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석사학위 논문

불균일 분포 무선 센서 네트워크를 위한 부하 균형 클러스터링

조선대학교 대학원
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Load Balanced Clustering for Wireless Sensor Networks with Non-Uniform Deployment

2012년 8월 24일

조선대학교 대학원

컴 퓨 터 공 학 과

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ABSTRACT

불균일 분포 무선 센서 네트워크를 위한 부하 균형 클러스터링

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무선 센서 네트워크(WSNs)는 일반적으로 값싼 소형 센서들로 이루어져 있으며, 이 센서들이 환경 모니터링 등을 위해 많은 어플리케이션에서 사용된다. 본 연구는 무선 센서 네트워크에서 무작위로 배치된 노드들이 영역에 따라 밀도가 다르다는 것에 초점을 맞춘다. 즉 네트워크 내부에 불균일하게 분포된 센서 노드들이 가져오는 문제를 다룬다. 이러한 불균일 분포 토폴로지는 클러스터링 프로토콜의 효율성을 저하시킨다. 이 문제를 해결하기 위해, 우리는 불균일 분포 무선 센서 네트워크를 위한 부하 균형 클러스터링 기법을 제안한다. 제안한 기법에서 각 노드는 자신 주변의 노드 밀도를 고려하여 자신이 클러스터 헤드가 될 확률을 조절한다. 그 결과로 각 클러스터의 커버리지 영역이 거의 동일한 면적으로 분포하게 되어 네트워크 안의 클러스터 영역 크기 사이의 편차가 현저하게 감소된다. 또한 클러스터 헤드는 노드가 밀집한 영역에서 과다하게 분포된 센서 노드들을 선별해 잠재움으로써, 불필요한 감지 및 중복적인 감지 결과의 전송도 최소화한다. 이는 네트워크 전체 영역에 거의 동등한 에너지 소비를 가져오며, 높은 노드 밀도를 가지고 있는 영역의 노드 수명을 연장시킨다. 성능 평가의 결과에 따르면, 제안된 기법은 불균일 분포된 네트워크 내부에서 기존의 프로토콜보다 클러스터 영역을 고르게 분포시켰을 뿐만 아니라, 네트워크의 수명을 증가시켰다.

I. INTRODUCTION

Wireless sensor networks (WSNs) are comprised of many battery-powered sensor nodes that detect their physical surroundings and send the sensed data to the sink node or base station. In many cases, the batteries are difficult to replace. Even if it is possible to replace the batteries, the replacement cost will be very high [1].

Routing in WSNs is a series of process of forwarding information gathered by sensors to the sink or base station (BS). Routing protocols are classified into three categories: hierarchical routing protocols, location-based routing protocols and flat routing protocols [3][4]. In a flat routing protocol, every sensor delivers information collected by itself to BS directly. Location-based routing uses the location information of sensor nodes. In these two schemes, if we want to collect information of entire area in a network, a large number of nodes are involved in data transmission, leading to much energy consumption. On the other hand, hierarchical routing uses a less number of nodes compared to other routing protocols. Thus, it is more energy-efficient and allocates network resources more evenly than the other two schemes. In a hierarchical routing protocol, sensor nodes (SNs) form multiple clusters by choosing some nodes as cluster heads (CHs) and the remaining nodes as members of clusters. Each CH collects the sensed data from member nodes, compresses the aggregated data, and then transmits them to BS. The necessary energy is known to be proportional to the fourth power of distance in the propagation model of two-ray ground reflection [6].

As shown in Figure 1, the flat routing is a very simple way but the total energy consumption is the largest because all sensor nodes transmit data to BS. In contrast, as only CH nodes transmit data to BS in the hierarchical routing, the energy consumption, congestion and collisions are significantly reduced. Therefore, the hierarchical routing is broadly used in WSNs.

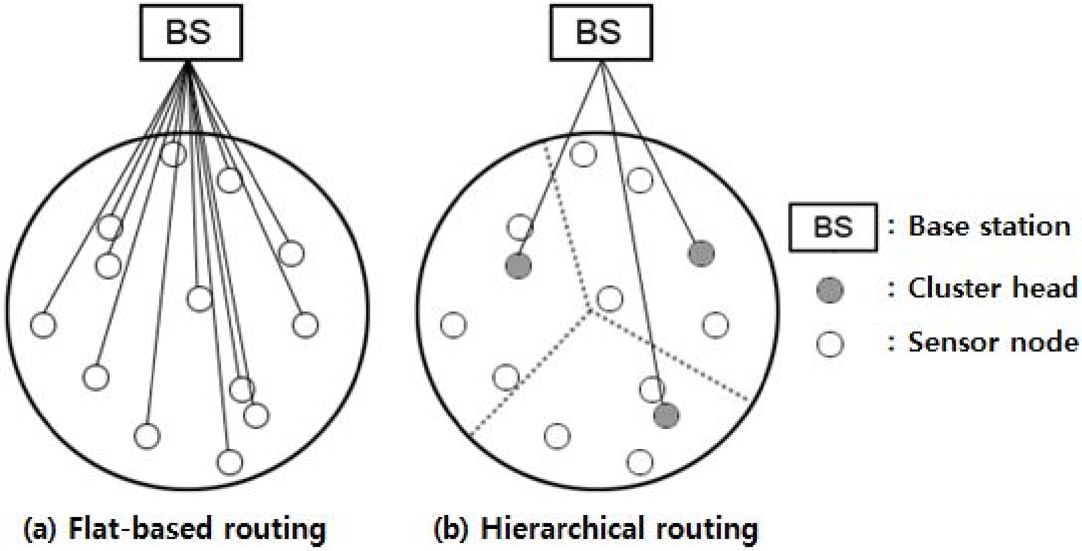

Figure 1. Flat-based and hierarchical routing in WSNs

The typical hierarchical routing protocols are LEACH (Low Energy Adaptive Clustering Hierarchy), PEGASIS (Power-Efficient Gathering in Sensor Information Systems), and TEEN (Threshold-sensitive Energy Efficient sensor Network protocol) [4]. LEACH [5] is the most famous one. This protocol is designed such that all the nodes in a WSN consume almost equal energy by becoming a CH alternately. The detailed description of LEACH will be discussed in section II.

In applications such as environment monitoring, sensor nodes are deployed randomly and, thus, they often distributed non-uniformly. In such a network, the node density differs region by region in nature. Note here that the node density in this paper is defined as the number of nodes within the node's sensing range. In the existing clustering algorithms such as LEACH, very node has the same probability to be a CH without considering the node density and the non-uniformity. As a result, the sensing area or coverage area of each cluster varies region by region; i.e., there are many small-area clusters in dense regions and a few large-area clusters in sparse regions. In the dense regions, sensed data are excessively overlapped, transmissions are severely conflicted, and more energy is unnecessarily consumed. On the other hand, in the sparse regions, some locations are not covered by sensors. Such a non-uniform deployment of sensors results in inefficient operation, poor performance, and lifetime degradation in the network. In this paper, we discuss how to solve the problem effectively. Energy efficiency is one of the most important metrics in WSNs because it affects network lifetime [2]. Not only total energy consumption but also balanced energy consumption among sensors is important to prolong the network lifetime. In this paper, we address a novel approach that can be easily adapted to different protocols to reduce unnecessary and redundant energy consumption.

In this paper, we propose a novel clustering algorithm called BCA (Balanced Clustering Algorithm) for non-uniformly deployed sensor networks in order to improve energy efficiency as well as to balance energy consumption. Activating all nodes in dense region leads to more resource usage and more energy consumption. After deployment, each node determines the probability that the node itself becomes CH on the basis of the node density so that the coverage area of each cluster is almost equally distributed. Then, unused redundant nodes are turned into sleep mode. Since the unnecessary redundant sensing and transmission are significantly reduces, the network lifetime is prolonged accordingly. The main ideas of the proposed algorithm are as follows:

- During the network configuration, each node calculates the node density and determines the probability that the node itself becomes a cluster head based on the density to make sure that cluster heads are uniformly distributed and clusters have almost the same coverage area.
- Cluster heads use the node density information again to have unnecessary nodes go into sleep mode for saving energy.

The rest of this paper is organized as follows: The LEACH protocol is reviewed and summarized in the following chapter. In Chapter III, we discuss the operating principles and characteristics of the proposed BCA by presenting the two mechanisms: A. the mechanism to make the coverage area of clusters the same and B. the mechanism to make unnecessary nodes sleep. In Chapter Ⅳ, we demonstrate the performance of the proposed algorithm and compare it with the conventional LEACH. Finally, the conclusions of this paper are summarized in Chapter Ⅴ.

Ⅱ. RELATED WORK

A lot of clustering-based protocols using randomness have been studied in the past decade. Among them, LEACH (Low Energy Adaptive Clustering Hierarchy) [5] is the most well-known protocol and it has been the base of this field. The basic idea of LEACH is to choose CH randomly among all of nodes according to the predetermined probability that a node becomes CH. As shown in Figure 2, LEACH operation is divided into two phases per each round: Set-up phase and Steady-state phase.

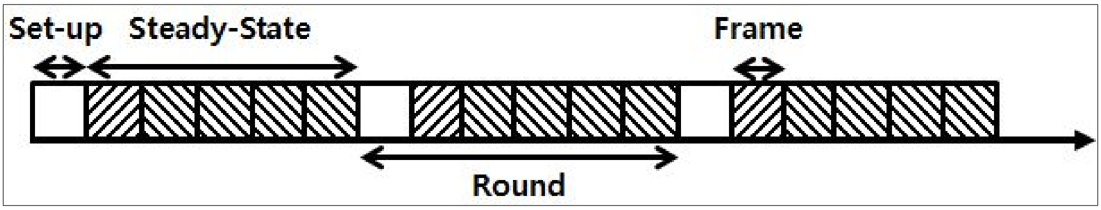

Figure 2. Operation of the LEACH protocol

A. Set-up phase

For the set-up phase, nodes operates restructuring for clusters to rotate role of Cluster head and remove unnecessary time slot for dead nodes from a schedule used in steady-state phase. In this phase, cluster heads are determined and networks area is divided into clusters. when this phase, every node reset own state. And each node generates a random number between 0 and 1 and then compares it with the threshold *T(n)* to determine whether the node is elected as a cluster head or not. The elected nodes become a cluster head if they have been not become a cluster head before and the rest become member nodes. This process is conducted independently by each sensor node. Equation (1) represents how the threshold *T(n)* is determined in the LEACH protocol.

$$T(n) = \begin{cases} \dfrac{P}{1 - P\left(r \bmod \dfrac{1}{P}\right)} & if \;\; n \in G \\ 0 & otherwise \end{cases} \qquad \cdots\cdots (1)$$

where P is the desired percentage of cluster heads over the total number of nodes, r is the identifier of the current round, and G is the set of nodes that have not clustered in the last $1/P$ rounds [5][7].

Cluster heads broadcast advertise message to inform own state and non-cluster head nodes (sensor nodes) receive this message. Sensor node determines own cluster head node according to a distance and participates in that cluster. Because cluster formation is changed in every round, transmission length between cluster head and sensor node is always stand to reason. After the participation of sensor nodes, cluster head creates TDMA (Time Division Multiple Access) schedule used in steady-state phase then sends own members.

B. Steady-state phase

In the steady-state phase, nodes operate sensing and routing depending on a TDMA schedule made at set-up phase. The phase consists of frame units that sensor nodes sense attributes then send the sensed data to their cluster head, and cluster head compresses these to a single signal then transmit the signal to base station at each frame.

A nodes wake up for data sensing and transmission to own cluster head when own TDMA slot time, but fall in sleep while other slots, thus sensor nodes can save energy efficiently. When all sensed data are collected, cluster head changes the data collected by sensor nodes to a compressed signal and then transmits it to BS. this operation will be repeated at each frame.

C. Weakness of LEACH

LEACH protocol outperforms classical clustering algorithms by using adaptive clusters and rotating cluster-heads, allowing the energy requirements of the system to be distributed among all the sensors [11]. But LEACH also has weaknesses so that many researcher have been study to improve these.

We can notice a disadvantage that LEACH assumes a homogeneous distribution of sensor nodes in the given area [12]. So, regardless of the node density that how many neighbor node are exist within a fixed range, probabilities of cluster head of every node are the same. If nodes are distributed not-evenly in network topology, elected cluster heads are concentrated in some areas that have comparatively many nodes comparing with other areas. As we mentioned earlier, sensor nodes join in nearest cluster head to conserve energy in set-up phase of LEACH protocol. Thus if almost cluster heads are concentrated, transmission length of many nodes become longer than normal case. This problem can bring inequality in energy consumption and shorter lifetime of WSNs.

In this paper, we proposes a new algorithm to solve the issues mentioned above by modify probability that cluster head become. Our proposal makes cluster heads more evenly distributed in entire network so that decrease deviation for transmission length between cluster head and sensor nodes. Some papers have taken that modify the probability to solve other problems of LEACH like as [9], but these approaches were assumed in a homogeneous distribution of sensor nodes so that be in same problem that we mentioned.

III. BALANCED CLUSTERING ALGORITHM

In this chapter, we discuss the operating principle and characteristics of the proposed balanced clustering algorithm by dividing it into two mechanisms: the mechanism to make each area of cluster to be the same size and mechanism to make unnecessary nodes to be in sleeping mode.

As mentioned earlier, when WSNs use a common clustering protocol, the problem is caused from that all sensor nodes are working all-round. The difference of sensed values of adjacent nodes is very little because detected area is almost similar. It is an unnecessary works that lead to waste of resources and short lifetime of network. the more non-uniformity a network has, the more intensified this phenomenon becomes.

Another problem is to elect CH based on the same probability. It looks very fair at first glance but not always. The higher node density of an area leads to the higher number of clusters in that particular area. If the distance between CHs is too short, it leads to congestions and collisions of packets because areas of clusters can be overlapped, mixed and reduced. Furthermore, the other clusters have to detect larger area if some clusters areas are overlapped. In worst case, some nodes cannot participate in any cluster since the number of clusters is limited in WSN, which means some areas are outside of coverage range of clusters. In any case, total distance of data communication is longer than normal case. Energy consumption is proportional to the two or fourth power of distance as the propagation model. Increasing total distance of data communication retards a performance of energy consumption of a network. it affects not only in imbalance of energy of nodes, but also make network’s lifetime shorter.

An area of network covered by nodes is based on the number of nodes and the sensing range of a node. The covered area of a cluster is a union of some nodes in terms of a cluster. The nodes of this union are classified into three types:

the non-overlapped node, the partially overlapped node and the entirely overlapped node. The non-overlapped node is necessary for area of the union. In contrast, the entirely overlapped node is unnecessary, because coverage area is the same whether these nodes are excluded or not. As for the partially overlapped node, it can become necessary or unnecessary node according to how much area is occupied by it.

The proposed algorithm makes the position of CHs more evenly distributed across the entire network and makes the mode of unnecessary nodes of a cluster a sleep state. The algorithm consists of two main mechanisms: the mechanism to make each area of cluster to be the same size and the mechanism to make unnecessary nodes to be in sleeping mode.

A. The Mechanism to Make the Coverage Area of Clusters the Same

The goal of this mechanism is to make the coverage area of every cluster be the same size in order to reduce both (i) packet collisions between clusters and (ii) nodes that communicate directly with BS. Figure 3 shows the purpose of this mechanism in which the network consists of four clusters of the same size.

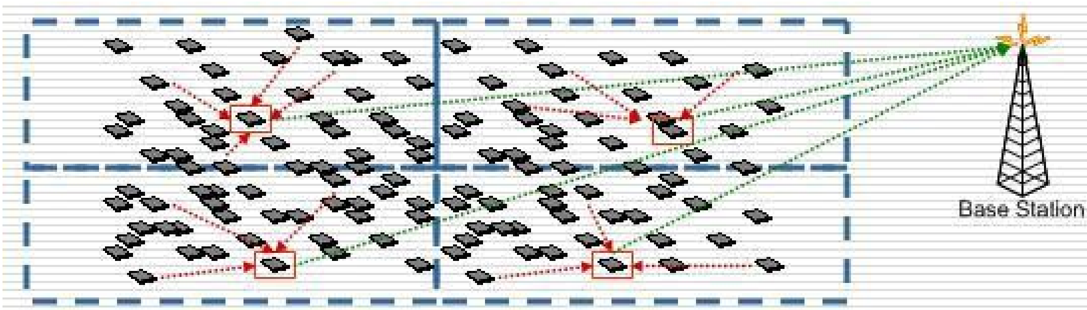

Figure 3. Clusters with the same coverage area

LEACH protocol handles a probability of CH by calculating threshold value *T(n)* for a fixed number of clusters at every round despite of dying nodes dynamically. Probabilistic methods are used in which a floating point number between [0, 1] is generated. If the number is smaller than *T(n)*, it becomes a

CH. In short, LEACH uses *T(n)* only for electing CH so that the probability is the same on all nodes. In the proposed algorithm, probability *T(n)* is modified by secondary equation attempting to distribute clusters uniformly while maintaining advantage of LEACH or other clustering protocols. Basic equation of *T(n)* is exactly the same but the difference is that it is modified by own node density. Thus nodes can elect CH flexibly according to node density. If all nodes have the same probability of CH, it is more possible that many cluster heads are elected in high density area. Every node except CHs chooses the nearest CH as own CH. To join a cluster, a node should send a join message to CH within the range between the node and the CH, but the time for sending this message is determined randomly. Thus the more the number of nodes in an area, the higher the probability of packet collision will be. If there are other CHs within the transmission range, A collision is not only for a wasted time. Every CH within the range wastes time at the same time. The heavy traffic by high node density can cause the participation failures of sensor nodes. The nodes that failed to be participated in a cluster will communicate with BS directly like a non-clustering approach. This phenomenon decreases a performance improvement of LEACH.

As mentioned above the purpose of this mechanism is to create non-overlapped clusters of the same size. It makes CHs distributed uniformly so that if there is a packet collision, just a single CH wastes its time and the number of direct communication node with BS. Moreover, this mechanism allows a deviation of the transmission ranges between CH and node in network to be decreased. If a distance between a CH and a SN (Sensor node) is far, the signal of a packet must be strong for a successful transmission. In non-uniformly deployed sensor networks, conventional protocol will have wide variations in transmissions of the intra cluster communication, it will cause the unbalanced energy consumption by nodes. So making areas evenly can have a chance for a energy consumption balancing in entire network.

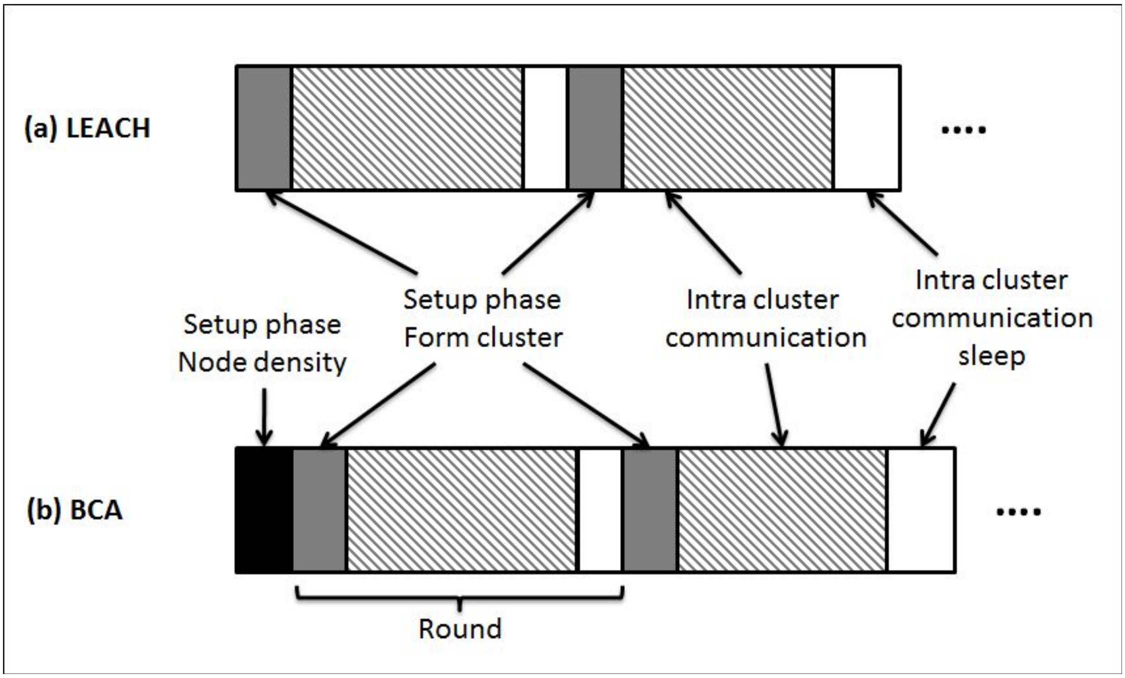

Figure 4. The mechanism to make the coverage area of clusters the same

Figure 4 shows the differences of BCA and LEACH phases. Mechanisms of algorithm are majorly related with the two setup phases. Immediately after the network is deployed, all nodes carry out the first setup phase to obtain the node density within the node's sensing range. This phase is called the node density detecting phase or node density setup phase, while the other is cluster forming phase. one major difference of two phases is that the node density detecting phase is executed only once - at the beginning – but the cluster forming phase is executed at every round.

In the node density detecting phase, every node has features of CH and SN at a time. Nodes have their own broadcast time for advertisement at random time like as the advertisement for informing SNs about CH state and hear other nodes advertisement except their own broadcast time until the end of this phase like as SN waiting CHs' advertisements. Since the broadcasting range for searching neighbor nodes is usually equal to sensing range, each node will get to know how many nodes are there within sensing range. Since the nodes' broadcast time is random within the node density setup phase, collisions can be occurred when more than two nodes transmit the advertisement packet simultaneously.

At the end of node density detecting phase, a node calculates the node density by using the number of neighbor nodes and average number of nodes per cluster area. Node density *D(n)* is defined as following equation:

$$D(n) = \frac{F}{n(\pi R^2 / A)} \quad \cdots\cdots (2)$$

where *F* is the number of neighbor nodes of a node, *R* is the neighbor node sensing distance, and *A* is the area of simulation. *R* is usually equal to sensing distance for sensor node, so this value is almost constant at every simulation having the same network topology. Node density *D(n)* of each node can have relative density value. So, *T(n)* can be modified as follows:

$$\widetilde{T}(n) = T(n) + \{\frac{nT(n)}{N}(\frac{1}{D(n)} - 1)\} \quad \cdots\cdots (3)$$

where n is the number of alive nodes in entire network and N is the total number of nodes in topology. However, if $\widetilde{T}(n)$ > 1, then $\widetilde{T}(n)$ becomes 1 again. As mentioned above, $T(n)$ is changed in every round. Accuracy of a node density also decreases according to the number of dead nodes because we assume that, so $\widetilde{T}(n)$ also need to have flexibility like equation (3). This equation consists of alsotwo parts based on original $T(n)$ of LEACH. The first $T(n)$ is for the nature of protocol and the second one is for making a standard range for adjustment. As the result of this mechanism, CHs can be distributed uniformly, not concentrated.

B. The Mechanism to Make Unnecessary Nodes Sleep

[13] points out other weaknesses caused by dynamic frame size of LEACH. Since each member has own time slot from a schedule for steady-state phase, if a cluster has a lot of member, the frame size of the cluster is also increased with the rate of the number of member nodes. Steady-state phase consists of frames, so bigger size of a frame become, less the number of frame of steady-state phase is. Time of sensing interval increase proportionally to size of a frame so that if frame size is big, it causes energy saving, but decrease the credibility of monitoring by the cluster. Otherwise, if size of a frame is small, energy consumption and the credibility of monitoring increase. This issue is not magnified in past studies related with LEACH protocol, the reason is the election way of LEACH based on probability. In LEACH protocol, even if a network with non-uniformly distributed nodes, many cluster heads are elected in high density area.

But we have to solve this problem in our proposal. Because of mechanism A that make the coverage area of clusters the same, a lot of nodes is participated in few clusters in networks with non-uniform deployment. In this case, a bulky frame size brings a waste of steady-state phase so that it can cause the performance cliff problem. figure 4 and 5 draw the performance cliff phenomenon by big-size fames and small-size frames respectively. Black square signifies static time of steady-state phase, dark-gray square with edge rounded is a valid frame and bright-gray square with edge rounded indicates a invalid frame. It is degree of side effect caused by the performance cliff problem that total steady-state time minus total time of the valid frames. two figures implies that one of big frame size can cause heavy side effect than small one.

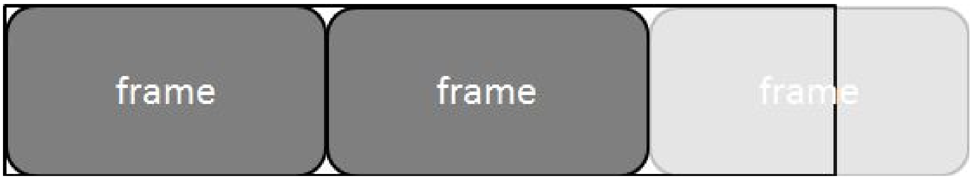

Figure 5. The performance cliff caused by big-size frames

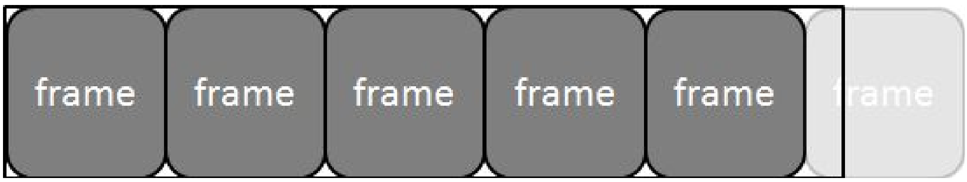

Figure 6. The performance cliff caused by small-size frames

Besides above problems, there is remained that almost protocols include LEACH have a chronic problem. Every node in usual protocol senses environment and send the collected information to own cluster head during all rounds. If the number of nodes in any area is too many, it is inefficient in terms of variety reasons as mentioned previously. Duplication of the covered area of the nodes results in unnecessary loss of energy and data. Some nodes do not need sense and communicate with own CH, because monitored information of the area are already sensed by other nodes of same area so that it create duplicated data. It is not efficient even compared with idle condition in terms of energy saving.

Second mechanism is for handling each node and location network traffic to remove the performance cliff problem. This mechanism assumes that the coverage area of clusters in the entire network almost the same. As a result, this mechanism can save energy consumption as well as resource usage by making some of nodes sleep. Some sensor nodes going to sleep mode can save energy but it has risk that the part of sensing area may not be sensed because of the sleeping nodes. We decrease the risk by the way that determines how many nodes have a sleep mode per round. The mechanism’s accuracy will be decreased according to the number of alive nodes as we conform this on equation (3). Because the node density information is collected just one time after simulation start. The more nodes are dead, the lower the accuracy of the information is. Thus the number of sleep nodes should be decreased depending on the number of alive nodes. But it is not enough to be efficient solution. Because nodes of high density area are left alive for very long time comparing with other areas. Thus the mechanism even will be working when alive nodes are not enough for alive network. We solve this problem by a threshold *P* that determine whether operates the sleep mechanism or not. The threshold is similar to the spurt point of an athlete. Every alive nodes will be working on end of lifetime. The number of nodes fallen in sleep mode of a cluster is defined as follows:

$$S(m,n) = m - \frac{n}{k} \quad \cdots\cdots (4)$$

$$\tilde{S}(m,n) = \begin{cases} \left\lceil \dfrac{S(m,n) * n}{n} \right\rceil, & if\ S(m,n) > P \\ 0 & otherwise \end{cases} \quad \cdots\cdots (5)$$

where *m* is the number of nodes of a cluster, *n* is the number of alive nodes in entire network, *k* is the expected number of clusters per round, *N* is the total number of nodes in topology and threshold *P* is the limit number of alive nodes to determine whether the sleep mode operates or not. The procedure of choosing sleep nodes is as follows:

- CH calculates the average number of nodes in a cluster by dividing the number of total nodes into the number of clusters.

- The number of sleep nodes in a cluster = the number of nodes in a cluster - the average number of nodes in a cluster.
- CH selects sleep nodes randomly and then sends a TDMA schedule (which contains sleep nodes' identifiers) to all the members.
- SN operates according to the schedule after removing sleep state nodes from the received schedule. The designated sleep nodes will fall in sleep state while a round.

It is very easy and efficient that choosing left sleep node, because it is the same principle for cluster heads to be concentrated on high density area.

IV. PERFORMANCE EVALUATION

In this section, we present the performance evaluation of BCA by comparing with the conventional LEACH algorithm. Simulations are performed using network simulator ns-2 [8] in various conditions. The simulation has been carried out by varying non-uniformity, the initial energy and the number of clusters.

First experiment is to prove the mechanism to make each area of cluster to be the same size. On the other hand, the second and third experiments are to prove the mechanism to make unnecessary nodes to sleep and show the performance of BCA. First experiment will show cluster formation that is formed at the first round to compare LEACH and modified-LEACH. In second experiment, we will change initial energy value uniformly applied to all nodes. The proposed algorithm collects node density information in order to distribute area of clusters uniformly at before first round, thus energy consumption for collecting node density information is inevitable in this process. The objective of this simulation is to know what the impact of initial energy consumption is to the lifetime of a node and entire network. Third experiment is designed to find out the impact of the number of nodes. Proposed algorithm has a feature that the number of sleep nodes is determined by the number of clusters and nodes in the network.

Table 1. Parameters for simulations

Parameter	Value
E_{da}	5 nJ/bit/signal
E_{elect}	50 nJ/bit
E_{sense}	5 nJ/bit
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
Initial energy	0.5, 1 and 2 Joule
Location of BS	(125, 75)
Network area	100 ′ 100 m^2
Number of clusters	5, 10 and 15
Number of nodes	200
Sensing range	10 m
Transmission range	136 m
Round interval	10 second

A. Simulation Environment

As mentioned earlier, the simulation is divided into three major parts: varying non-uniformity, varying initial energy, and varying the number of clusters. Each part has several sub-simulations for objective of analysis. All simulation parameters are based on default parameter shown in Table 1, and some of parameters will be added or modified based on the analysis goal of each simulation. In first experiment, we will show the effect of the mechanism that makes the coverage area of clusters the same. In second experiment, the number of clusters is changed as 5, 10 and 15 respectively. But it is not a static number because the CH selection is based on probability per round. In final experiment, the number of clusters is changed as 5, 15 respectively but same 2 joule initial energy. The neighbor node sensing distance is 10m, so each node judges that all nodes within 10m are neighbors. The simulations are performed for 100 times for each experiment and we will show the average value of results as result value.

For our experiment, we used energy consumption model [11] provided with LEACH source code. Propagation model is the same to one of LEACH protocol [5] and did not consider errors in wireless channels. Power control can be used to invert this loss by appropriately setting the power amplifier—if the distance is less than a threshold d_0, the free space (*fs*) model is used; otherwise, the multipath (*mp*) model is used. Thus, to transmit *k*-bits of message along the distance *d*, the radio power consumption is:

$$E_{Tx}(k,d) = E_{tx-elect}(k) + E_{Tx-amp}(k,d) = \begin{cases} kE_{elect} + k\varepsilon_{fs}d^2, & if\ d < d_0 \\ kE_{elect} + k\varepsilon_{mp}d^4, & otherwise \end{cases} \quad \cdots\cdots (6)$$

The radio power consumption for receiving k-bit of data is calculated as follows:

$$E_{Rx}(k,d) = E_{Rx-elec}(k) = kE_{elec} \quad \cdots\cdots (7)$$

E_{elec} is radio electronics transmission / reception energy depends on factors such as digital coding, modulation, filtering, and spreading of the signal. ε_{fs}^{2} and ε_{mp}^{4} are constant values for the amplifier energy depending on the distance to the receiver and acceptable bit-error rate. E_{da} is energy consumption of data aggregation. In this paper, the communication energy parameters are set as: E_{elec} is 50 nJ/bit, ε_{fs} is 10 pJ/bit/m2, ε_{mp} is 0.0013 pJ/bit/m4 and E_{da} is 5 nJ/bit/signal.

B. Simulation Results and Discussion

1. Varying non-uniformity

Figures 7 and 8 show the topology of initial round of LEACH and BCA, respectively, and both are non-uniformly deployed sensor networks. Blue circle indicates a sensor node, whereas red rhombus is a cluster head, and the black line is efficient boundary of clusters. Figure 8 shows dynamic cluster formation of LEACH modified by BCA. Variation of area is not only smaller than one of Figure 7, but also more uniformly distributed. This phenomenon was confirmed to apply to almost every round, but not always, because it is based on probability. Thus, we confirmed that the mechanism works as intended.

It is already mentioned in section III that every node of LEACH has the same probability of cluster head. If it is working on non-uniformly deployed Sensor Networks, CHs are also distributed non-uniformly on topology in some rounds. This problem is shown in the bottom-left of Figure 7; four cluster head nodes are concentrated closely at some area. We have to note that black line is not real boundary of clusters. In fact, there are no real boundaries, cluster is just a sensing area consists of member nodes. Therefore, areas of clusters can be mixed and overlapped similar to area of sensor nodes. An overlapped coverage area leads to unnecessary energy consumption. In Figure 7, we can find another problem that other CHs have to cover larger area because some CHs are concentrated; furthermore, shape of this cluster area is sharper and longer than one of CHs in Figure 8. And it again leads to inefficient performance because total communication distance between BS and SNs is longer than on another figure. In worst case, some nodes may require direct communication with BS -not CH- because of the long distance to a CH.

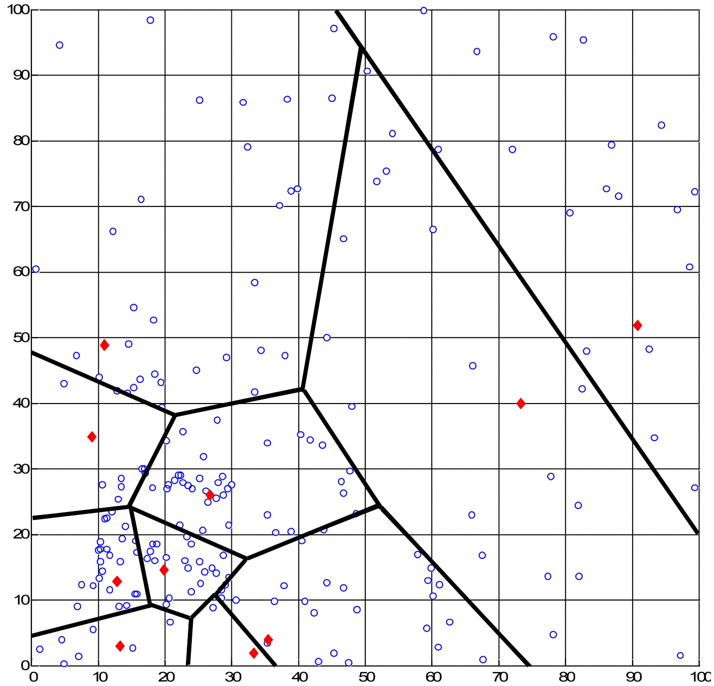

Figure 7. An example of cluster formation in LEACH

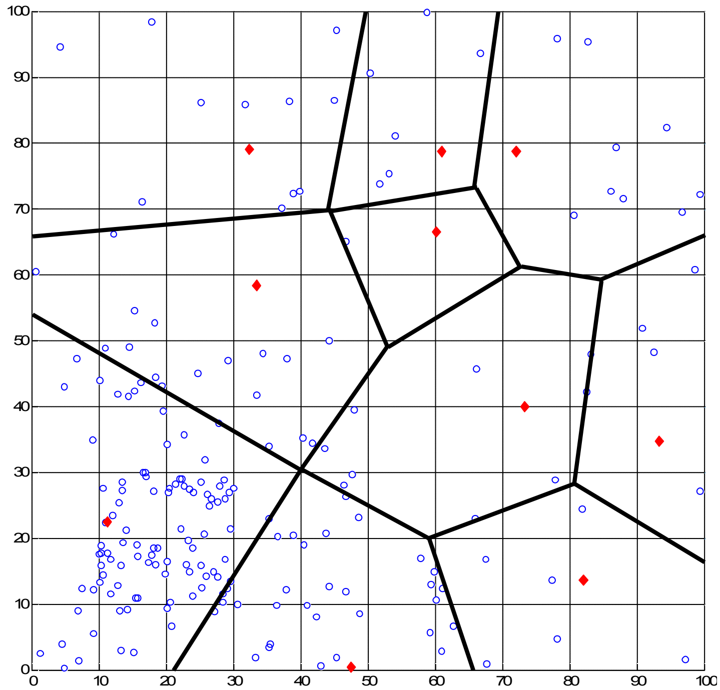

Figure 8. An example of cluster formation in BCA

2. Varying the initial energy

The three graphs of Figure 9, 10 and 11 show results of the simulations with initial energy of 0.5J, 1J, and 2J respectively. As shown in the graphs, the increase of initial energy is not one-dimensional effect, but has multi-dimensional positive effect. In the graph using 0.5J, performance of BCA is lower than LEACH until 57 seconds. It indicates that the energy is being consumed by detecting node density. Thus, we can guess that the lower the network energy is or the longer the neighbor node sensing distance is, the more our algorithm leads to bad effect. After 57 seconds, the performance is reversed. It indicates that energy of entire network is saved by using node sleep mechanism. But increased performance is lower than negative effect. As a result, BCA has a 8% disadvantage on the simulation with 0.5J. In the graph using 1J, the bad effect becomes shorter compared with Figure 9. Up until 85 seconds, the performance LEACH is better but the difference is smaller than before. The performance of BCA increased from 85 to 140 sec and it can be seen in the area between LEACH and BCA graph. This performance difference is maintained until the end of the simulation over overall network. As a result, the performance advantage is about 1% compared with LEACH. Figure 11 is result in an initial energy 2J. Bad effect duration has been reduced down to only 130 seconds since the start of simulation. as time passes, BCA drew gentler parabola than another. As a result, BCA has 7% performance improvement. Through the evidence in three figures, we are able to confirm that the larger the initial energy, the higher the network lifetime will be.

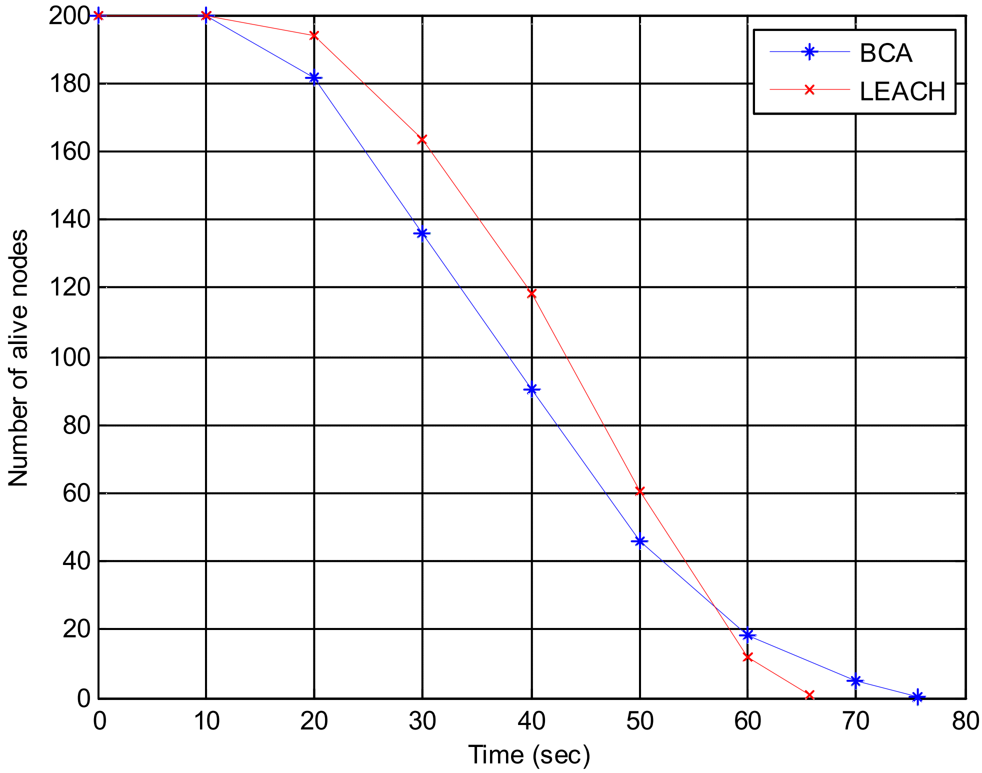

Figure 9. The number of alive nodes at Initial energy of 0.5J

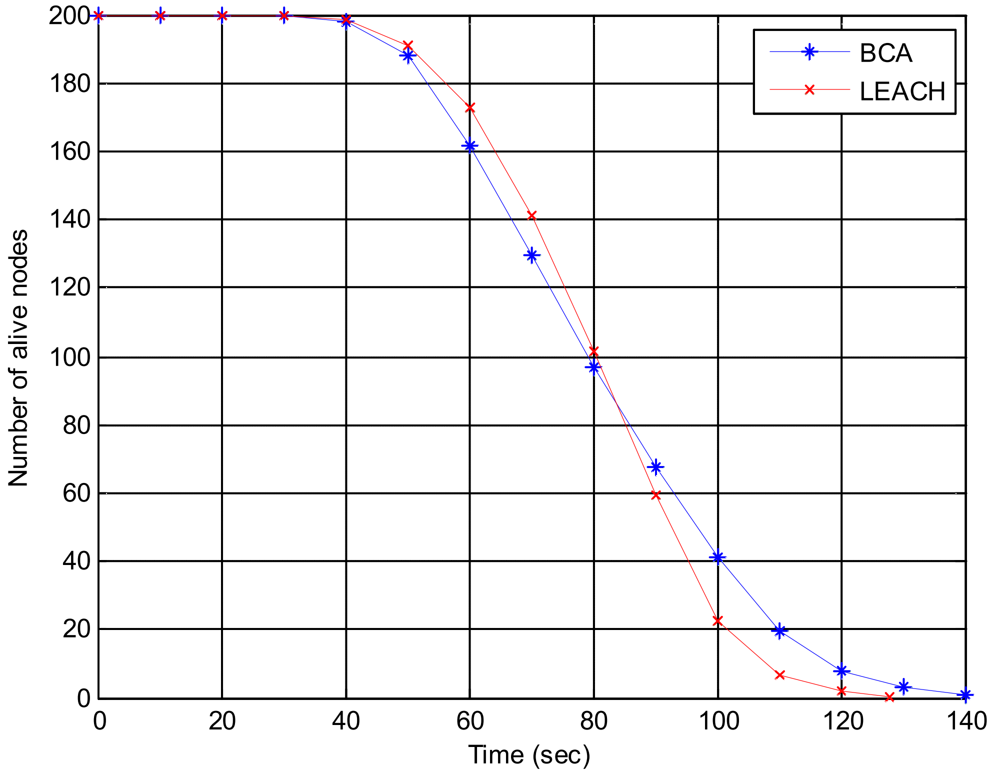

Figure 10. The number of alive nodes at Initial energy of 1J

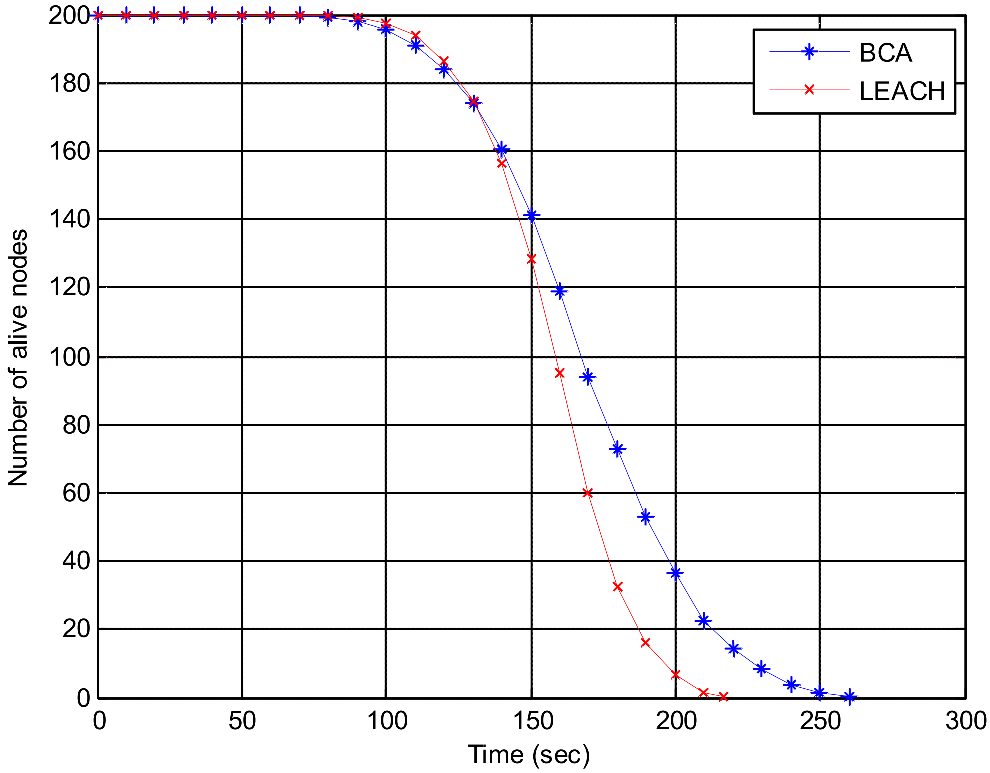

Figure 11. The number of alive nodes at Initial energy of 2J

Three graphs in Figure 12, 13 and 14 are the number of packets accepted on BS over time. A slope of any point on a graph indicates packet rate per unit time. Therefore the gentler the slope is, the lower the number of accepted packets will be. As can be seen from the graphs, the slope of LEACH is higher than one of BCA. Because some nodes of cluster with high density are fall in sleep mode when the mechanism making unnecessary nodes sleep works in non-uniformly deployed sensor networks. As a result, Packet rate and energy consumption is reduced. But low slope not only indicate energy saving by nodes of sleep mode, but also end of dead nodes. The slope of BCA with 0.5 joule of initial energy fluctuates violently. In comparison, the slope of BCA with 1J is gentler than with 0.5J. And the one with 2J is more than before. As mentioned above, the simulations are performed for 100 times. The higher energy BCA has, the more stable it has. This means that BCA have a bad effect on a reliability of network when the WSNs have low initial energy.

As described above, stability and reliability is closely related to how much total energy is used during the node density detecting phase. Because initial energy in Figure 12 is relatively smaller than others, the node density detection energy occupies a large proportion of total energy consumption compared with Figure 13 and 14. But this is not only reason for the result of simulation; we will mention it in part 3. On the other hand, because of small proportion of node density detection energy in BCA of Figure 13 and 14, the mechanism is working until later stage of simulation. We can guess that this is the reason of increasing network lifetime in two figures.

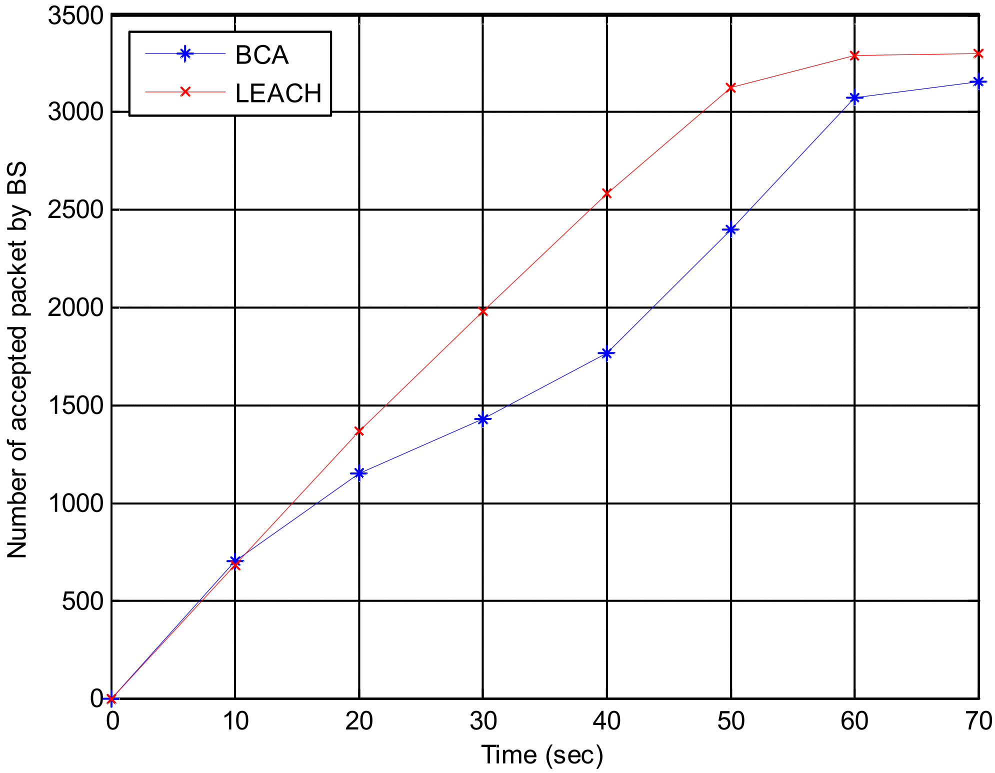

Figure 12. The number of packets accepted by BS at Initial energy of 0.5J

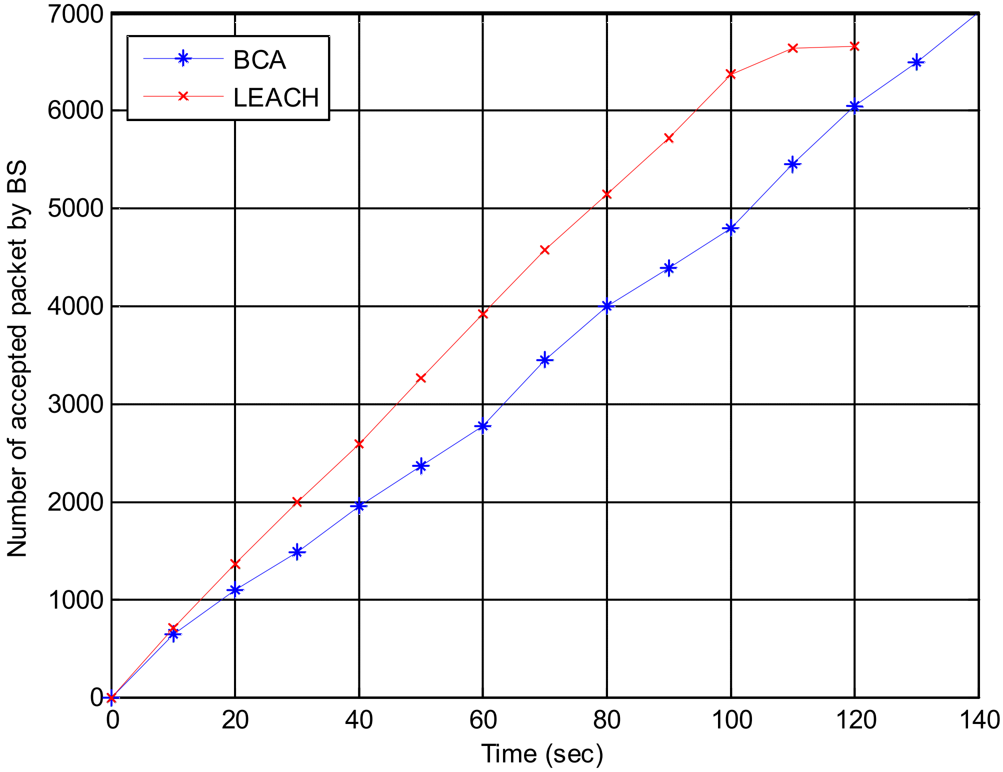

Figure 13. The number of packets accepted by BS at Initial energy of 1J

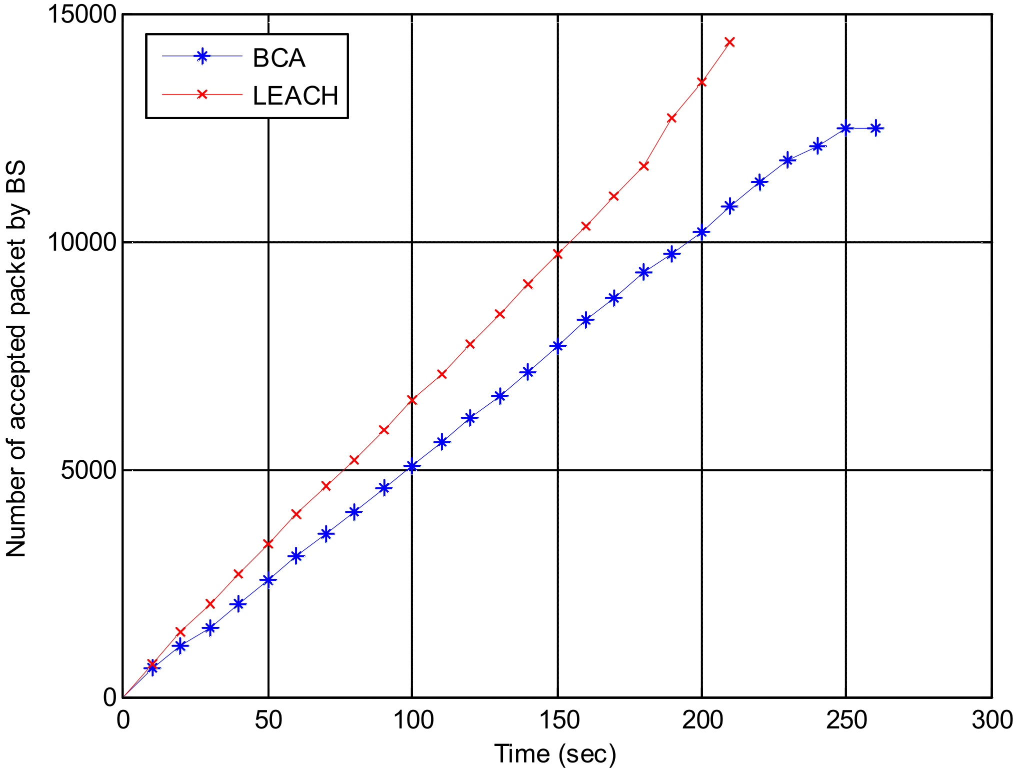

Figure 14. The number of packets accepted by BS at Initial energy of 2J

3. Varying the number of clusters

Since the BCA cares about non-uniformly deployed topology unlike other cluster protocols, we should study about an effect position of cluster heads cause. As we already mentioned earlier, principle of BCA is to make cluster area same and then to make unnecessary nodes sleep mode. But this is based on probability, the location of cluster heads are not always the best. When there is not any cluster head in a high density area and cluster heads are far from the high density area, total length between sensor nodes and cluster head becomes longer comparing with the case that there is cluster head in high density area and the number of sleep mode node also decrease. Two topology condition illusions of Figure 15 and 16 draw examples of the best and worst position of cluster heads respectively. Red circle indicates cluster head and black circle is sensor nodes, white circle is a sleep mode node and black line is transmission length between SN and CH; e.g., The number of nodes is 19 and the number of clusters is 3, so the number of necessary sensor node is 5 calculated by equation (3). In best case like Figure 15, the cluster located in center of topology makes three nodes sleep mode and transmission length between SNs and CHs is efficient. In the other hand, if cluster heads are elected like Figure 16, total length between SNs and CHs becomes rapidly increase and just one node is fallen in sleep mode. Thus sensors will be inefficient energy consumption in entire network. This is another reason of the bed effect mentioned part 2.

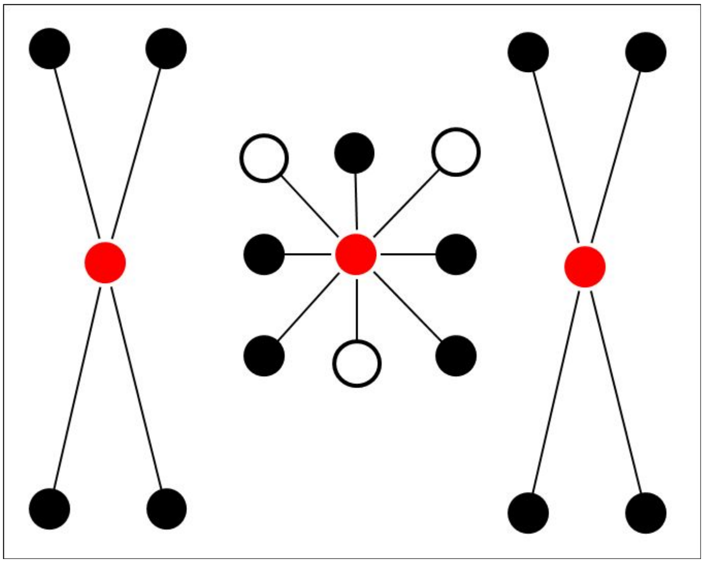

Figure 15. An example of the best position of cluster heads

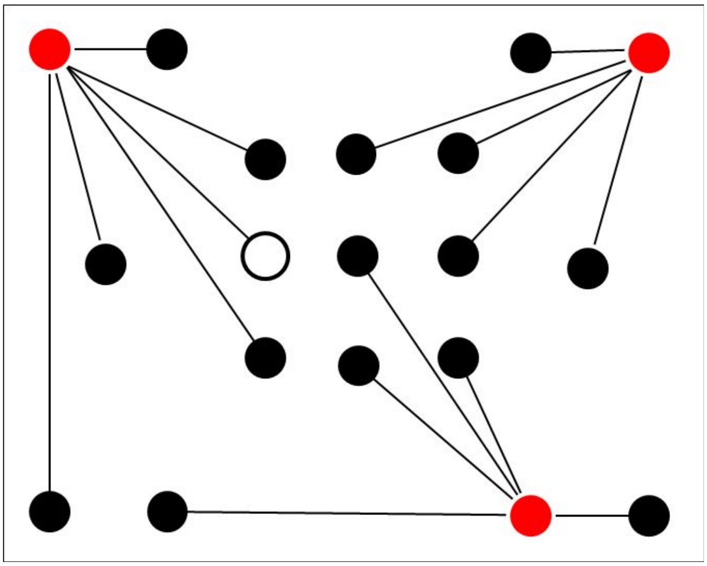

Figure 16. An example of the worst position of cluster heads

In clustering approach, the number of clusters is an important factor. It is a fact that the smaller the number of clusters, the larger area of each cluster becomes. If a network has few clusters, the sum of transmission length between SNs and CH increases, but it can save energy in terms of the reduced communication sessions between CHs and BS. In worst case, a SN cannot search any CH due to being too far; hence, it has to communicate directly with BS. Furthermore, since the number of nodes is too large for CH to handle, some sensed information is not sent. In the other hand, if a network has a lot of clusters, the sum of transmission length between SNs and CH decreases, but the networks can have efficient communication between CHs and BS. That is why selecting the number of clusters is crucial in all of clustering algorithms.

But this factor becomes more critical in BCA. Figures 17 and 18 draw graphs of the number of alive nodes versus time, with of initial energy 2J and different the number of clusters: 5 and 15. The performance of BCA in Figure 17 with 5 clusters is reduced until the middle of the simulation by the bed effects that includes an initial energy consumption and inefficient CH positioning. This bed performance is changed in after 170 second. As a result, the BCAs' performance of Figure 17 is a decline of 3 percent from LEACH. In result of Figure 18 with 15 clusters, the performance of BCA always overcomes the bed effects and has 34 percent advantage comparing with LEACH. As result of above, a network lifetime increases sharply and the bed effect is declined when the number of cluster is increased appropriately. It means that we can drastically improve the bed effect of the wrong CH positioning by adjusting the number of cluster heads. But we notice that the basic lifetime of a network will be declined when the number of cluster increase. As appears by two graphs, the improvement of Figure 18 is very high comparing with Figure 17, but basic network lifetime is lower than Figure 17. This phenomenon is caused by that the energy consumption of CH is higher than sensor node as mentioned above section and equation (6).

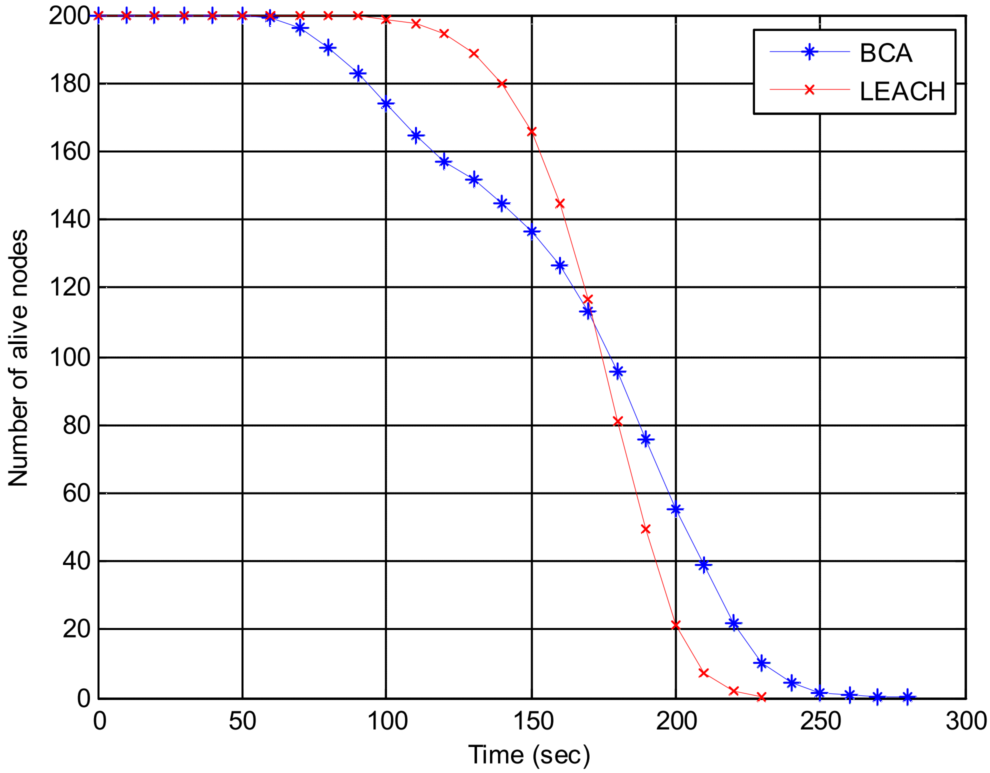

Figure 17. The number of alive nodes with 5 cluster heads

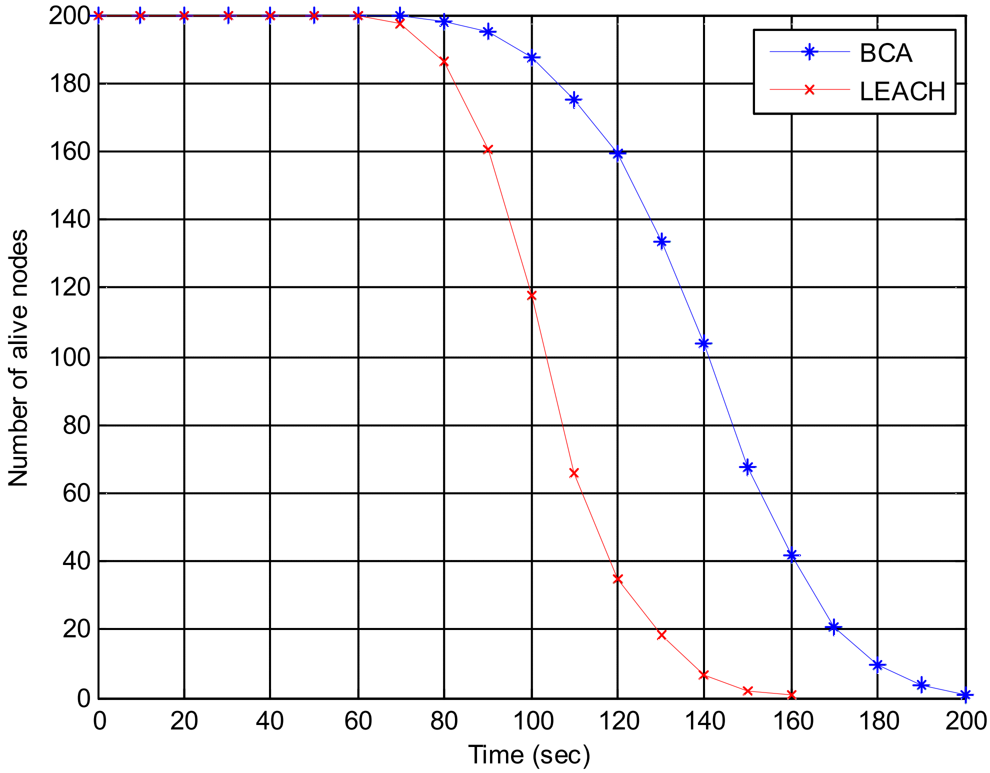

Figure 18. The number of alive nodes with 15 cluster heads

CONCLUSION

The main idea of the proposed BCA is to geographically distribute CHs more evenly in non-uniformly deployed WSNs by adjusting the probability that a node becomes CH. This is effectively implemented by taking the node density into consideration. Since more unused redundant nodes are turned into sleep mode, the energy consumption is reduced and thus network lifetime is prolonged accordingly.

According to our extensive computer simulation, the coverage area of each cluster in BCA is allocated almost evenly and thus inefficient energy consumption and packet collision are significantly decreased, resulting in prolonged network lifetime. We would like to emphasize the following features of BCA in terms of practical applications:

- The larger the initial energy, the more it increases the network lifetime;
- The higher the node density and non-uniformity, the more energy is saved;
- The number of cluster heads is critical factor of BCA.

In this paper, we have shown the performance results using three different initial energy values of 0.5J, 1J and 2J. In the real world, however, the battery capacity of nodes is usually higher than the above-mentioned initial energy and, thus, the network lifetime in BCA can be more improved. A possible future work is to improve the proposed algorithm to be applied in a dynamic topology.

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