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Extending the Lifetime of Wireless Sensor Networks by Adjusting the Node Density Near the Base Station

Divya Shree H.L, Chaitra R , Shakunthala B S

Dept.of Computer Science, Dept of Information Science
KIT, Tiptur, Karnataka, India

Abstract-- **Wireless Sensor Networks (WSNs) present new generation of real time embedded systems with limited power, energy that are being used in wide variety of applications where traditional networking infrastructure is practically infeasible. In recent years many approaches and techniques have been proposed for optimization of energy usage in Wireless Sensor Networks. In order to gather information more efficiently, wireless sensor networks are partitioned into clusters. However, these methods are not without problems. The most of the proposed clustering algorithms do not consider the location of the base station. This situation causes hot spots problem in multi-hop wireless sensor networks. Unequal clustering mechanisms, which are designed by considering the base station location, to some extent solve this problem. In this paper, we present issues related to these approaches. Limited power is the biggest constraint of the wireless sensor networks. It is not feasible to replace or recharge the thousand of high cost of sensors. In this work, we introduce an energy efficient clustering algorithm for sensor networks based on the LEACH protocol. LEACH (Low Energy Adaptive Clustering Hierarchy) is one of popular cluster-based structures, which has been widely proposed in wireless sensor networks. LEACH uses a TDMA based MAC protocol, and In order to maintain a balanced energy consumption. The proposed protocol adds feature to LEACH to reduce the consumption of the network resource in each round. The proposed protocol is simulated and the results show a significant reduction in network energy consumption compared to LEACH.**

Keywords: LEACH, cluster networks, wireless sensor networks, network lifetime

I. Introduction

Wireless sensor networks (WSNs) [1] are composed of hundreds or thousands of sensors that work cooperatively to monitor the environmental conditions of the sensor field. Sensor nodes collect sensed data and pass them to the base station. WSNs have various applications in many fields such as military, agriculture and health care etc.

The essence of routing algorithms is to find an optimal path that enables the efficient exchange of information between source node and base station, and to ensure correct transmission of data along the path. As the battery, capability of computing, storage and data processing of a sensor are limited, how to reduce the energy consumption while prolonging the network lifetime stays the key problem.

Data is collected at the wireless sensor node, compressed, and transmitted to the BS directly or, if required, uses other wireless sensor nodes to forward data to the BS [2].

The sensor nodes send the collected data to the neighbor nodes, which will forward the data to the base station. This approach solves the problem of high energy consumption in long-distance transmission, but it may cause some nodes to consume more energy by forwarding data for the other nodes and thus affecting the network lifetime.

The main objective of a routing algorithm is to find a better way for data transmission to save electric power. In LEACH, the energy consumption of entire network is evenly distributed to each sensor node, which aims to reduce energy consumption and improve the network lifetime. LEACH is a classic routing protocol [4] for cluster WSN 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, the base station selects a number of nodes as cluster heads based on random thresholds. All other nodes join their nearby clusters by sending out signals and discover the closest cluster heads. When clusters are formed, the wireless sensor network goes into a stable stage. Each node starts to collect and transmit data to its cluster head, and the cluster head forward these data to the base station together with their own collected data. The reason for LEACH to randomly select a fixed number of cluster heads in each round is to solve the problem of high energy consumption in direct-transmission approach and to balance the power consumption among all sensor nodes. During the operation of each round, LEACH generates a threshold value, which is sent to each sensor node to determine if it can become a cluster head by a probability function. The new cluster head has to aggregate data from sensor nodes in its cluster and transmit the data to the base station. In this way, all sensor nodes take turns to serve as a cluster head to balance the power consumption. Many routing algorithms were developed based on the same approach of LEACH in creating clusters, e.g., PAGASIS and TEEN.

However, it has some deficiencies:

1.It does not guarantee about even distribution of cluster heads over the network. Some very big clusters and very small clusters may exist in the network at the same time.

2. Cluster head selection is unreasonable in heterogeneous networks where nodes have different energy.
3. In this protocol it is assumed that each cluster head transmits data to base station over a single hop, which may consume much energy.

The coverage ratio of a WSN represents the percentage of area covered by the working sensor nodes among all application area, and it can also be used as an index for data integrity[8].

A WSN cannot achieve its function when the coverage ratio is too low. Besides, sensor nodes have more feasible routes for selection to reduce energy consumption when the coverage ratio is high. On the other hand, there often exist some holes [9] to block the shorter routes when the coverage ratio is low, so the sensor nodes may have to use a longer route to bypass the holes for data transmission. As the result, a lower coverage ratio may cause more energy consumption and lower data integrity. To extend the lifetime of WSN, a cluster allocation and routing algorithm based on node density is proposed in this study. The objective is to solve the problem of LEACH and the related routing algorithms for which the electric power of sensor nodes near the base station may exhaust quickly and thus reduce the coverage ratio.

This study adopts a fixed cluster allocation mechanism and a deployment method based on the node density for extending network lifetime. At the beginning, the algorithm allocates the sensor nodes to a number of clusters, and the goal is to create clusters containing more sensor nodes to share the energy consumption of their cluster head in forwarding data to the base station. For indirect transmission mode, the sensor nodes near the base station may exhaust their energy quickly due to forwarding data for other sensor nodes, and it may also disable the data transmission of the outer sensor nodes.

Therefore, this study proposed to increase the node density near the base station to compensate for the requirement of higher energy consumption in this area. Without changing the total number of sensor nodes, the node density in the outer area is reduced accordingly. The goal of the density deployment method is to remain a high coverage ratio for extending the lifetime of WSN. Simulation results are provided to show the efficiency of this approach.

II RELATED METHODS

The cluster allocation and routing algorithm proposed in this study is based on LEACH's clustered architecture. The difference is that the cluster allocation is done only once at the beginning and remains fixed for the rest of time. Also, the node density near the base station is increased during the deployment stage to achieve a higher coverage ratio and a longer lifetime as well. The methods of high-energy-first mechanism for determining the cluster heads, finding the forwarding node with the smallest angle [12], data compression [13] and sleep mode [14, 15] were also incorporated in the routing algorithm to further reduce the energy consumption and extend the lifetime of WSN. These methods are described in the following.

A. *High-Energy-First Method*

In LEACH, a recently retired cluster head still has a chance to be selected again according to the probability function, which may lead to fast exhaustion of its electric power. Therefore, this study adopts the high-energy-first method to select cluster heads in each round to remedy this drawback. After collecting data, each sensor node has to send out data together with the information about its remaining electric power, and then the base station can decide which nodes are to be selected as cluster heads in the next round using broadcast messages.

B. *Determining Forwarding Node*

In each round, a cluster head has to determine the forwarding node, which is also a cluster head in its neighborhood. The most direct forwarding route is determined based on the angle between the directions of the base station and the forwarding node. The neighbor cluster head with the smallest angle is chosen as the candidate first, and the purpose is to use the shortest route to reduce energy consumption in forwarding data. However, if the cluster head with the smallest angle refuses to forward data due to its low electricity, the one with the second smallest angle is chosen next, and so on. If no cluster heads within 90 degree are available, the requesting cluster head must transmit data directly to the base station when the distance is reachable at the cost of consuming more energy; otherwise, it will seek for cluster heads outside 90-degree area as the forwarding node using a longer route.

C. *Data Compression*

In WSN, the amount of data transmitted can also affect the energy consumption of sensor nodes. When a cluster head detects the same or similar data packets which are being transmitted, it can use the data compression method to filter out similar data packets. This method can reduce the amount of data and therefore save some energy.

D. *Sleep Mode*

When sensor nodes are scattered randomly during the deployment of a WSN, some nodes may be too close to each other and collect the same data. Therefore, using sleep mode can reduce the data amount and energy consumption. In this study, a grouping method is used to divide sensor nodes into a number of groups within a cluster. In each group, the node with more electric power is selected as the active node while the other nodes may enter sleep mode. The main objective of the grouping method is to evenly distribute active nodes in each cluster to reduce data similarity. Furthermore, the ratio of active nodes and the group size can be adjusted according to the requirement of data precision.

III OUR PROPOSED CLUSTER ALLOCATION AND ROUTING ALGORITHM

At first, the base station sends a threshold value to all sensor nodes for the selection of cluster heads. Then, this study used the cluster allocation algorithm to create clusters with more sensor nodes. After that, each sensor node sends the information back to the base station for later usage, including node number, cluster number, location and remaining electricity. As soon as the initialization stage is completed, the WSN begins its operation in each round to collect and transmit data by the routing algorithm.

A. Cluster Allocation

The concept of set operation is used in dividing the sensor nodes in a WSN into a number of clusters. At the beginning, the initial stage of LEACH is used for selecting cluster heads, and then the cluster heads create their own clusters by communicating with the sensor nodes within the sensing area. For simplicity, the created clusters are defined as the allocated sets, while the sensor nodes not invited by any cluster heads are left in the unallocated set. Then, the allocated sets are sorted by the number of their sensor nodes, and those in the intersected sets are re allocated to the set with more sensor nodes. The objective is to produce clusters with more sensor nodes such that they are more powerful in forwarding data for other nodes. After that, the sets with very few nodes will be deleted, and their nodes are put into the unallocated set. When all sensor nodes in the intersected sets are reallocated, each sensor node belongs to a unique clust there are still some sensor nodes in the unallocated set, the algorithm repeats the same process as described above until the remaining sensor nodes have been allocated to a certain cluster. The reason for re-allocating the sensor nodes in the intersected set is to produce clusters with more sensor nodes to compensate for the high energy consumption by cluster heads in forwarding data (Figure 1)

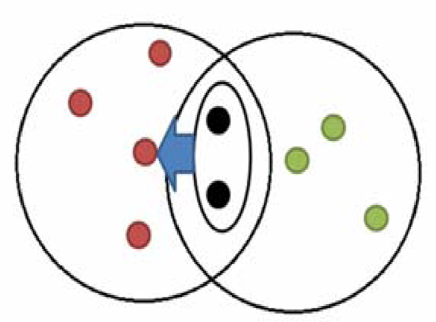

Figure 1. Allocating the intersected set to the set with more nodes

Step1: The initial stage of LEACH is used for selecting cluster heads from all sensor nodes, and then the cluster heads create a number of clusters by communicating with the sensor nodes within the sensing area. The sensor nodes not invited by any cluster heads are assigned in unallocated set *C0*.

Step2: Sort the allocated sets by their node numbers in descending order such that the number of nodes in set *Ci* is greater than or equal to that of set *Cj* if *i<j*.

Step3: Starting from the allocated set with more nodes, assign the nodes in the intersection $C_i \cap C_j$ to set $C_i \forall i$ and *i<j*. If the assigned cluster head in set $C_j \in C_i \cap C_j$, assign the remaining nodes in *Cj* to *C0* and remove *Cj* from the list of allocated sets.

Step4: If $c0 \neq \emptyset$, select some nodes in C_0 as cluster heads to form more clusters. The nodes in the newly created sets are removed from *Co.* Repeat step2 to step4 until $C0=\emptyset$ or the condition of the initial coverage ratio is satisfied.

B. Routing

The routing algorithm operates by rounds. After sensor node deployment and cluster allocation, the routing algorithm uses high-energy-first method to select sensor nodes with more electric power as the cluster heads, and determines the forwarding nodes for data transmission. After that, all sensor nodes start to collect data, which are aggregated by the cluster heads and forwarded to the base station. Finally, the base station computes the coverage ratio to decide if the operation will continue or not. If the coverage ratio is acceptable, the system goes to the next round to repeat its operation.

As shown in Figure 2, 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 the 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.

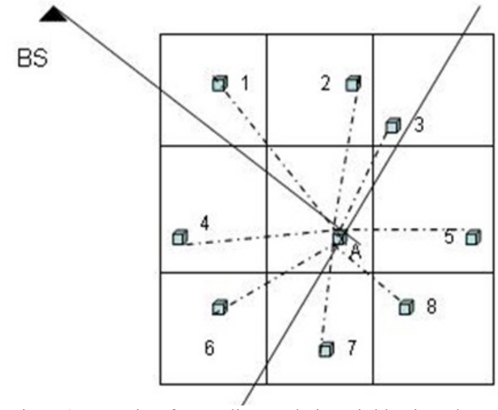

Figure2. Locating forwarding node in neighboring clusters

IV. SIMULATION RESULTS

This study conducted several simulation experiments to analyze if the proposed algorithm could extend the lifetime of WSN. In addition, this study would like to investigate if raising the node density around the base station without increasing the total number of sensor nodes can deal with the high energy consumption problem in this area. This study also tried to find out a better density proportion for usage in the deployment stage to extend the lifetime of WSN. The results were compared with those of LEACH algorithm under the same conditions.

Before the simulation experiments, this study provides the following analysis about the power consumption by sensor nodes. Basically, the energy required for transmitting a signal is highly related to the distance [16]. The following equation shows the energy consumed when sending a signal to a distance *d* by an amplifier.

$$\textbf{Energy consumption} = \begin{cases} \epsilon_{fs} \times d^2, & \text{if } d \le d_0 \\ \epsilon_{tr} \times d^4, & \text{if } d > d_0 \end{cases}$$

Using d_0 as a threshold, if the transmission distance is shorter than d_0 , a free-space propagation model is used to calculate the consumed energy, which is proportional to the square of distance. If transmission distance is longer 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 a great influence on the wireless communication system. In the above equation, ϵ_{fs} and ϵ_{tr} are the parameters for the free-space propagation model and tworay ground propagation model with their values equal to 10 pJ/bit/m^2 and 0.0013 pJ/bit/m^4 , respectively; Here,d_0 is defined as , which is the threshold of transmission distance and its value is about 87.7. To simplify the computation, it is assumed that d_0 =100m.

For most sensor nodes in WSN, the consumed energy is proportional to the square of distance when collecting and sending data to their cluster head. The cluster allocation algorithm can increase the node density in a cluster and thus reduce the distance and consumed energy in transmitting data. As the operation continues, the sensor nodes near the base station may exhaust their electricity and thus can not forward data for the outer sensor nodes. Consequently, the outer sensor nodes may need to transmit data directly to the base station at a longer distance, so the energy consumed is proportional to the fourth power of distance.

A. Computing Coverage Ratio

The coverage ratio of a WSN represents the percentage of area under monitoring (Figure 3), which is computed as the area covered by the working sensor nodes divided by the total application area (700m×700m =490000m2). The sensor nodes can function correctly only when they have enough electricity, so the electric power is the major factor affecting coverage ratio. In this study, the WSN stops its operation if the coverage ratio goes below 80%, and the number of rounds at this time is defined as its lifetime.

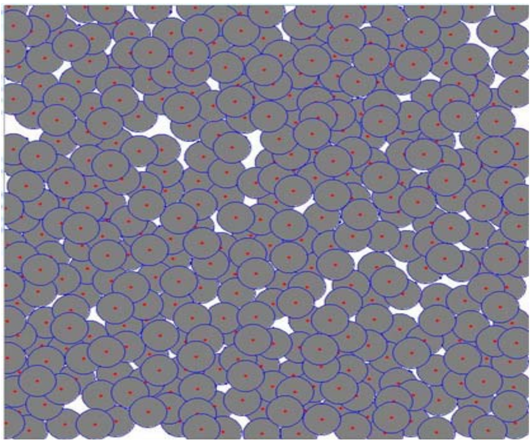

Figure 3. The area covered by working sensor nodes

B. Location of Base Station

The location of base station has a great influence on the energy consumption of sensor nodes (Table 1). To find out a better location for the base station, an experiment was conducted to simulate the operation of a WSN with the base station situated in three different locations, i.e., upper left (Figure 4), left (Figure 5), and center (Figure 6). In these figures, green spots indicate the base station, and black lines represent the forwarding routes. The node colour is used to represent the status of remaining electric power in a sensor node as follows: blue (sufficient), red (low), and black (exhausted). The algorithm proposed in this study was used for collecting and sending data, and the WSN stops its operation when the coverage ratio goes below 80%. According to the lifetimes of the base station situated at three different locations, it can be seen that the location of the base station plays an important role to affect the lifetime of WSN. The lifetime is the longest when the base station is located at the center. The reason is that there were more sensor nodes to share the high energy consumption around the base station.

TABLE I.
LIFETIME VS. THE LOCATION OF BASE STATION

Location of base station	Lifetime
Upper left	1500
Left	2655
Center	8342

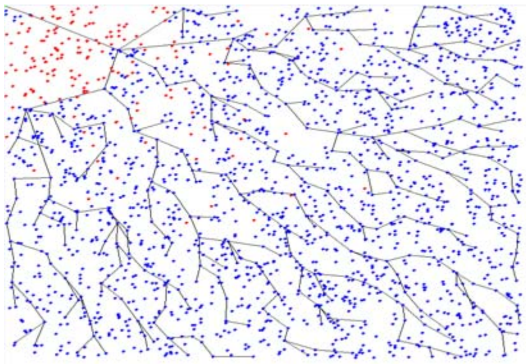

Figure 2. The base station is located at upper left

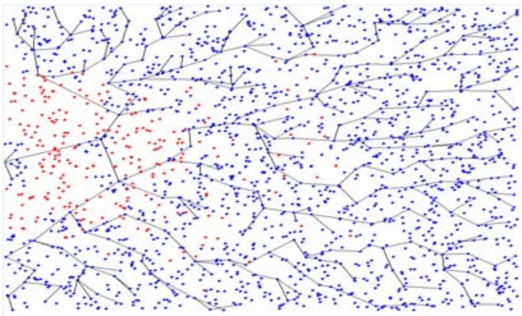

Figure 3. The base station is located at the left

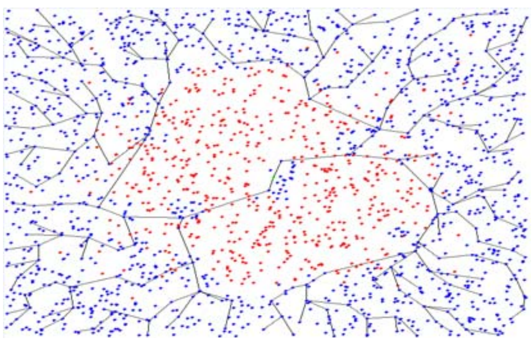

Figure 4. The base station is located at the center

C. Comparison with LEACH

In this experiment, 2000 sensor nodes were deployed in a 700m×700m application area. The proposed algorithm and LEACH were used to collect and transmit data. The lifetimes (in rounds) for both algorithms were recorded until the coverage ratio dropped below 80%. As we can see in Figure 5, the initial coverage ratio is about 99% for both algorithms. For LEACH, the coverage ratio goes below 80% at the time of 5002 rounds. For the proposed algorithm, the coverage ratio goes below 80% at the time of 8342 rounds. Hence, the proposed algorithm can efficiently increase the lifetime of WSN, and the percentage of increment is 66%.

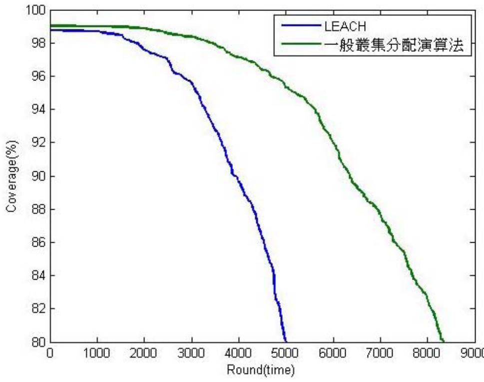

Figure 5. Comparing the lifetimes of LEACH and proposed algorithm

D. Adjusting Node Density

When the indirect transmission mode is used in WSN, the sensor nodes near the base station often exhaust their energy first due to forwarding data for other nodes, which can also result in the early death of WSN. As we can see from the above results, there are a lot of active sensor nodes in outer areas not able to transmit data to the base station because most of the inner sensor nodes have exhausted their electricity. Hence, this study proposed a density deployment method to raise the density of sensor nodes near the base station without increasing the total number of sensor nodes. The simulation results showed that this approach was very useful in extending the lifetime of WSN. To find out a better density proportion for deploying sensor nodes, an experiment was conducted by dividing the application environment into 3 areas:

(A) the area within 200m of the base station,

(B) the area of distance between 200m and 300m from the base station, and

(C) the area of distance longer than 300m from the base station. According to previous results, the sensor nodes in area A will consume more energy, and those in area B will consume less energy, and those in area C will consume the least energy. By adjusting the node density in these 3 areas, this study tried to find out a better density proportion to increase the coverage ratio of WSN and its lifetime as well. There are 2000 sensor nodes deployed according to the designated density in each area. Because the proportion of these 3 areas is $200^2\pi:(300^2-200^2)\pi:(700^2-300^2)\pi=4\pi:5\pi:49-9\pi$, if their node densities are the same, the numbers of sensor nodes in these 3 areas are computed as

$N_A=2000\times4\pi\div49=513$, $N_B=2000\times5\pi\div49=641$, and $N_C=2000\times(49-9\pi)\div49=846$.

The experiment compared the lifetimes (in rounds) for five different density proportions when the coverage ratio dropped below 80% by the proposed algorithm and LEACH. It is noted that the lifetime for each case was computed by the average of 100 simulation results. The results in Table II shows that raising the node density in the area near the base station can increase the lifetime of WSN. When the density proportion is 4:2.5:1, the lifetime for the cluster allocation and routing algorithm is the longest (16789 rounds). The same situation can also be found in LEACH algorithm, and the longest lifetime equals 11379 rounds when the density proportion is 4:2.5:1.

Density proportion	Node number			Rounds when coverage ratio dropped below 80%	
	A	B	C	Proposed algorithm	Leach
1:1:1	513	641	846	8342	5002
2:1.5:1	724	678	598	13569	9932
3:2:1	839	699	462	15073	10622
4:2.5:1	912	712	376	16789	11379
5:3:1	961	721	318	15598	10676
6:3.5:1	998	727	275	16288	11019

As we can see from the above results, raising the node density near the base station can increase the lifetime of WSN. This study further compared the results of LEACH and the proposed algorithm under the density proportion of 4:2.5:1. As we can see in Figure 6, the initial coverage ratios for both algorithms are about 95%. The coverage ratio of LEACH drops to 80% at the time of 11379 rounds, which is increased by 127% when compared with the case without adjusting node density (5002 rounds). The coverage ratio of the proposed algorithm drops to 80% at the time of 16789 rounds, increased by 101% when compared with the case without adjusting node density (8342 rounds). For both algorithms, their lifetimes have been increased by more than 100% (as shown in Table III) if the proposed density deployment method was applied.

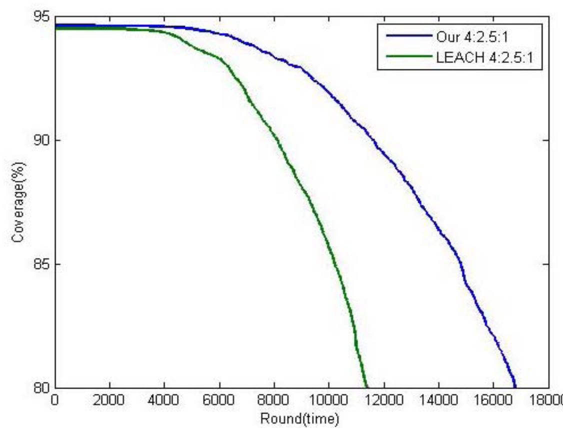

Figure 6. Comparing the results after density adjustment

TABLE III. INITIAL COVERAGE RATIO AND LIFETIME BY ADJUSTING NODE DENSITY FOR BOTH ALGORITHMS

Algorithm	Initial coverage		Rounds when coverage ratio dropped below 80%	
	Density adjusted		Density adjusted	
	no	Yes	No	Yes
LEACH	99%	95%	5002	11379
PROPOSED	99%	95%	8342	16789

V. CONCLUSION

For wireless sensor networks, clustering is one of the most popular routing methodologies that can effectively manage network energy consumption via data aggregation. We propose a Density-based Energy-efficient Clustering Algorithm for WSNs. How to deploy sensor nodes to cooperate with efficient routing algorithms for extending lifetime is an important topic in the research of WSN. For large-area applications, most routing algorithms adopt indirect transmission mode to solve the problem of high energy consumption due to long-distance transmission, but it may also cause the sensor nodes near the base station to exhaust electricity quickly. This study proposed a cluster allocation algorithm based on node density to remain a high coverage ratio and thus extend the lifetime of WSN. The simulation results showed that the lifetime (in rounds) for the proposed algorithm was 66% higher than that of LEACH.

In addition, this study proposed a deployment method to adjust node density without increasing the total number of sensor nodes. The objective was to increase the sensor nodes near the base station to compensate for the high energy consumption due to forwarding data for other nodes. The simulation results showed that it was very efficient in increasing the lifetime of WSN. For the proposed algorithm and LEACH, their lifetimes were increased by more than 100% if the density proportion of 4:2.5:1 was used for deployment. Therefore, the cluster allocation algorithm and the density deployment method proposed in this study are very efficient in extending the lifetime of WSN.

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