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Nâng cao hiệu quả giao thức LEACH trong mạng cảm biến không dây

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TÓM TẮT

Trong những năm gần đây, mạng cảm biến không dây (Wireless Sensor Network – WSN) được nghiên cứu và ứng dụng trong nhiều lĩnh vực trong cuộc sống như cứu hộ, giám sát môi trường, tích hợp các ứng dụng IoT… Đặc biệt, trong các trường hợp mà nguồn năng lượng bị giới hạn thì việc duy trì thời gian hoạt động của các nút cảm biến trong hệ thống mạng trở nên quan trọng. Trong bài báo này, chúng tôi tìm hiểu hoạt động giao thức LEACH (Low Energy Adaptive Clustering Hierarchy) – một giao thức tương thích với nguồn năng lượng thấp và đề xuất giải pháp cải tiến để nâng cao hiệu quả sử dụng trong mạng cảm biến không dây. Các kết quả mô phỏng cho thấy, giải pháp của chúng tôi đề xuất tốt hơn về số lượng gói tin đến được trạm gốc và thời gian sống trung bình của các nút cảm biến.

Từ khóa: *Mạng cảm biến không dây, phân cụm, năng lượng trong mạng cảm biến không dây, giao thức định tuyến.*

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Improve the efficiency of LEACH protocol in Wireless Sensor Networks

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ABSTRACT

In recent years, Wireless Sensor Network (WSN) has been researched and applied in many fields such as rescuing, environmental monitoring, and IoT applications, etc. Especially, when the power source is limited, maintaining the working status of the sensor nodes in the network becomes more and more important. In this article, we explore the operation of the LEACH (Low Energy Adaptive Clustering Hierarchy) protocol - a protocol compatible with low-energy sources and propose a solution to improve efficiency in wireless sensor networks. The simulation results show that our solution is better in terms of the number of packets reaching the base station and the average lifetime of the sensor nodes.

Keywords: *Wireless Sensor Network, clustering, energy in wireless sensor networks, routing protocols.*

1. INTRODUCTION

A Wireless Sensor Network (WSN) consists of wireless sensor nodes scattered in a given space to collect data of the physical signals at the sensor node and send it to the Base Station (BS).[1] The BS will aggregate the data and send it back to the user via the Internet. A wireless sensor node is equipped with components such as a sensor, microprocessor, memory, radio transmitter/receiver, and limited battery power. BS has an unlimited energy source. Wireless sensor networks are often deployed in places with complex terrain, so recharging or replacing batteries for sensor nodes is not possible.

Therefore, the research on solutions to increase the lifetime of the sensor nodes is always of interest. One of the solutions to improve the efficiency and increase the lifetime of the wireless sensor network is to design a routing protocol for transferring sensor data to the BS.[2,3]

LEACH (Low Energy Adaptive Clustering Hierarchy) is a distributed routing protocol used in wireless sensor networks based on the cluster proposed by Heinzelman, which allows data within a cluster to be processed locally to remove redundant data before transmission.[4] Since the publication of LEACH, various solutions have been proposed by the research community based on LEACH to save energy consumption further and increase network lifetime.[6-9]

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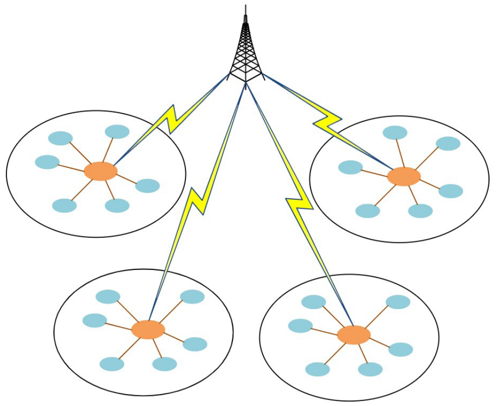

Figure 1. WSN architecture under LEACH protocol.

The LEACH protocol has many disadvantages in selecting cluster heads and assigning sensor nodes to clusters, causing unnecessary energy consumption.[5] We study the operation of the LEACH protocol and consider its limitations, thereby proposing a solution based on LEACH to improve some parameters such as network lifetime, the amount of data received by the BS, and the energy consumed by the network. This paper consists of five parts. First, we introduce the wireless sensor networks and issues to be researched. Part 2 presents the LEACH routing protocol and power consumption model. Part 3 proposes solutions to improve LEACH. Part 4 simulates and analyzes the results. Finally, concluding remarks are made in part 5.

2. LEACH PROTOCOL

2.1. Two phases of LEACH

The operation of LEACH is divided into rounds. Each round consists of two phases: the set-up phase and the steady phase.

2.2.1. Set-up phase

In the setup phase, the clusters are organized and CHs are selected. The CH creates a TDMA (Time Division Multiple Access) schedule for member nodes. Thus, the sensor nodes send their data to CH in time slots allocated by the CH node.

Selection of cluster head

At the beginning of each round, LEACH chooses a few nodes in the network to be the cluster head. A sensor node chooses a random number, r, between 0 and 1. If this random number is less than a threshold value, T(n), the node becomes a cluster head for the current round. T(n) is defined:

$$T(n) = \begin{cases} \frac{P}{1-P\left(r \bmod \frac{1}{P}\right)} & if\ n \in G \\ 0 & if\ n \notin G \end{cases} \quad (1)$$

Where:

– P is the percentage of cluster heads

– r is the selected rounds

– G is the set of non-cluster heads in the last 1/P rounds

According to the threshold equation, each node can be a cluster head only once in an interval (*1/P* rounds). The threshold value *T(n)* increases with each round in *1/P* rounds, which means that the probability of a node becoming a CH increases after rounds. In the last round of a cycle, the threshold *T(n) = 1*, so all nodes that are not selected as CH will become CH in this round. After this round, LEACH will move to a new cycle and all live nodes in the network have an equal chance of becoming CH.

Cluster formation: The cluster heads will send a broadcast packet to the entire network to announce that it is a cluster head, all non-CH nodes will receive information from the CHs and select the nearest CH node to join the cluster based on the signal strength. At this point, the network has formed clusters, each with a CH and member nodes.

Schedule data transmission: After the clusters have been formed, the CH schedules the member nodes to send sensor data to the CH node using the Time Division Multiple Access (TDMA) method. TDMA schedule helps nodes know when it sends data to the CH to reduce communication conflicts with other nodes in the cluster.

2.1.2. Steady-state phase

In the Steady-state phase, sensor nodes use their allocated TDMA slot to send the collected data to the CH. After receiving the data from its cluster members, CH aggregates and compresses them into a packet, and transfers it to the BS. This process reduces the amount of data that needs to be sent to the base station to reduce the energy consumption of the sensor nodes.

After the CH nodes send data to the base station, the network will move on to the next round.

2.2. Radio energy model

Sensor nodes use radio waves to transmit broadcast data. Therefore, each cluster uses a code to filter the signal according to the CDMA (Code-Division Multiple Access) technique to avoid conflicts with other clusters. The energy usage model[1] is depicted in Figure 2.

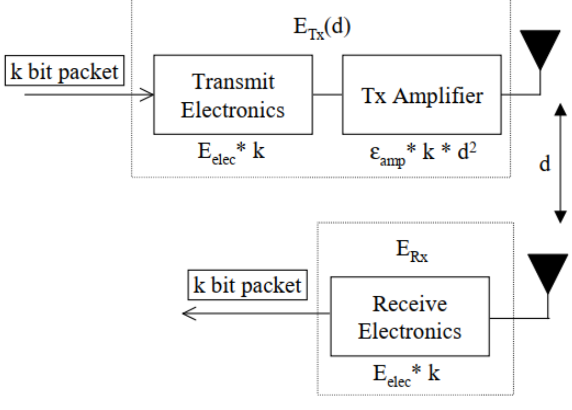

Figure 2. Radio energy consumption model.

The energy to transmit k bits of data between two sensor nodes with a distance of d using radio waves as shown above is calculated by the following formula:

$$E_{Tx}(k,d) = E_{elec} * k + \varepsilon_{amp} * k * d^2 \quad (2)$$

Where E_{elec} is the energy to run transceiver circuitry; ε_{amp} is the energy consumption of the amplifier.

The energy to receive k bits of data:

$$E_{Rx} = E_{elec} * k$$

3. IMPROVEMENT OF LEACH

In LEACH, the remaining energy of the CH plays an important role in aggregating data from the member nodes and transmitting it to the base station. It is easy to see that a node with less residual energy can still be selected as the CH node. With a low-power CH node, the possibility of running out of energy while aggregating and transmitting data to the BS is very high, causing sensor packet loss.

The E-LEACH[3] solution has partially overcome the disadvantages of the LEACH protocol with a new approach for cluster head selection based on residual energy. When the remaining energy of a node is lower than 50% of the initial energy then the E-LEACH algorithm is used as in Equation (3).

$$T(n) = 2P \; * \frac{E_{residual}}{E_{inittial}} \quad (3)$$

Where, P is the percentage of nodes that can become cluster head; $E_{residual}$ is remaining energy; $E_{inittial}$ is initial energy of a sensor node.

Another disadvantage of the LEACH protocol is that member nodes select the nearest CH to join the cluster, which is the case where a sensor node can send data back to the CH in the opposite direction towards BS wasting energy.

To overcome the above two disadvantages, we propose an improvement of the LEACH protocol, called LEACH-MODI as follows:

Cluster head selection

We use the same solution as E-LEACH[3] in selecting the CH node, when the remaining energy of the node is greater than or equal to 50%,

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we use the threshold value *T(n)* as formula (1). Otherwise, we apply the cluster head selection as shown in formula (3). Thus, nodes with a larger remaining power source have a greater probability of becoming a CH node.

After selecting the CH node, it will send a broadcast packet HEAD_ADV to announce that it is the cluster head and its location to the entire network. Other sensor nodes receive HEAD_ADV packets from CH nodes and decide to join a cluster in the following way.

Non-CH node joins a cluster

Non-CH node CMj will join the cluster that contains CH_i with the smallest *f(i)* according to formula (4) and send a request packet to join the cluster CH_i.

$$f(i) = 2*d(j, CH_i) + d(CH_i, BS) \qquad (4)$$

Where:

– $d(j, CH_i)$: distance between node CM_j and node CH_i

– $d(CH_i, BS)$: distance between node CH_i and BS

The distance from node a to node b is calculated according to the formula (5).

$$d(a,b) = \sqrt{(x_a - x_b)^2 + (y_a - y_b)^2} \qquad (5)$$

Building the cluster according to formula (4) helps the sensor node to choose the CH node with the closer sensor packet path length, but the number of sensor nodes between the clusters is not too different.

LEACH_MODI is depicted in diagram Figure 3.

4. SIMULATION AND ANALYSIS

We perform a simulation with 100 sensor nodes randomly distributed in the simulation area of 100m x 100m. The base station position is (50,150). The above number of sensor nodes and simulation areas can be applied to the monitoring water environment (e.g., shrimp ponds) or monitoring the health of patients of a department in the hospital. The coverage range of HEAD_ADV and JOIN_Cluster packets is 50m. In case a sensor node cannot find a cluster to join, it sends the sensor packet directly to the base station. In each round, all sensor nodes send a 32-bit packet to CH and then aggregate and send it to the base station.

The simulation parameters[1] are presented in the following table:

Table 1. Simulation parameters.

Number of nodes	100
Network size	100m x 100m
Base station location	(50,150)
Initial energy	0.75J
Data packet size	32 bit
Desired percentage of CH	5%
E_{elec}	50 nJ/bit
ε_{amp}	100 pJ/bit/m^2

The simulation is performed until 70% of the network nodes run out of energy. The simulation scenario is built on NS3 software and uses the following parameters to evaluate the effectiveness of the proposed protocol:

– Number of sensor packets that reach the base station

– Number of sensor nodes that run out of energy

– Average power consumption of the network

– Average lifetime of network nodes

The location of the 100 sensor nodes and the base station locations are shown in Figure 4.

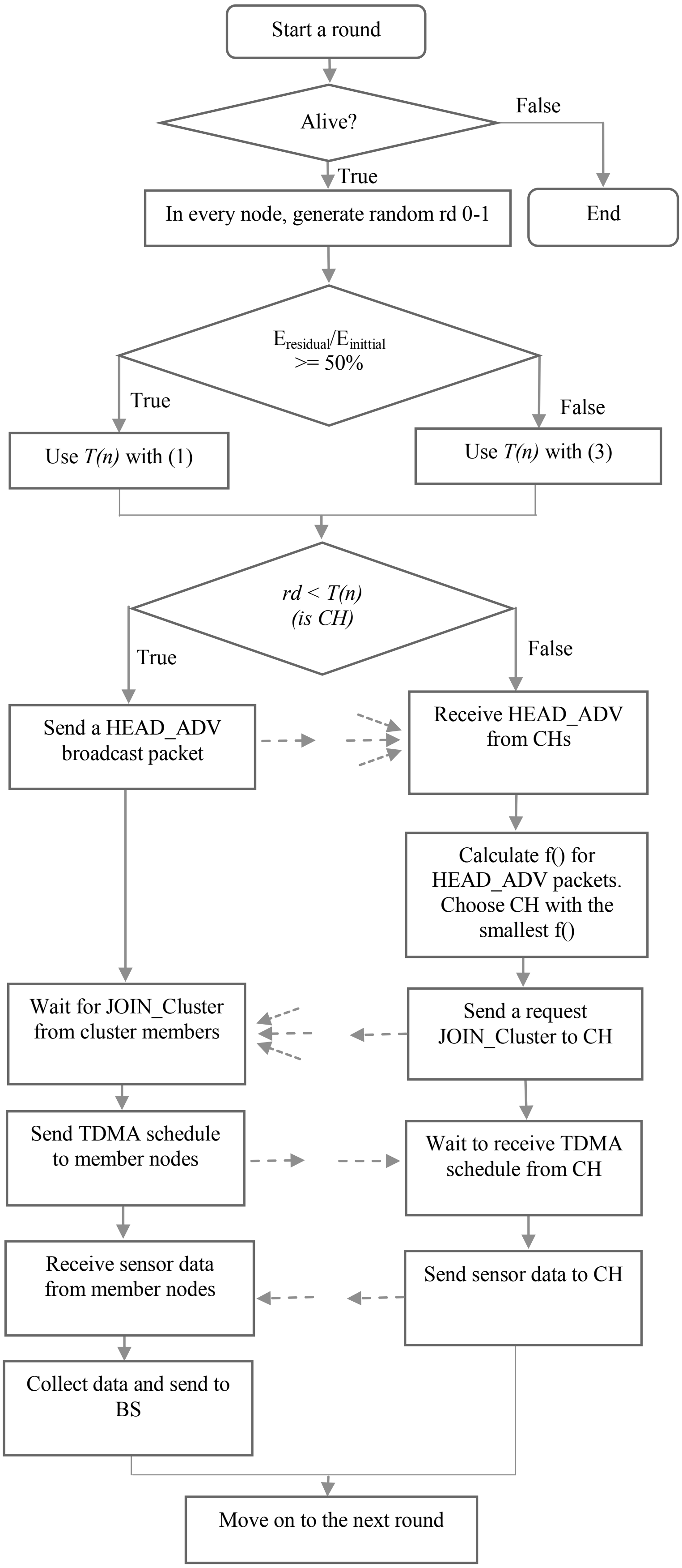

Figure 3. Flow chart of the LEACH-MODI.

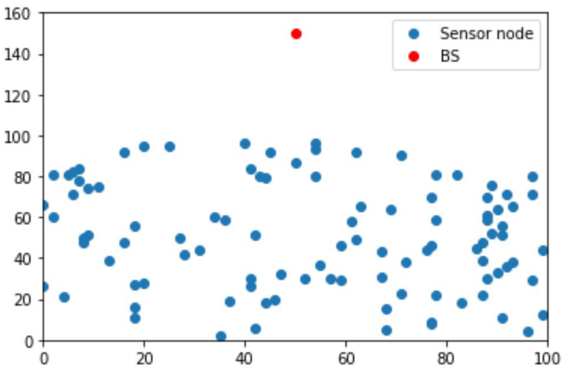

Figure 4. Location of sensor nodes.

We present the simulation result in the form of graphs (Figure 5, Figure 6, Figure 7) and a data table (Table 2).

According to Figure 5, LEACH-MODI and E-LEACH protocols are better than LEACH protocols in maintaining the number of live nodes. This result is obtained by changing the threshold value T(n) according to formula (3) when the nodes have the remaining energy less than 50% of the initial energy. Therefore, nodes with more energy have a higher probability of becoming CH, so energy consumption is more uniform between nodes. Because of the more even distribution of energy between nodes in the LEACH-MODI and E-LEACH protocols, the number of nodes running out of energy increases rapidly in the last period. The LEACH-MODI protocol maintains the number of alive nodes better than the E-LEACH protocol for the duration of the simulation because of the way a member node joins the cluster.

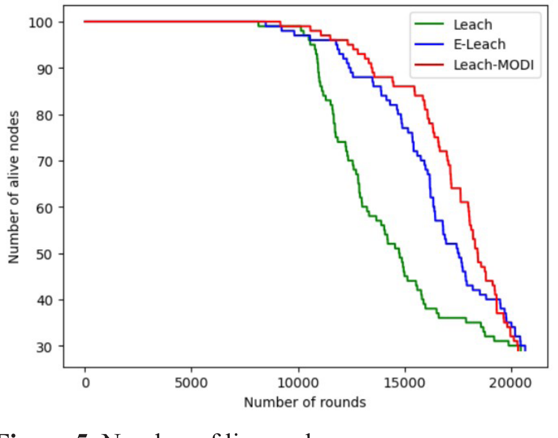

Figure 5. Number of live nodes.

The power consumption in a wireless sensor network is shown in Figure 6. The LEACH and E-LEACH protocols consume the same power for the first half of the time. Because the operation of the protocols is the same when the power is more than 50% of the initial energy. The LEACH-MODI protocol consumes less power than the other two protocols in the first period because of the way the member node selects the cluster leader node according to formula (4) instead of selecting the nearest cluster leader node to join the cluster. This approach avoids the case of sending sensor packets to the CH in the opposite direction to the BS. Round 15000 and later, the average remaining energy of the LEACH-MODI protocol decreases rapidly because its number of live nodes is much more than the other two protocols.

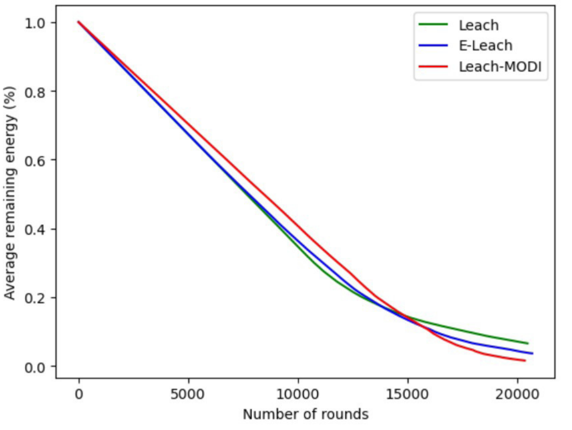

Figure 6. Average remaining energy.

Figure 7 shows the number of packets that reached the base station. The three protocols have the same number of packets arriving at the BS as no node runs out of power. The LEACH protocol is less efficient at the end time because CH nodes run out of energy while aggregating data from member nodes. Furthermore, the number of nodes alive is less than in the other two protocols.

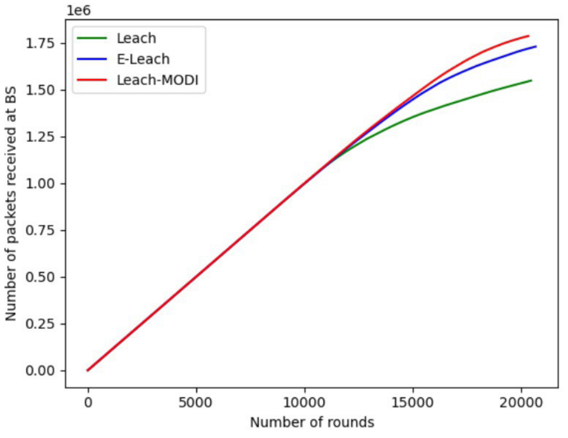

Figure 7. Number of sensor packets reached by BS.

The lifetime of the sensor nodes and the number of packets arriving at the BS are shown in Table 2, showing that the LEACH-MODI protocol is better than the LEACH and E-LEACH protocols.

Table 2. Summary of simulation results.

	Leach	E-Leach	Leach-MODI
The first round has a dead node	8.145	8.487	9.174
Average number of rounds of dead nodes	13.457	15.938	16.838
Number of data packets reaching the base station	1.548.120	1.729.970	1.786.580

Simulation results show that the LEACH-MODI protocol is better than the other two protocols in some evaluation parameters but still has many disadvantages. For example, the selection of cluster heads without considering the geographical location of the nodes affects the network's energy consumption. Moreover, LEACH-MODI has not considered the case of complex network environments such as many obstacles. In a transmission environment with many obstacles, the sensor node transmitting a signal with signal strength based on distance is no longer suitable.

5. CONCLUSION

Energy efficiency and energy load balancing in wireless sensor networks are issues of great concern today. In this paper, we have proposed a LEACH-MODI solution based on LEACH by changing the way a cluster head node is selected and how a cluster is selected for the joining of a member node. The results of the paper show that our proposed protocol is better than the LEACH protocol in maintaining the average lifetime of the network nodes and the number of packets reaching the base station. However, the LEACH-MODI protocol has some disadvantages in selecting cluster heads and when the network operates in complex environments. Therefore, we will focus on research to overcome the disadvantages of LEACH-MODI in the coming time.

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