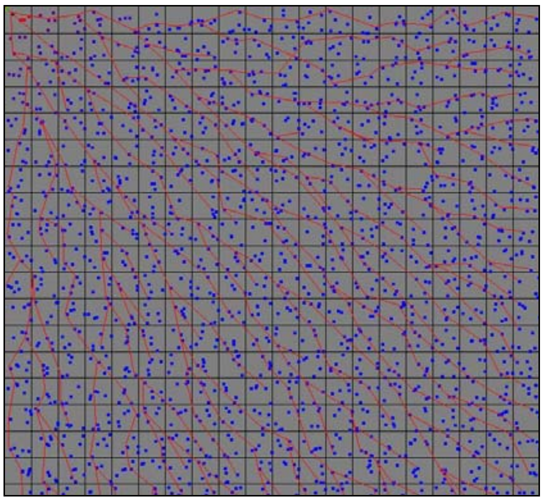

Fig. 9 The location of base station is on the upper left

The location of base station has great influence on the energy consumption. To find out a better location for the base station, an experiment was conducted to compute the energy consumption and lifetime for the same wireless sensor network with three different base station locations: upper left

(Fig. 9), left (Fig. 10), and center (Fig. 11). The simulation did not include the adaptive mechanisms such as dynamic routing or cluster merging, but it compares the results of with or without data aggregation and sleep mode. In these figures, green spots indicate the base station, and red lines represent the forwarding routes. Coloring of nodes is used to represent the status of remaining electric power as follows: blue (sufficient), red (low), black (drained or dead).

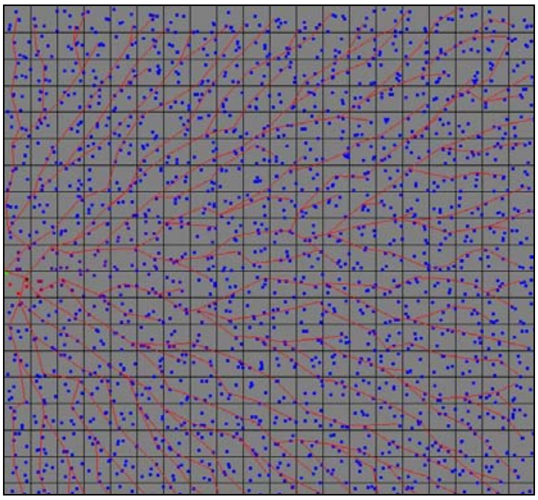

Fig. 10 The location of base station is on the left

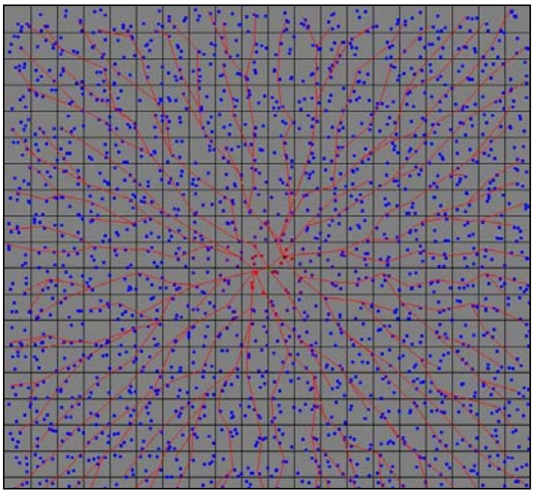

Fig. 11 The location of base station is in the center

As we can see from Table II, the lifetime of the wireless sensor network is longer when the base station is in the center. This is due to balanced energy consumption in the surrounding clusters. In addition, sleep mode and data aggregation can also improve overall network lifetime.

TABLE II
THE LIFETIME (IN ROUNDS) FOR DIFFERENT BASE STATION LOCATIONS

base station location	upper left	left	center
with sleeping mode and data aggressing	1053	1458	2120
without sleeping mode and data aggressing	535	726	1694

B. Order for applying adaptive mechanisms

There are two adaptive mechanisms proposed in this study for extending the network lifetime, i.e., cluster merging and dynamic routing. The order and timing for applying these two mechanisms have great influence on network lifetime. Fig. 12 shows the simulation result of network lifetime with cluster merging followed by dynamic routing. As shown in the figure, the effect of dynamic routing is more significant than that of cluster merging. Besides, the later dynamic routing is applied, the longer the network lifetime will be. The network lifetime without dynamic routing (threshold=0%) is about half that of the network with dynamic routing at threshold=10%.

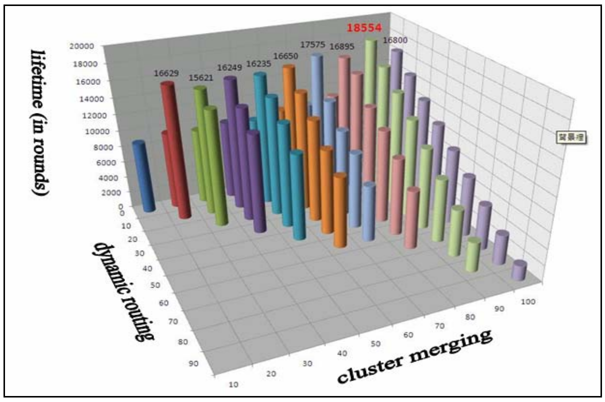

Fig. 12 Lifetime vs. timing (thresholds of electric power) for applying adaptive mechanisms with cluster merging first

Fig. 13 shows the simulation result of network lifetime with dynamic routing followed by cluster merging. If dynamic routing is applied in an early stage, or its threshold is higher, the number of cluster heads refusing to forward data will increase, which results in more clusters not able to send data to the base station. It is worth to note that the network fails at a receiving ratio lower than 98%. Therefore, dynamic routing is better to be applied in a later stage. However, the cluster merging almost has no chance to occur since the network fails at the time when most cluster heads still have electric power higher than threshold value. Therefore, cluster merging can not take place to improve network lifetime when it is applied after dynamic routing.

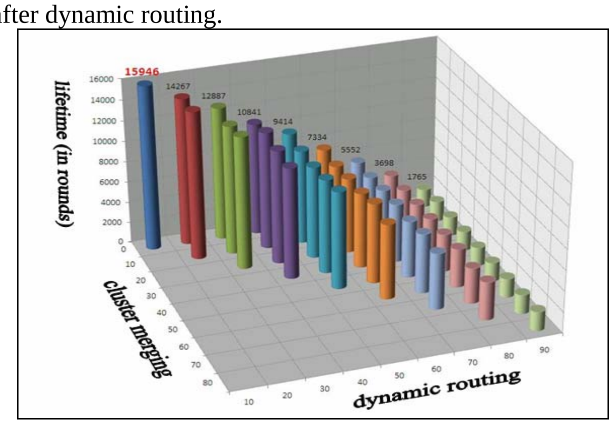

Fig. 13 Lifetime vs. timing (thresholds of electric power) for applying adaptive mechanisms with dynamic routing first

C. Timing for applying adaptive mechanism

The above results have suggested that it is better to apply cluster merging first and then dynamic routing. Table III shows the simulation results of network lifetime with adaptive mechanisms applied at different combinations of threshold values, where x and y stand for the thresholds of electric power (in percentage) to apply cluster merging and dynamic routing, respectively. The network lifetime (in rounds) is computed based on the average of 100 simulations

TABLE III
The result of network lifetime by applying adaptive mechanisms

x	y	Lifetime	x	y	Lifetime	x	y	Lifetime
10	0	8960	60	40	10503	90	20	16323
20	0	9623	60	50	8773	90	30	14282
20	10	16629	70	0	10427	90	40	12254
30	0	9391	70	10	17575	90	50	10102
30	10	15621	70	20	15210	90	60	7861
30	20	14437	70	30	13175	90	70	5788
40	0	9791	70	40	10804	90	80	3651
40	10	16249	70	50	9398	100	0	11203
40	20	14077	70	60	6954	100	10	16800
40	30	12335	80	0	11034	100	20	14808
50	0	9523	80	10	16895	100	30	12839
50	10	16235	80	20	15955	100	40	11060
50	20	14727	80	30	13084	100	50	9244
50	30	12895	80	40	11531	100	60	7353
50	40	10711	80	50	9514	100	70	5510
60	0	10280	80	60	7187	100	80	3650
60	10	16650	80	70	5496	100	90	1825
60	20	14733	90	0	11351			
60	30	12715	90	10	18553			

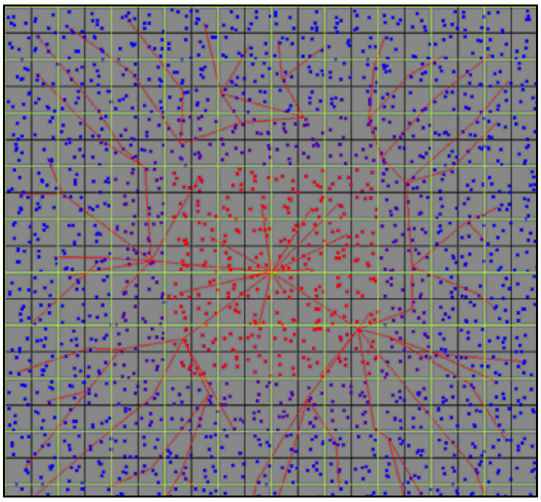

Fig. 14 The case of applying cluster merging at the beginning (x=100%, y=10%, lifetime=16800)

The intent of cluster merging is to increase the number of sensor nodes in a cluster to share the workload of cluster head. The above results have shown that a higher threshold for cluster merging can lead to a longer network lifetime. However, if a larger cluster of the size 70mx70m is used at the beginning, the regular nodes have to consume more energy when sending data to their cluster heads (Fig. 14) and thus the result may not be the optimal. On the other hand, if cluster merging is applied too late, the cluster heads near the base station will use up their energy quickly and become unable to forward data for other clusters (Fig. 15).

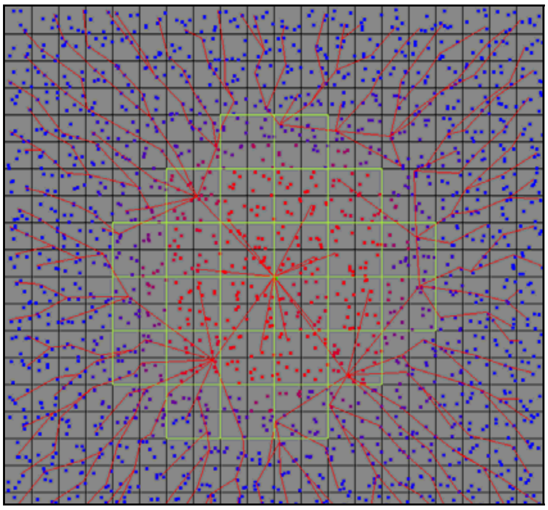

Fig. 15 The case of applying cluster merging in a later stage (x=30%, y=10%, lifetime=15621)

Different from cluster merging, it's better to apply dynamic routing at a later time. However, setting the threshold to 0% (or without applying dynamic routing) is not the best case (Fig. 16). On the other hand, the consequence of applying dynamic routing at an early time may cause more cluster heads to refuse forwarding data for other clusters, which will result in direct transmission with a longer distance or forwarding data using detoured routes and thus consuming more energy. The former can also affect the receiving ratio if the transmission distance is beyond the range of 200m (Fig. 17).

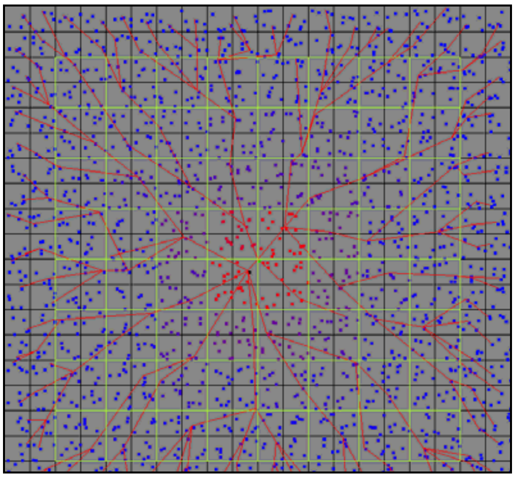

Fig. 16 The case of without using dynamic routing mechanism (x=90%, y=0%, lifetime=11351)

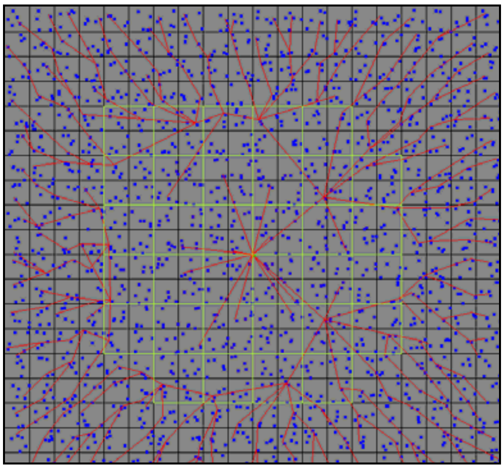

Fig. 17 The case of applying dynamic routing in an early stage (*x*=90%, *y*=80%, lifetime=3651)

The best case for applying adaptive mechanisms is to set the threshold of cluster merging at *x*=90% and the threshold of dynamic routing at *y*=10%, which results in the longest lifetime (Fig. 18). The reason is early cluster merging can bring in more nodes to share the workload of cluster heads. When the electric power of a cluster is about to exhaust, it can refuse forwarding data for the other clusters. This helps reduce energy consumption and therefore extend the overall network lifetime to 18554 rounds, which is about 9 times that of regular networks without adaptive mechanism (2120 rounds). In stead of giving up transmission when a cluster head is declined, it can use a detoured route to forward data to the base station to maintain a higher receiving ratio.

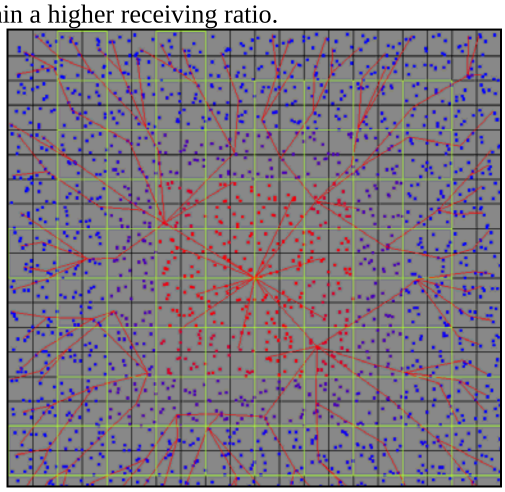

Fig. 18 The best case of applying adaptive mechanisms (*x*=90%, *y*=10%, lifetime=18554)

V. Conclusion

In the wireless sensor network, extending network lifetime by saving energy is an important issue. A number of studies have been conducted in small-area environments, but only a few researches in large-area environments have been found so far. This study focuses on how to extend network lifetime without causing extra costs by cluster merging and dynamic routing mechanisms. The network topology and forwarding routes can be reconfigured by the adaptive mechanisms to extend network lifetime. Cluster merging can increase the number of nodes in a cluster to share the workload of cluster head; dynamic routing prevents cluster heads from exhausting their electric power and thus extends the lifetime of clusters near the base station; forwarding data using a detoured route can further increase the receiving ratio of base station.

The location of base station has great influence on the network lifetime, which is longer when the base station is in the center due to balanced energy consumption. In addition, sleep mode and data aggregation can also improve network lifetime by reducing the amount of data. This study tries to find the proper order and the best timing for applying the adaptive mechanisms. The simulation results show that cluster merging followed by dynamic routing is more efficient in extending network lifetime. The best combination for applying adaptive mechanisms is to set the threshold of cluster merging at *x*=90% and the threshold of dynamic routing at *y*=10%, which results in the longest lifetime and is about 9 times that of regular networks without using adaptive mechanisms.

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