Stepwise Clustering Algorithm for Wireless Sensor Networks [1]

Shin-nosuke Toyoda†, Fumiaki Sato‡

†Graduate School of Science, Toho University, Japan
‡Faculty of Science, Toho University, Japan
†6511013t@nc.toho-u.ac.jp
‡fsato@is.sci.toho-u.ac.jp

Abstract - Sensor networks consisting of nodes with limited battery power and wireless communications are deployed to collect useful information from the field. Gathering sensed information in an energy efficient manner is critical to operate the sensor network for a long period of time. LEACH is very energy-efficient routing protocol based on clustering of the sensor nodes. However, energy consumption of nodes tends to become uneven in LEACH. HEED improves the LEACH clustering algorithm by using information of residual electric power of nodes. Although HEED provides better performance than LEACH, it does not consider the number of adjacent nodes. Therefore, the cluster head does not efficiently cover the nodes in HEED. HIT and MR-LEACH are based on a small transmission range and multi-hop communication. Though these methods have improved the performance dramatically, unbalance of the electric power consumption is remained. In this paper, we propose energy-efficient clustering algorithm considering adjacent nodes and residual electric power. Characteristics of our approach are stepwise clustering from an initial cluster head and dynamic change of cluster size.

Keywords: sensor networks, stepwise clustering, energy-efficient routing.

1 INTRODUCTION

In recent years, there has been a growing interest in wireless sensor networks. Wireless sensor networks are composed of a large number of sensor nodes with limited energy resources. Energy efficiency is a key design issue that needs to be enhanced in order to improve the life span of the entire network. Usually, energy consumption can be divided into three domains: sensing, communication and data processing. Of the three domains, a sensor node expends maximum energy in data communication. One of the primary concerns with respect to sensor networks applications is the design and development of energy-efficient routing protocols that consume power more evenly, thus result into a prolonged network lifetime.

Available routing protocols for sensor networks are classified as data centric, location-based, QoS aware, and hierarchical. Data centric protocols use flooding or gossiping to transmit data [1-3]. Though the cost of routing is small, the number of data will be transmitted. Location based routing require the location information to determine an optimal path so that flooding of routing-related control packets is not necessary [4-6]. On the other hand, QoS aware protocols address various requirements such as energy efficiency, reliability, and real-time requirements [7]. Finally, the hierarchical protocols such as LEACH[8], HEED[9], HIT[10] and MR-LEACH[11] form clusters with cluster heads in order to minimize the energy consumption both for processing and transmission of data.

Clustering in Wireless Sensor Networks (WSNs) provides scalability and robustness for the network; it allows spatial reuse of the bandwidth, simpler routing decisions, and results in decreased energy dissipation of the whole system by minimizing the number of nodes that take part in long distance communication. LEACH is very energy-efficient routing protocol based on the clustering of the sensor nodes. In LEACH, non-cluster-head nodes first send their data to the cluster heads (CHs), and then CHs send the data to the base station (BS). Each link of non-cluster-head to CH and CH to BS is one hop. The cluster formation in LEACH is changed and CH is also changed periodically. Therefore, the load of CH is distributed all sensor nodes. However, energy consumption of nodes tends to become uneven in LEACH. On the other hand, HEED improves the LEACH clustering algorithm by using information of remaining electric power of nodes. Although HEED provides better performance than LEACH, it does not consider the number of adjacent nodes. Therefore, the CH does not efficiently cover the nodes in HEED. HIT and MR-LEACH are based on a small transmission range and multi-hop communication. Though HIT has improved the performance dramatically, unbalance of the electric power consumption is remained. Since MR-LEACH did not take account about the node coverage by CH, the effect of the cost reduction of CH was not so high.

To improve the life time of wireless sensor networks, we have proposed an energy-efficient clustering algorithm [12]. The algorithm selects CHs by using information of adjacent nodes and residual electric power. Sensor nodes are covered with few CHs and sensed data is transmitted to sink node by multi-hop communication. Therefore, the life time of the sensor networks is improved. However, because the cluster size is fixed in our previous work, some sensor nodes not covered by CH become single CH which is a problem of our algorithm. In this paper, we propose energy-efficient clustering algorithm considering adjacent nodes and residual electric power. The size of the cluster gradually grows from

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a small size, and the algorithm can efficiently cover the sensor nodes.

The remainder of the paper is organized as follows. Section 2 summarizes related work. In Section 3 we present our clustering algorithm in detail. In Section 4 we show effectiveness of our algorithm via simulations and compare it to other clustering techniques. Finally, we conclude our paper and draw directions for future work in Section 5.

2 RELATED WORKS

2.1 LEACH

In this section, we described LEACH (Low-Energy Adaptive Clustering Hierarchy)[8], a clustering-based routing protocol that minimizes global energy usage by distributing the load to all the nodes at different points in time. LEACH is completely distributed, requiring no control information from the base station, and the nodes do not require knowledge of the global network in order for LEACH to operate. The key features of LEACH are:

1) Localized coordination and control for cluster setup and operation.
2) Randomized rotation of the "base stations" or "cluster-heads" and the corresponding clusters.

As a result, the load is distributed, and longevity on the entire network can be extended. Here, the "cycle" is the period which all nodes send the data once to the base station. The "round" is the period between the changes of CH.

All nodes can communicate to the base station directly in LEACH. All nodes know the probability p which each node try to become CH in the first round. When the round changes, node n decide whether try to become CH in the new round based on the equation (2.1). If a random number created by the node n is greater than the result of the equation (2.1), the node tries to become CH.

$$T(n) = \begin{cases} \dfrac{p}{1 - p * (r \bmod \frac{1}{p})} & if\ n \in G \\ 0 & otherwise \end{cases} \quad (2.1)$$

Here, the r is a number of rounds, G is the set of nodes which did not become CH in the 1/p past round (0<p<1). In other words, each node must become CH once in 1/p rounds.

The node which tries to become the CH sends the CH advertisement to neighboring nodes. The node which does not try to become the CH waits the CH advertisement during the fixed time. The node which receives the CH advertisement adds the node to the list of CHs with the RSSI (Received Signal Strength Indicator) of the node. When the waiting time is finished, non-cluster head node chooses the CH with the strongest RSSI among the list, and transmits the participation request. Data is transmitted directly to the sink without belonging to the cluster when there is no node which received the CH advertisement. On the other hand, the node transmitting the CH advertisement waits the participation request. When all the participation requests are received, the TDMA transmission schedule of the cluster member is made, and the CH transmits to the member. If the transmission schedule is received, the member memorizes the order of the transmission until the CH alternates. If the round changes, the process is executed for each round.

The cluster member transmits the sensor data to the CH in order on schedule after the schedule reception, and the CH compresses the data and transmits the data to the sink after data is received from all members. This is a flow of one cycle of one round in LEACH.

In LEACH, however, there is a problem that the power consumption of the node becomes unbalance easily. The reason is that the decision to become CH is based on only the frequency. Therefore, the node far from the sink node consumes energy early. There is the CH that no members exist in the cluster. There is the round that any nodes do not become the CH.

2.2 HEED

HEED (Hybrid, Energy-Efficient Distributed clustering)[9] is a clustering algorithm that improves the problems in the LEACH. The probability to become CH is based on the ratio of the initial electric power E_{max} and the current residual electric power $E_{residual}$ in HEED. Therefore, the node that has the more electric power is easier to become CH.

There are two states in the CH, the tentative CH and final CH. If the node broadcasts the final CH advertisement, the node serves the CH in the round. On the other hand, if the node broadcasts the tentative CH advertisement, the node may cancel the advertisement and join to other cluster that the total communication cost becomes small.

In HEED, the probability of the node that try to become CH (CH_{prob}) is given as follows.

$$CH_{prob} = \max\left(C_{prob} * \frac{E_{residual}}{E_{\max}}, p_{\min} \right) \quad (2.2)$$

Here, C_{prob} is the rate of the CH given beforehand. p_{min} is the minimum value of the CH_{prob}, that is decided in inverse proportion to E_{max}.

After calculating CH_{prob} by equation (2.2), each node repeats the following process. Flowchart is depicted in Fig.2.1.

(1)When one or more CH advertisements are received including own one:

The node that the communication cost is smallest is selected as CH.

If the node is myself:

a)If CH_{prob}=1, the node broadcasts final_CH message.

b) If CH_{prob}<1, the node broadcasts tentative_CH message.

(2) When no CH advertisement is received:

a)If CH_{prob}=1, the node broadcasts final_CH message.

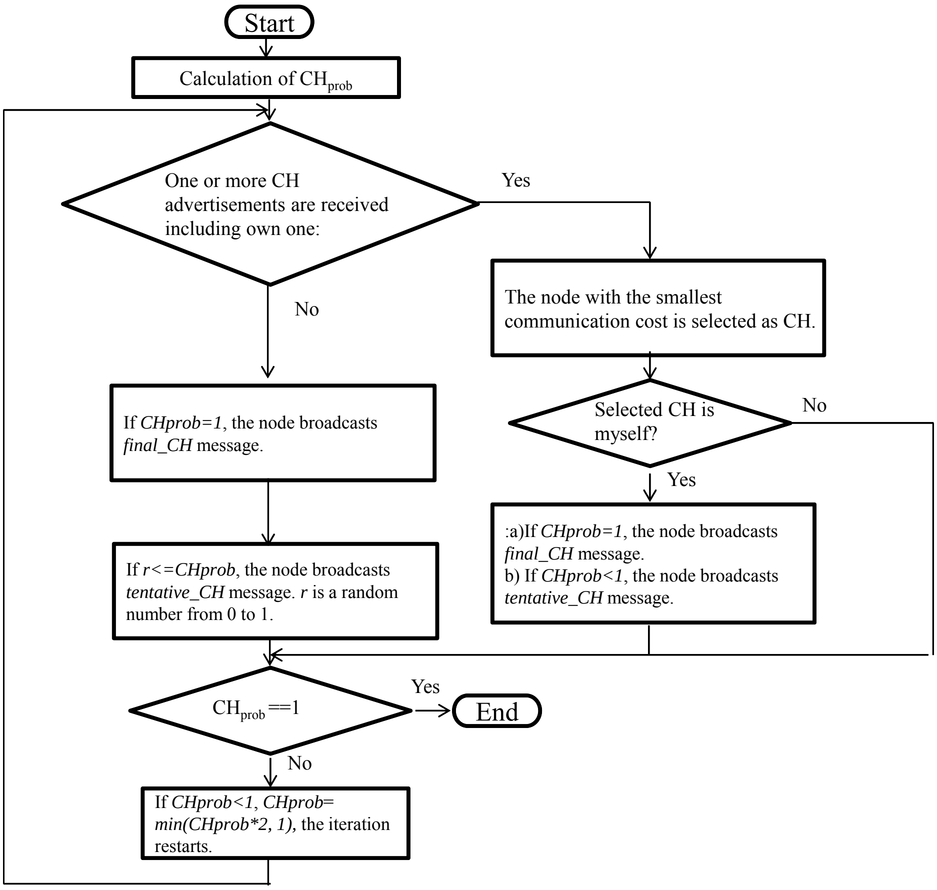

Fig. 2.1 Flowchart of HEED.

b) If r<=CH_{prob}, the node broadcasts tentative_CH message. r is a random number from 0 to 1.

(3) If CH_{prob}=1, the iteration is end.

(4) If CH_{prob}<1, CH_{prob}= min(CH_{prob}*2, 1), the iteration restarts.

If the node does not broadcast the final_CH message in the iteration, the node selects the own CH from other nodes from which the node receives the final_CH message. If there is no node that the node receives the final_CH message, the node becomes CH and broadcasts the final_CH message.

2.3 HIT

HIT (Hybrid Indirect Transmissions) [10] uses multi-hop communication to control electric wave interference and to reduce the electric power consumption. It is effective to support parallel communication. HIT consists of the following seven phases.

(1)Phase 1: CH selection

In this phase, one or more CHs are selected. Each cluster has one CH. In case of single cluster, CH can be rotated based on the node ID.

(2)Phase 2: CH advertisement

In this phase, the selected CHs broadcast the node information as the Advertise message. The node j which is not CH and receives the message calculates the distance from the CH and joins to the nearest cluster. The node j has the distance to node H (CH) as the d(H, j).

(3)Phase 3: Cluster set up

In this phase, one or more clusters are created and relation of upstream/downstream are set up. At first, the node j which is not CH broadcasts Member message that includes the CH and distance to CH. By this exchange of information, all nodes calculate the distance to other node and keep the information to the distance to CH of other nodes. From this information, the upstream node u of node i is calculated by that information base on the following condition.

1)d(u, H)<d(i, H)

2)d(i, u)<d(i, H)

The condition 1) means that the transmission cost to the upstream node is smaller than to the CH. The condition 2) means that the upstream node is nearer to the CH than node i.

(4)Phase 4: Route set up

All nodes broadcast the Upstream message that includes the distance to the upstream node after the decision of the upstream node in Phase 3. All nodes are notified that the all upstream nodes of all nodes by this message. All nodes can set up the downstream node set.

(5)Phase 5: Blocking set calculation

In this phase, the node j which is blocked by node i is calculated, when node i transmit to the upstream node. The condition is as follows.

d(i, ui)>d(i, uj)

Now, ui is the upstream node of i and uj is the upstream node of j.

The nodes that satisfy the condition are called as the Block node list. Each node broadcasts the list. The node that the message receives makes the Block table that is the node set blocks to transmit to the upstream node.

(6)Phase 6: TDMA scheduling

In this phase, each node calculates the TDMA schedules that maximize the parallel communication that avoid the collision.

(7)Phase 7: Data transmission

In this phase, each node senses the environment and transmits the data based on the TDMA schedule made by the previous phase.

2.4 MR-LEACH

MR-LEACH [11] uses multi-hop communication to reduce the electric power consumption. In this method, the residual battery power is considered to select the CH node. There are two phases to construct clusters in this method. First phase is a cluster construction phase and second phase is a route construction phase.

(1)Cluster construction phase

At first in the round, all nodes in the network exchange a Hello message with the nodes in the area of distance *r*. In the message, the sender node ID and residual battery power are included. Each node receives the Hello messages from neighboring nodes and manages this information. After the exchange of the Hello message, each node compares the residual battery power. If a node has the maximum battery power in the neighboring nodes, the node becomes CH and sends CH advertisement message. In the message, the node ID of the CH is included. If non-CH node receives the CH advertisement message from neighboring node, the node ID and the strength of received signal are stored in the memory. After receiving some advertisement messages, the non-CH node select the CH which has the strongest received signal.

(2)Route construction phase

At first in this phase, the sink node broadcasts the confirmation message to all nodes. The all CH nodes which receive the confirmation message broadcast the response message within the range of *r'* (*r'*>*r*).

The sink node receives the response messages and stores the ID of CH node to the node list of the layer 1. In a word, the list of layer 1 is the list of CH in the range of *r'* from the sink. Next, the sink node broadcasts the confirmation message including the node list of layer 1.

The CH node which receives the confirmation message confirms whether this node is included in the list. If the node included in the list, the node understands that the node is included in the layer 1. Otherwise, the node broadcasts the response message within the range of *r'*.

If CH in layer 1 receives the response from other CH, it sends the node ID of the response message to the sink. If the sink receives the message, it stores the node ID to the node list of the layer 2.

After receiving all layer 2 node IDs, the sink node broadcasts the confirmation message including the node list of layer 1 and 2. Then, the CH which is not included in the layer 1 and 2 responses the message.

This process is iterated until all CH doesn't respond. As a result, a hierarchical cluster that centers on the sink is composed like Fig.2.2.

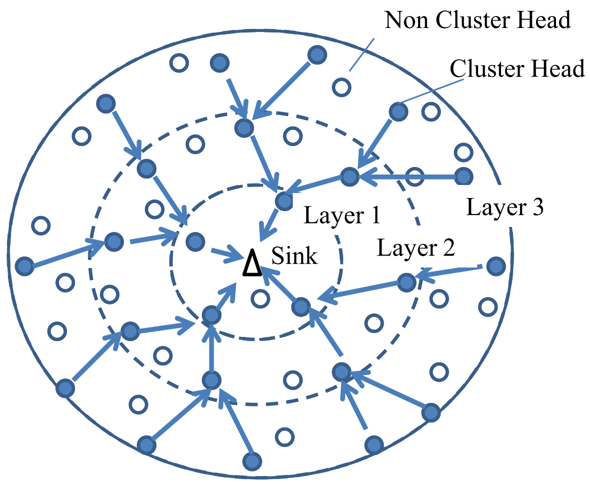

Fig.2.2 Route construction in MR-LEACH.

2.5 Other related works

There is PEGASIS[13] as one of the other methods. PEGASIS uses the chain structure instead of the cluster. TPC[14] uses the chain structure in the intra-cluster communication. These methods are based on location information. Because our method is not based on location information, these methods are not compared in this paper.

RPL[15] is a routing protocol for low power and lossy networks. Security improvement of RPL is proposed in [16]. Performance of data gathering is improved in [17]. These protocols are offering routing based on the reliability of the link. Because usual reliability is assumed in the link in our method, these methods are not compared in this paper.

3 CLUSTERING ALGORITHM

3.1 Basic concept

In this section, we propose the clustering method to consider the adjacent node set and the residual electric power. In the proposal method, all nodes other than the sink exchange the Hello message of each round, which contains information on own residual electric power and the adjacent node set. As a result, each node can maintain information on the adjacent node set and the residual electric power for the nodes.

At first, the sink selects the first CH. Other CHs are selected radially by the first CH to cover the surrounding nodes. To prevent flooding of the CH, the CH is selected to cover a lot of nodes. CH has been selected like evenly consuming the electric power by considering the amount of the electric power remainder. The transmission power is saved as the small range for collection of the sensor data. The range is controlled by the sink node. The collection of the sensor data from the node which cannot communicate with the sink node directly becomes possible by using multi-hop communication of CHs.

The transmission power used in the clustering phase is small at first. The transmission power means the size of the cluster. In our algorithm, some sizes are prepared to the cluster. If all nodes in the network are not covered by any clusters, the size of the cluster is enlarged and clustering is executed again.

3.2 Cluster head selection

In this section, the algorithm for CHs selection in a round is explained. It is designed by modifying the algorithm for the landmark node selection in ad hoc networks[17]. The following is the process of the algorithm.

(1)Hello message exchange phase.
(2)Representative node selection phase.
(3)CH selection phase.
(4)End report phase.

Each phase is explained as follows.

(1) Hello message exchange phase.

When a new round begins, the sink node broadcasts the message that request to exchange the Hello messages with each other. This request message includes the maximum transmission range R in this round.

Each node broadcasts the Hello message includes the node ID and residual electric power after receives the request message. Each node receives the Hello message from other nodes and constructs the adjacent node list (ANL) which includes the adjacent node IDs and residual electric power (REP) of them. The adjacent node means the node which exists within the range R. Each node broadcasts the second Hello message which includes the ANL after the first Hello message. Each node receives the second Hello message and constructs the two-hop adjacent node list (TANL). TANL means the list of the nodes which can be reached in just 2 hops from the node.

(2) Representative node selection phase.

After the Hello message exchange phase, each node selects the representative node. The node which has the largest REP is selected as the representative node. Because all nodes receive the Hello message, all nodes can learn who selected as a representative node. Now, the representative node is the one of the CHs.

(3) CH selection of representative node.

After the fixed time, representative node L starts the selection of the other CHs. L calculates evaluation value v_n for all nodes included in the ANL. Here, evaluation value v_n of adjacent node n is calculated by the following equation (3.1) by using c_n: the number of overlapping nodes between adjacent nodes of L and adjacent nodes of n, e_n: the residual electric power of node n, and e_{ave}: the mean value of the residual electric power of all adjacent nodes of L.

$$v_n = \frac{1}{c_n} * \left(\frac{e_n}{e_{ave}} \right)^w \qquad (3.1)$$

Here, the w is a constant which shows the weight of the residual electric power. In a word, the evaluation value rises in the node that the number of overlapping node between adjacent nodes of n and adjacent node of L is small, and the residual electric power is large. The node n1 with the largest evaluation value is selected as the one of the CHs.

The next CH would be selected if the 2-hop-coverage is smaller than the threshold. The ratio 2-hop-coverage means the ratio between the number of TANL of L and the number of node covered by the n1. L calculates evaluation values v_n of all adjacent nodes n except n1 again. v_n is calculated for the set of nodes which excluded common part with adjacent node of n1 from TANL of L, that is called as non-covered node list thereafter. v_n is calculated by the following equation (3.2) using d_n: the number of overlapping nodes between non-covered node and the adjacent nodes of n, e_n: the residual electric power of n, e_{ave}: the average residual electric power of the adjacent all node of L except n1.

$$v_n = d_n * \left(\frac{e_n}{e_{ave}} \right)^w \qquad (3.2)$$

Here, the evaluation value rises in the node that the number of overlapping node between adjacent nodes of n and non-covered node is large, and the residual electric power is large. The node n2 that has the biggest evaluation value is selected to be the next CH as well as n1, and the adjacent node of n2 is deleted from the list of non-covered nodes. And, if 2-hop-coverage does not exceed the threshold, the next CH is repeatedly chosen until the threshold of 2-hop-coverage is exceeded.

When representative node L finishes the selection of the CH, it broadcasts the CH advertisement in the range R. The CH advertisement includes information on the selected CHs and non-covered node list. The non-covered node list in the advertisement is called as the 3-hop-check-list. Adjacent node n of L which receives the CH advertisement of L adds L to the adjacent CH list of oneself. If n is selected as the CH, L is called as the n's parent CH and n starts to select the next CH with the same process.

When the selection of the CH is finished, node n creates 3-hop-check response for 3-hop-check-list from the parents CH. As for 3- hop-check response, the node which can reach by two hops from n via the adjacent CH of n is stored, which is included in the 3-hop-check-list. The adjacent CHs include the CH that n newly selects. In a word, it becomes nodes which can reach by three hops from the parents CH. After the calculation, n broadcasts the CH advertisement in the range R. The CH advertisement includes information on the selected CHs, 3-hop-check-list of n, and 3- hop-check response to parents CH.

After transmitting 3-hop-check-list, CH n waits 3-hop-check response during the fixed time. n deletes the node included in the non-covered node list, that found in the 3-hop-check response. If the fixed time ends and 3-hop-check-list does not empty, the evaluation value of the node included in the adjacent node list of n is calculated again based on expression (3.2). Node n2 whose evaluation value is the highest is newly chosen to be a CH, and 3-hop-check-list is transmitted to n2 on CH-request message.

CH n2 selects the CH according to the procedure of (3) when this is received, and broadcasts CH advertisement including 3-hop-check response to n. When 3-hop-check-list does not empty even if n receives this, CH n repeats these processes until 3-hop-check-list empties.

(4)End report phase.

When the non-covered node list empties, and the CH is not selected newly, CH n transmits the end report of the CH selection to the parents CH. In addition, when the end report is received from the all child CHs, and the non-covered node list empties, the parents CH transmits the end report to the upper parents CH. Thus, all nodes on the network can belong to either of CH when the end report is forwarded, and the sink receives the end report. Therefore, the selection of the CH is ended now.

When the selection of the CH ends, the sink node broadcast the request to participate to a cluster. The node which received this makes the CH with the strongest RSSI of the CH advertisement a parents CH among lists of the adjacent CH, and transmits the participation request. On the other hand, in case of the child CH of the CH receives the request to participate to a cluster, the child CH rebroadcast the message. As a result, all nodes will participate to either of CH.

The CH makes the cluster member's data transmission schedule and broadcasts it after the fixed time later of broadcast of the request to participate to a cluster. When the schedule is received, the child node maintains the order of the transmission until the round changes.

However, there is the case that some nodes do not belong to any clusters because the transmission range R is too small. In this algorithm, the representative node enlarges the transmission range R and restarts the clustering.

Message sequence chart of proposed algorithm is shown in Fig.3.1. Representative node in Fig.3.1 is indicated as CH1. CH2 and CH3 are selected CH by CH1 and CH2 respectively. CHx is extra selected CH by CH1 after receiving CH advertisement from CH2. CHy is selected CH by CHx.

3.3 Collection of sensing data

The timing of data collection is notified by the data request message from the sink node. If the child CH node of the sink receives the data request, the CH rebroadcasts the message to the cluster members. If there is CH node in the cluster, it rebroadcasts the message. The message is spread in all nodes by repeating this process.

If a CH node receives all sensing data from all member nodes and child CHs, it compresses these data and own data, and send to the upper CH. The parent CH also sends the data to the upper CH similarly.

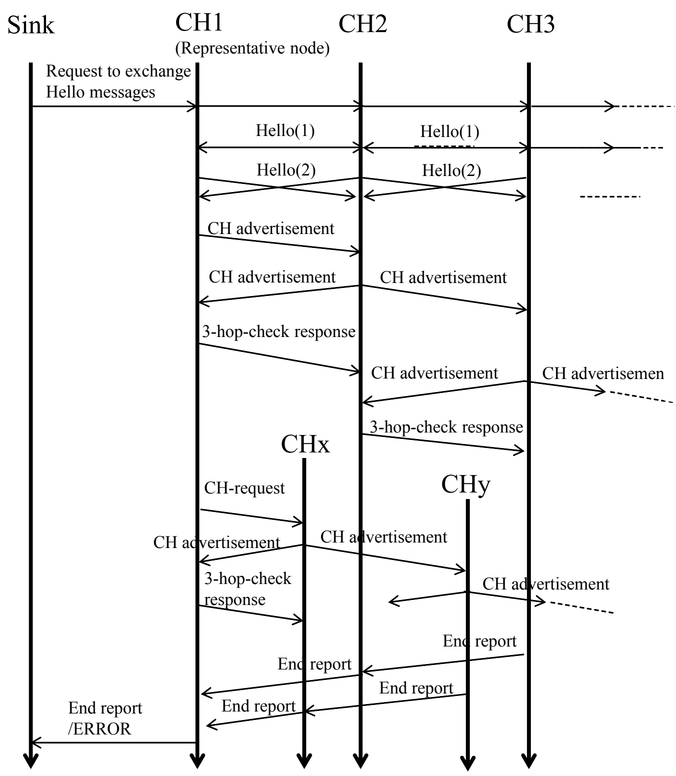

Fig.3.1 Message sequence chart of proposed algorithm.

Thus, the sensor data that all nodes collected from the end of the network is collected in the sink. When the sink finishes collecting all data, one cycle is completed. After some cycles are repeated, it moves to the next round.

4 SIMULATION

Simulation program written in Java is used to evaluate the LEACH, HEED, HIT, MR-LEACH and proposed method. Neither a physical layer nor the MAC layer are included in the simulation program. The situation that the sensors are scattered to the observation area that the person cannot enter is assumed. The sink node is out of the observation area. The assumed observation area is shown in the figure as follows.

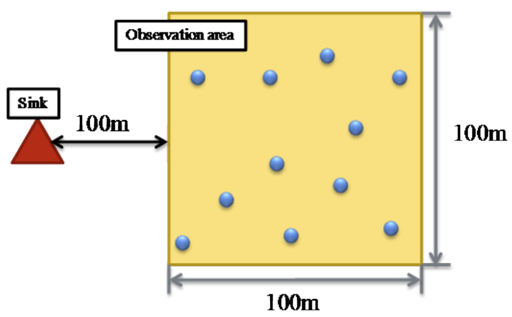

Fig.4.1 Simulation environment.

4.1 Simulation environment

In the simulation environment, the observation area is 100m x 100m and the sink node is located at the point that 50m to south and 100m to west from the northwest end point of the observation area. Maximum transmission range of the node is 150m. In the proposed method, 25m is used CH selection process in the observation area.

Power consumption model of the transmission and reception is used in [1]. Consumed power E_T for k bits transmission to the node that d m away from sender is expressed in the equation (4.1). The Consumed power E_R for k bits reception is equation (4.2).

$$E_T = E_{elec}k + \varepsilon_{amp}kd^2 \qquad (4.1)$$

$$E_R = E_{elec}k \qquad (4.2)$$

Here, E_{elec} is the consumed power to send/receive 1 bit, ε_{amp} is the consumed power to send the data.

The simulation is executed until all nodes exhaust the electric power. After the simulation, the number of cycles, the maximum and average residual electric power is compared. Common parameters used in the simulation are shown in Table 4.1.

Table 4.1 Common parameters.

Parameter	Value
E_{elec}	50nJ/bit
ε_{amp}	100pJ/bit/m^2
Control message size	500bits
Data size	2000bits
Number of nodes	100
Max transmission range	150m
Step of transmission range R	20m, 30m, 40m, 150m (4 steps)

The number of cycles in a round and the probability of the node to try to become CH should be decided in LEACH. From the preliminary simulation to decide the parameters, the number of cycles and probability is decided as 10 and 0.05 respectively.

The number of cycles in a round and the probability of the node to try to become CH (CH_{prob}) should be decided in HEED. From the preliminary simulation like as LEACH, the number of cycles and probability CH_{prob} is decided as 10 and 0.1 respectively.

In HIT, the number of cycles in a round is decided as 250 from the preliminary simulation.

The number of cycles in a round is 50, the threshold of 2-hop-coverage is 0.7, and the weight *w* of the residual electric power is 2.0. These parameters are obtained from the preliminary simulation. Moreover, there are some parameters in our and previous algorithms are selected the best values obtained from the preliminary experiments.

At first, the transmission range R is set as 20m, the smallest size. If there are any nodes which are not included in any clusters, the range R is changed to the next size and the clustering process restarts. The maximum size of R can cover the all nodes in the field.

4.2 Simulator model

The simulator used for our evaluation is based on the discrete event simulation. It is able to set up the arrangement of nodes and reproduce the reachability of message frame based on the distance between nodes. The power consumption model used in LEACH is also implemented.

In this method and the simulation environment, transmitting power is required to be controllable for the appropriate strength to the specified distance between nodes. The according to the received signal strength, the distance between sender node and receiver node can be estimated. These assumptions are used in the previous researches, and are not peculiar to our method.

Moreover, our simulator doesn't include the model of the packet loss caused by the interference or noise. In a word, the frame will be correctly sent and received without packet loss if the nodes in the transmission range of RF. The reason is that we would like to compare the pure cost to construct the cluster and battery power efficiency to collect the sensed data. Because the properties of packet loss and collision depend on the physical layer and MAC layer, we thought that the ideal environment is a best way to compare the algorithms. Moreover, I might think that I can reduce the packet loss and collision by using the wide inter-frame interval or the TDM based schedule. The message cost to cluster in an ideal environment that doesn't contain the frame loss or collision properties can be evaluated by using this simulator. The power consumption for the message transmission and reception also can be evaluated.

4.3 Simulation results and discussion

The first simulation result is the number of node alive until the all nodes exhaust the electric power (Fig.4.2). From the simulation results, the number of node alive of proposed method becomes better performance than other methods.

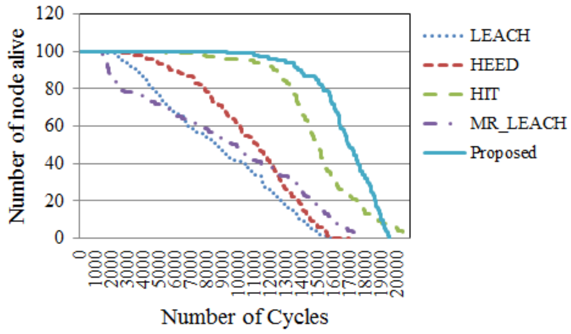

Fig.4.2 Number of node alive.

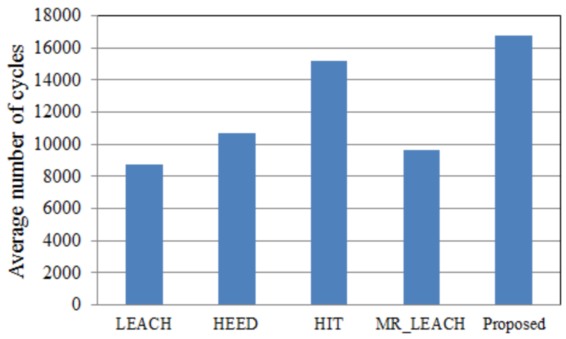

Fig4.3 Average Number of cycles.

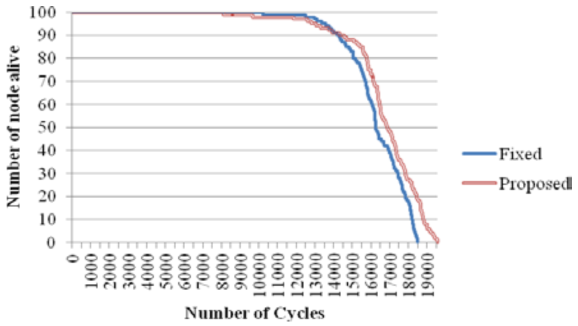

Fig.4.4 Number of node alive.

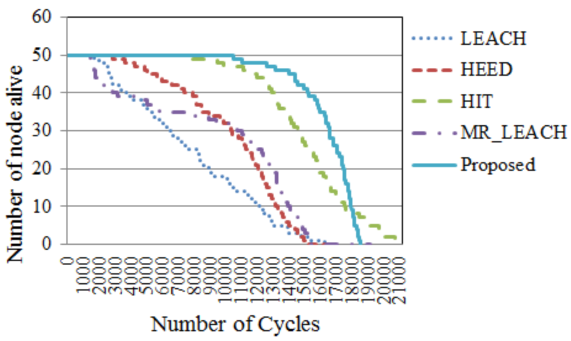

Fig.4.5 Number of node alive.(node = 50)

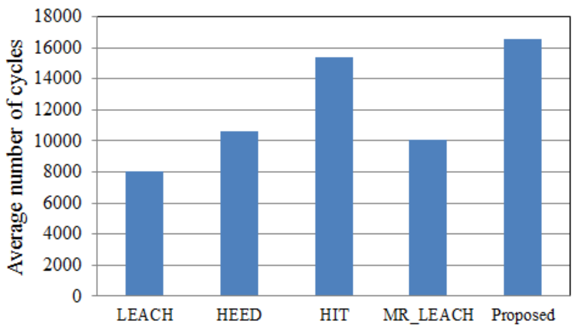

Fig4.6 Average Number of cycles.(node = 50)

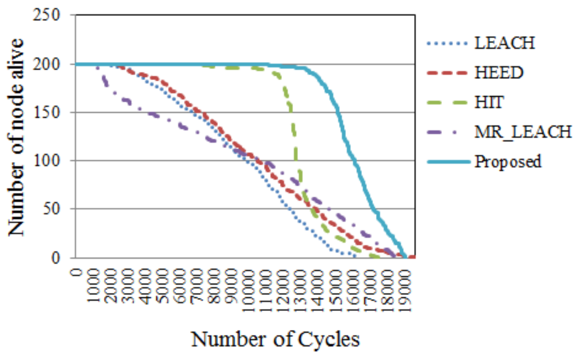

Fig.4.7 Number of node alive.(node = 200)

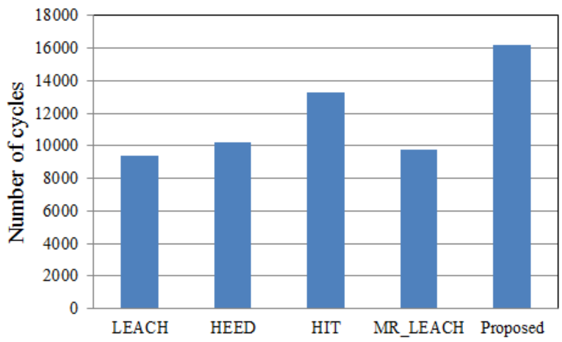

Fig4.8 Average Number of cycles.(node = 200)

Around 1700 cycle, the number of node alive becomes smaller than HIT. However, the number of cycles that 80% node alive becomes 25% longer than HIT. It means that the life time of the sensor network is improved.

Figure 4.3 shows the average number of cycles of node until the all nodes exhaust the electric power. The result of the proposed method is about 10% better than HIT.

Figure 4.4 shows the comparison between the fixed transmission power and the changed transmission power. The changed transmission power proposed in this paper is better than fixed one.

Figure 4.5 to Fig.4.8 show the results of the number of node alive and average number of cycles until the all nodes exhaust the electric power. The number of node is 50 and 200 respectively. Our algorithm shows a good result in each number of nodes. Especially, there is a difference with other methods remarkably when there are a lot of nodes in the network.

5 CONCLUSIONS

In this paper, we proposed energy-efficient clustering algorithm considering adjacent nodes and residual electric power. In addition, we inspected effectiveness of our method by comparing our method with the traditional method by the simulation.

As a result, proposed method showed higher performance than LEACH, HEED, HIT and MR-LEACH. The number of cycles that 80% node alive becomes 125 % of HIT algorithm.

However, the evaluation was executed in an ideal environment. The communication interference should be discussed in the real environment. Especially, the packet loss by the interference is the problem in our method. In our algorithm, the exchange of the Hello packet is the most critical phase we think. In our future work, the phase will be changed from broadcast to flooding of Hello messages.

On the other hand, we think the difference of shape and the size of the range will not make a big influence. Because the clustering process uses the hand-shake process, the uni-directional link based on the difference of the range can be avoided.

Furthermore, parameters used in our algorithm like as *w* which is obtained from the preliminary experiment should be selected from experiment in the real environment.

Therefore, future work of our research is detailed evaluation based on the well-known simulator which includes a physical layer model and MAC layer model. Improvement of our algorithm to consider the coverage of the sensor area is also our future work.

REFERENCES

[1] W. R. Heinzelman, J. Kulik, and H. Balakrishnan, “Adaptive protocols for information dissemination in wireless sensor networks,” Proceedings of the 5th annual ACM/IEEE international conference on Mobile computing and networking (MobiCom '99), pp. 174-185 (1999).

[2] C. Intanagonwiwat, R. Govindan, D. Estrin, and J. Heidemann, “Directed diffusion for wireless sensor networking, ” IEEE/ACM Transactions on Networking (TON), Vol. 11, Issue 1, pp. 2-16 (2003).

[3] F. Ye, G. Zhong, S. Lu, and L. Zhang, “GRAdient Broadcast: A Robust Data Delivery Protocol for Large Scale Sensor Networks,” ACM Wireless Networks, Vol. 11, pp. 285-298 (2005).

[4] J. Hill, R. Szewczyk, A. Woo, S. Hollar, D. Culler, and K. Pister, “System architecture directions for networked sensors,” Proceedings of the 9th international conference on Architectural support for programming languages and operating systems, pp. 93-104 (2000).

[5] J. Zhang, Z. Yang, B. Cheng, and P. McKinley, “Adding Safeness to Dynamic Adaptation Techniques,” Proceedings of the ICSE 2004 Workshop Architecting Dependable Systems, pp. 17-21 (2004).

[6] H. Luo, F. Ye, J. Cheng, S. Lu, and L. Zhang, “TTDD: A Two-tier Data Dissemination Model for Large-scale Wireless Sensor Networks,” Proceedings of the 8th annual ACM/IEEE international conference on Mobile computing and networking (MobiCom '02), pp. 148-159 (2003).

[7] T. He, J. A. Stankovic, C. Lu, and T. Abdelzaher, “SPEED: a stateless protocol for real-time communication in sensor networks,” Proceedings of the 23rd International Conference on Distributed Computing Systems, pp. 46-55 (2003).

[8] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “Energy-Efficient Communication Protocol for Wireless Microsensor Networks,” Proceedings of the 33rd Hawaii International Conference on System Sciences, pp. 1-10 (2000).

[9] O. Younis, and S. Fahmy, “HEED: A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks,” IEEE Transaction on Mobile Computing, Vol. 3, No. 4, pp. 366-379 (2004).

[10] B. J. Culpepper, L. Dung, and M. Moh, “Design and Analysis of Hybrid Indirect Transmissions (HIT) for Data Gathering in Wireless Micro Sensor Networks,” ACM Mobile Computing and Communications Review, Vol. 3, pp. 61-83 (2004).

[11] M. O. Farooq, A. B. Dogar, and G. A. Shah, “MR-LEACH: Multi-hop Routing with Low Energy Adaptive Clustering Hierarchy,” Proceedings of the 4th International Conference on Sensor Technologies and Applications (SENSORCOMM 2010), pp. 262-268 (2010).

[12] S. Toyoda, and F. Sato, “Energy-Effective Clustering Algorithm Based on Adjacent Nodes and Residual Electric Power in Wireless Sensor Networks,” Proceedings of the 26th International Conference on Advanced Information Networking and Applications Workshops (WAINA), pp. 601-606 (2012).

[13] S. Lindsey, C. Raghavenda, and K. M. Sivalingam, “Data Gathering Algorithms in Sensor Networks Using Energy Metrics,” IEEE Transactions on Parallel and Distributed Systems, Vol. 13, No. 9, pp. 924-935 (2002).

[14] W. Choi, P. Shah, and S. K. Das, “A framework for energy-saving data gathering using two-phase clustering in wireless sensor networks,” Proceedings of the 1st Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services, pp. 203-212 (2004).

[15] RPL, “IPv6 Routing Protocol for Low power and Lossy Networks,” ROLL IETF Internet-Draft (2011).

[16] A. Dvir, T. Holczer, and L. Buttyan, “VeRA - Version Number and Rank Authentication in RPL,” Proceedings of the IEEE 8th International Conference on Mobile Adhoc and Sensor Systems (MASS 2011), pp. 709-714 (2011).

[17] B. Pavkovi, F. Theoleyre, and A. Duda, “Multipath opportunistic RPL routing over IEEE 802.15.4,” Proceedings of the 14th ACM international conference on Modeling, analysis and simulation of wireless and mobile systems (MSWiM '11), pp. 179-186 (2011).

[18] [18] J. Ushijima, M. Okino, T. Kato, and S. Ito, “Proposal and Evaluation of a Selecting Method of Landmark Nodes for Message Relaying over High Density Ad hoc Network,” IEICE technical report 103(202), pp. 93-96 (2003).

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Shin-nosuke Toyoda received BSc and MSc from Faculty of Science, Toho University in 2011 and 2013. He joined Japan Process Development Co., LTD in 2013. His research interest includes the wireless sensor networks and mobile computing. He is a member of Information Processing Society of Japan (IPSJ).

Fumiaki Sato received BE from Iwate University in 1984. He received ME and DE from Tohoku University in 1986 and 1992 respectively. He joined Mitsubishi Electric Corporation in 1986. He served as Associate Professor in Shizuoka University from 1996. He is Professor of Toho University from 2005. His research areas of interest include communication protocols, ad-hoc networks, sensor networks, P2P systems, network security, distributed processing systems, and communication software design. He is a member of IPSJ, IEEE, and ACM.