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무선 센서 네트워크에서 시간지연 기반 향상된 커버리지 효율적인 클러스터링 방안

(An Improved Coverage Efficient Clustering Method based on Time Delay for Wireless Sensor Networks)

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요 약

에너지 효율적인 동작은 무선 센서 네트워크에 전체 수명을 연장하기 위한 원천적인 기술요소이다. 클러스터 기반 프로토콜은 데이터를 수집하는 과정에서 에너지를 보존하기 위한 가장 널리 쓰이는 기법이다. 본 논문은 시간 지연을 기반으로 에너지를 인식하면서 자율적으로 클러스터를 구성하는 방안을 제시한다. 제안된 방안은 3단계로 구성되어 있다. 먼저 노드의 에너지 잔류를 반영한 시간 지연을 수단으로 임의 클러스터의 커버리지 효율성을 반영하여 후보 클러스터 헤더가 선정된다. 다음으로 후보 클러스터 헤더중에 클러스터 헤더를 정의하기 위해서 시간지연이 다시 적용된다. 마지막으로 임의 클러스터에 포함되지 못한 고아노드의 문제를 해결한다. 시뮬레이션 결과는 제안된 방안이 LEACH[4] 방법보다 네트워크의 수명을 3배정도 늘리고 있음을 보인다. 또한 클러스터 헤더의 변화가 상대적으로 작으며, 클러스터 헤더의 에너지가 작게 소모됨을 보이고 있다.

Abstract

Energy efficient operations are essential to increase the life time of wireless sensor network. A cluster-based protocol is the most common approach to preserve energy during a data aggregation. This paper deals with an energy awareness and autonomous clustering method based on time delay. This method consists of three stages. In the first phase, Candidate Cluster Headers(CCHs) are selected based on a time delay which reflects the remaining energy of a node, with considering coverage efficiency of a cluster. Then, time delay is again applied to declare Cluster Headers(CHs) out of the CCHs. In the last phase, the issue on an orphan node which is not included into a cluster is resolved. The simulation results show that the proposed method increases the life time of the network around triple times longer than LEACH(Low Energy Adaptive Cluster Hierarchy)[4]. Moreover, the cluster header frequency is less diverse, and the energy on cluster heads is less spent.

Keywords : wireless sensor networks, clustering, autonomous, energy awareness, LEACH

Ⅰ. Introduction

Due to technological advances, the manufacturing of small and low cost of sensors becomes technically and economically feasible[1]. Recently, using Wireless Sensor Network(WSN), an increasing interest has been reported in various applications, including large scale environment monitoring, battle field surveillance, security management, and location tracking. In these applications, hundreds of sensor nodes are left to be unattended to report monitored data to users. Since sensor nodes are placed randomly, and sometimes are

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deployed in underwater[10], it is impossible to replace batteries often when batteries run out. Therefore, reducing energy consumption is the most important design consideration for sensor networks.

If the sensor nodes are deployed densely, there is possibility of tremendous redundant data. Various routing protocols have been proposed for wireless sensor networks to alleviate the data redundancy problem. Generally speaking, two classes are defined: flat-based[5] and cluster-based[8]. In flat-based routing protocols, all nodes typically are assigned equal roles and functions. The Sensor Protocols for Information via Negotiation(SPIN)[5] protocol belongs to flat-based protocols. In the case of SPIN, a mount of energy spent in communication among nodes, such as advertising, requesting, this reduces the lifetime of network. Therefore, flat-based routings are not preferred in a large scale WSN[8].

In cluster-based routing protocols, nodes are partitioned into a number of small groups called clusters. In each cluster, a Cluster Header(CH) node aggregates the data from other nodes, which are called Cluster Member(CM) nodes, and sends the aggregated data to the central base through other CHs or directly. Clustering concept reduces the channel contention, and packet collisions as well, resulting in better network throughput under high load[9]. Because a cluster-based routing protocol results in a better throughput and reduces messages passing among the sensor node, we develop a new cluster formation method.

The effectiveness of clustering formation is a great role for cluster-based routing protocols. In previous work, we presented a CETD(Coverage Efficient Based on Time Delay) clustering method for wireless sensor networks. However, two communication ranges are required for cluster header selection, that increases the design complexity of sensors. In this paper, an ICETD(Improved CETD) method based on the remaining energy and coverage efficiency of sensor nodes is proposed. We define the coverage efficiency of a node i, as the more residual covered area by node i excluding the areas covered by all other nodes, the more coverage efficiency of node i has. A node with a higher energy level and more coverage efficiency is chosen as a CH. In addition, ICETD is a distributed competitive algorithm, where CHs are selected locally. ICETD is different from LEACH[4] in terms of less computation, and from ACS(Autonomous Clustering Scheme)[2] in terms of location requirement.

The remainder of this paper is organized as follows. Section II covers related work in this area. In section III, we discuss network model and radio model. Details description of the proposed protocol is given in section IV. Simulation results and conclusion are in the last two sections.

II. Related Works

LEACH is a classic and probability based clustering protocol for periodical data gathering applications in WSN. Sensors elect themselves as CHs at any given time with a predefined probability. These CHs advertise their status by broadcasting a message. All other nodes determine to which cluster it wants to join in based on the received signal strengths. LEACH provides load balancing, scalability, and energy saving effectively[7]. Nevertheless, the probability that there is only one CH or there is no CH is high when the desired value of CH is small. Thus, when no CH is elected, all nodes must send data to base station directly.

ACS[2] is a distributed cluster-based protocol. However, every node must equip a GPS-like device or other positioning techniques, and extensive computation has to be performed to calculate delay time. This may be power consuming, and increase the cost of a sensor node. Furthermore, the number of CHs centralizes in 10, which is not an optimal number for a 100-node network according to the reference[6]. The number CHs are excessive in ACS, and an elimination on CHs must be conducted.

CETD[3] is a distributed and autonomous clustering protocol. CH selection is based on time delay. A node with a higher energy level declares itself as a *Candidate Cluster Header*(CCH) earlier. A self-pruning algorithm is performed to select best CHs among CCHs. Nevertheless, two communication ranges must be required for cluster header selection process.

The contribution of this paper is that CH selection is not based on probability. In addition, only one communication range is required during clustering, and nodes are not necessary equipped with GPS. Furthermore, the there is less computation during CH selection procedure.

Ⅲ. Network and Radio Model

Consider a sensor network consisting of hundreds of sensor networks dispersed on a rectangular field. We assume the nodes are homeogenous, and have the same capability of sensing, processing, and communication. Nodes in the network are quasi-stationary. Every node is assigned with a unique ID, and a fixed sink node is far away from to all sensors. Furthermore, sensors are sensing the environment at a fixed rate, and thus always have data to send to the BS(Base Station).

The radio model has been borrowed from the reference[4]. The total transmission cost E_{tx} for transmitting a *k* bit message to a distance *d* meter is given by equation(1), and energy E_{rx} spent on receiving a *k* bit message is given by equation(2).

$$E_{tx}(t,d) = \begin{cases} k \times E_{elec} + k \times e_{fs} \times d^2, \ d < d_o \\ k \times E_{elec} + k \times e_{mp} \times d^4, \ d \geq d_o \end{cases} \quad (1)$$

$$E_{rx}(k) = k \times E_{elec} \quad (2)$$

The electronic energy, E_{elec} depends on factors such as the digital coding, modulation, filtering, and spreading of the signal[9]. e_{fs} and e_{mp} stand for the amplifier energy. If the transmission distance is greater than a threshold value d_o, where is defined as 87m in reference[9], *multi-path(ms)* fading channel model is used, otherwise, *free space(fs)* fading channel model is applied.

Ⅳ. Cluster Header Selection

4.1 Cluster Setup

As discussed previously, our proposed method for CH selection is distributed, and generated locally without BS involvement. In the setup phase, every node calculates its own *delay* time depending on its remaining energy level as follows:

$$T_{delay} = (1 - E_{remaining} / E_{\max}) + \alpha \quad (3)$$

E_{max} is the initial power energy of battery, and $E_{remaining}$ is the residual energy of a α node. α is a random number that prevents message colliding when nodes have the same remaining energy level. Thus, α has been chosen between [0, 0.1]. A node broadcasts a CCH declaration message when delay time expires. From the above equation, it can be seen that a node with a higher energy level has a shorter T_{delay}, that is, a higher energy level node broadcasts a CCH declaration message always earlier than a lower energy level node.

In the setup phase, there are totally four states: *Tentative Member(TM), CCH, CM,* and *CH*. All the nodes are in TM state before T_{delay} expires. A node transfers from TM state to CCH state if a CCH declaration message is broadcast. Also a node transfers to CM state from either TM or CCH state if three CCH declaration messages are heard from neighboring nodes. CH nodes are the final cluster headers. The reason of a node quits broadcasting a CCH message comes from the low or none coverage efficiency after three CCH declaration messages are received. Because its neighboring nodes have covered all or most area that this node covers. The following example is to explain it more clearly.

Fig.1 shows an elimination strategy of a redundant cluster. TM nodes are *i, j, k,* and *m* with their delay time is 0.22 0.1, 0.2 and 0.21 respectively, with reflecting their remaining energy. Node *i* received a

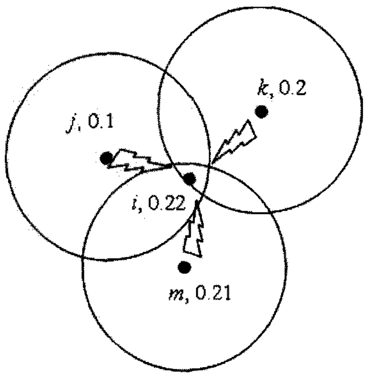


그림 1. 중복 클러스터 제거 전략
Fig. 1. Eliminating strategy of a redundant cluster.

CCH declaration message from node *j*, since node *j* has the shortest delay time. After that, coverage efficiency of node *i* gets lower. After the node *i* received another two CCH declaration messages from node *k* and *m*, its coverage efficiency could be extremely low or zero. Therefore, A TM node *i* is not necessary to be a CCH node, and becomes a CM. This is a part of CH elimination strategy in order to achieve an optimal number of CH in the network.

4.2 Operational Details

1) stage one : After cluster setup phase, every node starts to broadcast a CCH declaration message based on T_{delay}. The main point is that a node becomes a CM node whenever three CCH messages are received. Since the coverage efficiency of such node is very low, it gives up for declaring itself as a CCH node, and becomes a CM node. Meanwhile, a CCH node becomes a CM node as well if three CCH declaration messages are received from neighboring nodes, whose delay time expires later. A node turns into a sleep mode as long as it is a CM node in order to save energy consumption. This stage is named as *broadcasting CCH declaration messages*, and is illustrated in Fig.2. The number denotes the sequence of declaring a CCH declaration message, that is, node 1 broadcasts first, after that node 2 broadcasts, and so on. Some nodes do not broadcast a CCH declaration message because they have received three CCH messages from neighboring nodes before its own delay time expires.

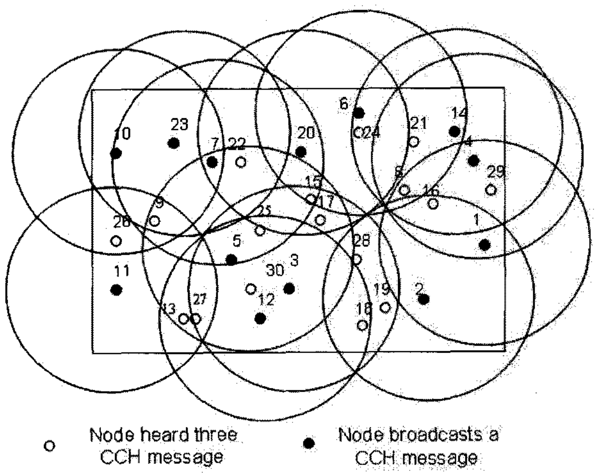


그림 2. CCH 선언 메시지 브로드케스팅
Fig. 2. Broadcasting CCH declaration messages.

Depending on the network topology, excessive CCH nodes may happen after stage one. Network efficiency degrades if all CCHs become CHs. According to[6], the network is the most efficient when the number of CHs is between three and five in a 100-node network. Therefore, reducing the number of CCHs is required if excessive CCHs exist. The CH elimination strategy for reducing excessive CCHs is that only one CH is permitted in the same cluster. Stage one takes 1.1 seconds.

2) stage two : The second stage starts at 1.1 seconds. It aims to reduce the number of CCH nodes. This stage is named as the *first phase CH competition*. Nodes with black dots in Fig.3 are CCH nodes which are generated from stage one. At this stage, all CM nodes are still in the sleep mode, and only CCH nodes are awake. Because CHs have not generated yet, a CM node does not want to hear a CH declaration message from a CCH node.

A CCH node competes to be a CH node by broadcasting a CH declaration message at a random time α , α is still chosen between [0, 0.1]. According to our self-elimination strategy, only one CH is permitted in a cluster. Therefore, a CCH node becomes a CM node if a CH declaration message, that contains a higher energy level than itself, is received. Otherwise, it becomes as a CH. For an example, node 12 received

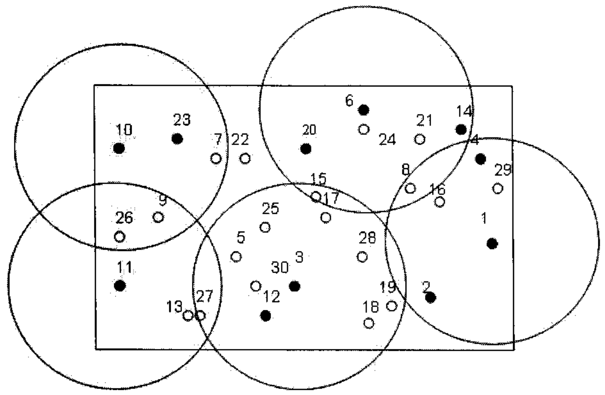


그림 3. CH 경쟁의 첫 번째 단계
Fig. 3. The first phase for CH competition.

a CH declaration message from node 3, and compares its energy level with node 3 in Fig.3. Then, node 12 becomes a CM node based on our assumption that a smaller number denotes a higher energy level. Stage two takes 0.1 second, and CH nodes are generated at the end of stage two. At 1.2 second, all CM nodes wake up to receive a CH declaration message from CHs.

Nevertheless, a node has to transmit data to BS directly if no CH declaration message is received. Such a node is called an orphan node in our paper. The *second phase CH competition* is introduced for solving an orphan node issue.

3) stage three: All nodes turn into the sleep mode again except for orphan nodes at the beginning of stage three. Then an orphan node can be considered as a CCH node in the stage two. In Fig.4, an orphan node 22 broadcasts a CH declaration message at a random α. When multiple orphan nodes exist in a cluster range, we still only select one orphan node as a CH in a cluster. The CH competition among orphan nodes follows the same strategy in the stage two. The final cluster formation is shown in Fig.4. At the end of stage three, all nodes wake up, and receive a CH declaration message for CH nodes. A CM node chooses a CH whichever is the closest.

In the case that no orphan nodes happen, all nodes just keep silent in this stage, and select the best CH

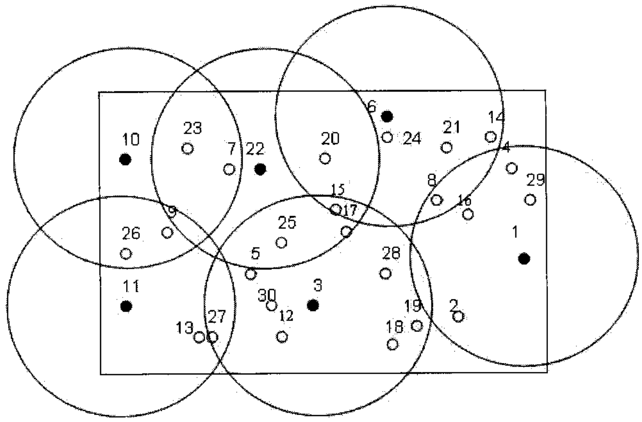


그림 4. CH 경재의 두 번째 단계
Fig. 4. The second phase for CH competition.

after stage three ends. The stage three only takes 0.1 second, therefore, it does not increase too much overhead for the cluster formation when there is not an orphan node.

In the proposed method, CCH nodes are generated firstly, and then the CH declaration message is broadcast out of CCH nodes in stage two. In stage three, an orphan node considers itself as a CCH node and redoes the procedure in stage two, meanwhile, all other nodes are in the sleep node so that they cannot hear any CH declaration messages, which are used as for competing to be CHs among orphan nodes. At the end of stage three, CH nodes are generated.

4.3 Cluster Header Selection Algorithm and Time Chart

For the sake of completeness, we provide the pseudo code of CH selection in Algorithm 1. In the CH selection algorithm, each TM node calculates T_{delay}, and starts to listen a CCH declaration message from neighboring nodes. This is the stage one according to previous definition, and it finishes in line 4. Stage two starts from line 5 and ends in line 12. During stage two, a CCH node broadcasts a CH declaration message in a random time α in order to complete to be a CH node. In the end of stage two, CHs broadcast a CH declaration message to all nodes. A node is an orphan node if no CH message is received. Stage three is to solve the orphan node issue. Finally, CH nodes broadcast a CH declaration message, and a CM node chooses the closest CH, and joins in that cluster.

Algorithm 1: Cluster Header Selection

setup phase:
1 Calculate T_{delay} for each node;

stage one:
2. Each TM or CCH node listens and receives the CCH declaration message from neighbor nodes;
3. if three CCH declaration message are received then becomes a CM and turns into sleep mode
4. end if

stage two: (only CCH nodes are awake for receiving and sending messages)
5. if a CH declaration message received then
6. the one with a higher energy level becomes a CH;
7. else if no CH declaration message received then becomes a CH;
8. end
9. All nodes are awake, and CH nodes broadcast a CH declaration message;
10. if No CH messasge received then
11. ophan_node = true;
12. end

stage three:
13. orphan nodes compete to be CHs;
14. CM nodes choose the closest CH, and cluster formation finishes

A time schedule chart for proposed cluster header selection is plotted in Fig 5. It demonstrates the state of each node during three stages. At the beginning of stage one, every node is in TM state. A node becomes a CCH node if a CCH declaration message is sent. However, a TM node or a CCH node changes into a CM node if three CCH declaration messages are heard from neighboring nodes, and turns itself into the sleep mode. The first stage is accomplished at time 1.1. At stage two, CH selection is conducted among CCH nodes. In the end of stage two, all nodes in the sleep mode have to wake up synchronously for receiving a CH declaration message from CHs. If a CM node does not have a CH choice, then it is an orphan node. Stage two ends on time 1.2. Stage three is to solve the orphan node issue. After three stages, CH selection is

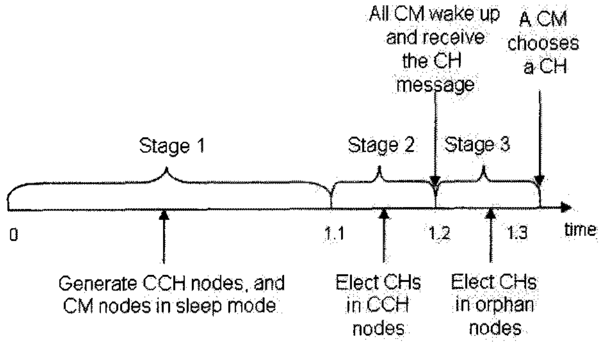


그림 5. 클러스터 구성을 위한 시간 스케쥴
Fig. 5. Time schedule for cluster formation.

finished. Hence, CH starts to aggregate data, and sends it to base station.

V. Simulation and Evaluation

5.1 Simulation Environment

To verify the effects of the ICETD algorithm, we simulated ICETD protocol using ns2[10]. For a fair comparison, we make use of the same network model used in LEACH. Simulation environment and parameters are listed in Table 1 .

For the intra-cluster communication, each CH sets up a TDMA schedule for its CM nodes. Hence, each of the CM nodes can transmit data to the CH at a given time. This schedule is broadcast to all the nodes in a cluster, and all nodes keep their radio off while they are

표 1. 시뮬레이션 파라메터
Table 1. Simulation parameters.

Parameters	Value
Network size	100 m × 100 m
Sink coordinates	x = 0, y =0
E_{elec}	50 m/J/bit
e_{fs}	10 pJ/bit/m^2
e_{mp}	0.0013 pJ/bit/m^4
$E_{aggregation}$	5 nJ/bit/signal
Data packet size	500 bytes
Number of nodes	100
Broadcast packet size	25 bytes
Packet header size	25 bytes
Initial energy	2 J/battery
Broadcast range	75 m, 50m
Max transmission of CH	100 m
Time for each round	20 secs

not transmitting data. For the inter-cluster communication, CHs transfer the aggregated data to BS at the maximum transmission range.

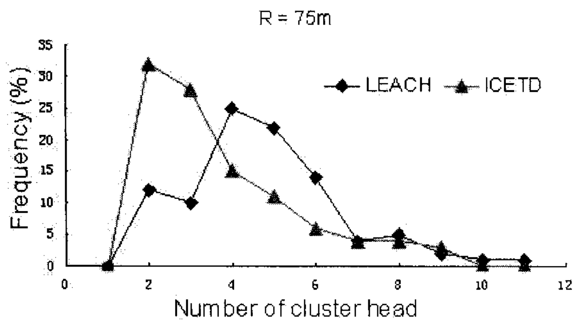
We evaluate the performance of our approach ICETD with LEACH in terms of CH distribution, energy consumption by CH, and network lifetime. The lifetime of network is defined when only 10% nodes alive. Our proposed method generates CH nodes more evenly, and avoids two CH nodes locate in the same cluster.

5.2 Performance Evaluation

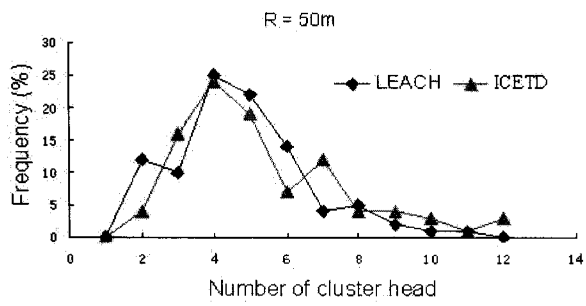
At first, a comparison between the CH frequency between ICETD and LEACH protocol is conducted. The CH frequency is how often a certain number of CHs occurs during cluster formation. Fig.6 shows the number of CHs ranges from 1 to 13 in LEACH. In contrast to LEACH, ICETD shows less diverse frequency distribution pattern especially when R = 75m.

It is known that the network is the most efficient when number of CHs is between two and five in a 100-node network[6]. Therefore, the more chances of the number of CHs is between two and five, the better of the network performance will be achieved. The improvement grained through ICETD is that the percentage that the number of CH centers between two to four is over 80% when transmission range R = 75m in Fig.6(a), which outperforms LEACH protocol. When the transmission range R = 50m in ICETD protocol, the frequency of CH distribution does not vary too much in contrast to LEACH. However, the network time is still prolonged twice longer than LEACH protocol in Fig.8(b). This comes from the fact the CH is well distributed in ICETD.

The decreased transmission range R from 75m to 50m increases the number of CHs and CCHs. The increased number in CHs and CCHs of ICETD can be interpreted the increase of broadcasts required. Finding an optimal number of CHs for an energy efficient sensor network is essential for an application, because

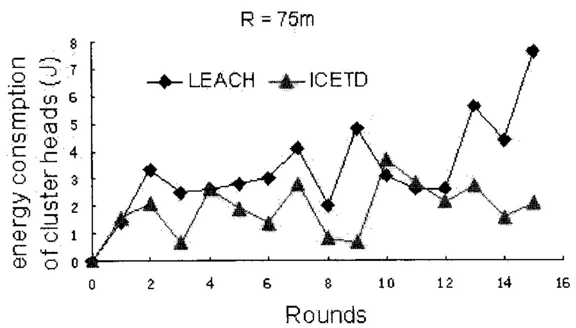


(a) R = 75m

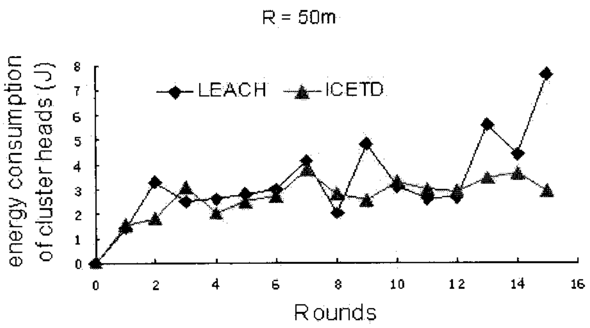


(b) R = 50m

그림 6. CH 수의 변화율
Fig. 6. Frequency rate of the number of CH.

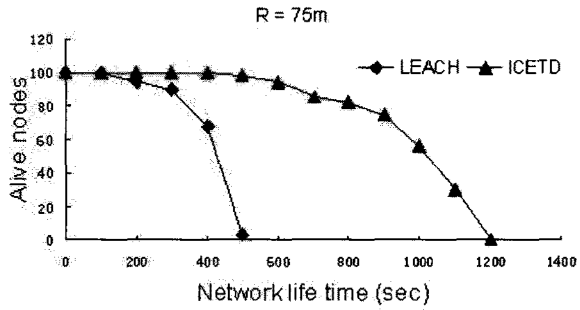


(a) R = 75

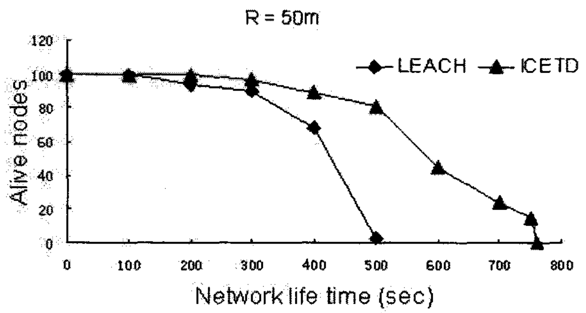


(b) R = 50m

그림 7. CH에 의해 소비된 에너지의 량
Fig. 7. The amount of energy spent by CHs.



(a) R = 75m



(b) R = 50m

그림 8. 전체적인 네트워크 수명
Fig. 8. Network lifetime as a whole.

there is a tradeoff between the number of CHs and the level of transmission power for communication.

Next, we compare the amount of energy spent by CHs. 15 rounds of simulations are sampled, and the amount of total energy spent by all CHs is shown in Fig.7. The energy spent is less in ICETD than LEACH, especially when R is chosen as 75m. Because the distribution of selected CHs is uncontrollable in LEACH, there is a dramatically variation of energy consumption of CHs.

Lastly, we analyze the network lifetime between ICETD and LEACH. Fig.8(a) shows that ICETD prolongs the life time of network three times longer than LEACH protocol when R equals to 75m, and it also shows the network life time is increased twice when R has been chosen as 50m. The well distribution of CH is the most important part in ICETD. It makes the lifetime of network longer. With the CH elimination algorithm, only one CH is allowed in the same communication range, which makes CHs fairly distributed over the network.

5.3 Discussion

In the simulation, one communication range is enough for CH selection in ICETD in contract to CETD. One hop communication is assumed for inter-cluster communication so that CHs still have to use the maximum transmission to send the data to BS. The maximum transmission is used limits the scalibility of the protocol. Since only one CH is permitted in a cluster, that is, none of two CHs are not in a communication range. Therefore, reply nodes have to be placed between any two CHs if a CH wants to transmit data to BS through other CHs. The better method is CHs should form a multihop backbone whereby data are transmitted among CHS until they reach the BS instead of using reply nodes.

Furthermore, intra-cluster communication scheme may be needed to rethink about. Currently, we assume nodes always transmit data to BS on their allocated time schedule based on TDMA. In the practise, nodes may only need to transmit data to BS if some tasks are detected. In this case, how to make sure we efficiently utilize bandwidth when not all nodes communicate to the CH all the time[9].

In addition, load balancing is not considered in our proposed approach. A CM node chooses a CH whichever is the closest in ICETD, which results in cluster unbalance issue. Unbalance cluster degrades the network efficiency.

CH elimination factor should be adjusted more precisely. We state any node becomes a CM node if three CCH declaration messages are received. It is arbitrary to make such a statement, though its simulation performance beats LEACH.. At last, the hidden terminal problem is not considered in our simulation. When a CM node sends a Join-REQ message to a CH, we adjust the transmission range to 2R to avoid the hidden terminal problem.

Ⅵ. Conclusion

To increase the lifetime of wireless sensor networks, we illustrate a novel cluster header selection protocol, which is based on energy level, and coverage efficiency of nodes. During the clustering, a node keeps silent until its delay time expires, which is determined according to remaining energy level. A node with a higher energy level, and more coverage efficiency is selected to be a CH, meanwhile, only one CH is allowed in a cluster. Thus, CHs are well distributed. In addition, Fig.1 and Fig.2 are enough to satisfy all the possible cases to make selecting CHs effectively.

The simulation results show that ICETD outperforms LEACH by uniformly placing CHs throughout the whole sensor field, and the number of CHs of each round is not in a diverse pattern. Therefore, it is concluded that ICETD provides an energy-efficient routing scheme that is suitable for a vast range of sensing applications.

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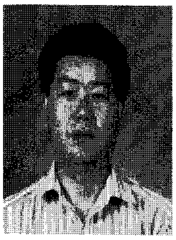

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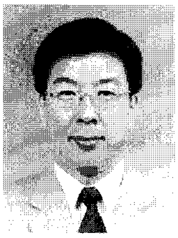

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