An Energy-Based Clustering Algorithm for Ad-Hoc Sensor Networks

LIU Yueyang  JI Hong  YUE Guangxin

School of Telecommunications Engineering, Beijing University of Posts and Telecommunications
No.10 Xi Tu Cheng Road, Haidian District, Beijing, P.R. China
lyueyang@126.com

School of Telecommunications Engineering, Beijing University of Posts and Telecommunications
No.10 Xi Tu Cheng Road, Haidian District, Beijing, P.R. China
jihong@bupt.edu.cn

Abstract: Sensor networks are distributed event-based systems that differ from traditional communication networks. Transporting information in an energy efficient manner is critical to operating the sensor network for a long period of time. LEACH, a clustering-based protocol that utilizes randomized rotation of local cluster to evenly distribute the energy load among the sensors in the network. It presented an elegant solution where clusters are formed to fuse data before transmitting to the BS. In this paper, we propose a improved scheme which is a randomized clustering algorithm to organize the sensors in a wireless sensor network into clusters. It forms cluster according to residual energy of sensors and distance between sensors that differs from randomized rotation of LEACH. Through analytic evaluation and simulation, we can see that the new scheme can use energy more efficient and send much data.

Keywords: sensor networks, clustering, energy-efficient

1. INTRODUCTION

Recent advances in wireless communications and micro electro-mechanical systems have motivated the development of extremely small, low-cost sensors that possess sensing, signal processing and wireless communication capabilities [1], [2], [4], [7]. These sensors can be deployed at a cost much lower than traditional wired sensor systems. The Smart Dust Project at University of California, Berkeley [5] and WINS Project at UCLA [3], are two of the research projects attempting to build such low-cost and extremely small sensors.

To keep the cost and size of these sensors small, they are equipped with small batteries that can store at most several Joule [8]. The energy-constraint limits the transmission range and data rate. Sensor nodes can communicate directly with other nodes with small distance. Sensor nodes should consume as less as energy in order to maintain long life.

The LEACH protocol presented an elegant solution where clusters are formed to
fuse data before transmitting to the BS [6]. By randomizing the cluster-heads chosen to transmit to the base station, LEACH achieves some improvement compared to direct transmissions, as measured in terms of networks life[7]. Although LEACH has some advantage over direct transmissions, it exits several shortcomings in essence: firstly, randomized rotation of cluster results in much broadcast times that it wastes energy; secondly, cluster formation doesn’t considerate distance between sensor nodes that leads to consume much more energy in transmission data; thirdly, in every cluster formation, all sensors which not yet be cluster head must join reselecting phase that increasing complexity of cluster formation.

In this paper, we propose a improved scheme-EBCA. In EBCA, when the residual energy of cluster head dropped under threshold, BS begins to select new cluster head. This event-triggered mechanism reduces the number of broadcast times that it can save energy in some sense. In the operation of selecting cluster head, the BS considers residual energy and distance between sensor nodes in order to reduce energy consumption. Through the integration of residual energy and distance, we can save much more energy.

There are many possible models for wireless sensor networks. In this paper, we consider networks where [6]:

· The base station is fixed and located far from the sensors.
· All nodes in the network are homogeneous and energy-constrained.

The rest of the paper is organized as follows: in the next section, introduce radio model which is applied in this paper and describe new approach particularly; and then, analyzes approach to explain why it better than LEACH; after that, give simulation result to illuminate ex-analysis; lastly, we conclude the paper.

2. DESCRIPTION of EBCA

In this section, we will describe the radio model and protocol detail. Firstly, let see the radio model for this paper.

2.1. Radio Model for Energy Calculation

In this paper, we use the first order radio model which is discussed in [2]. In this model, a radio dissipates $E_{elec} = 50nJ / bit$ to run the transmitter or receiver circuitry and $e_{amp} = 100pJ / bit / m^2$ for the transmitter amplifier. The radios have power control and can expend the minimum required energy to reach the intended recipients. The radios can be turned off to avoid receiving unintended transmissions. We also assume an $r^2$ energy loss due to channel transmission. Thus, to transmit a $k-bit$ message a distance $d$, the radio expends:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d)$$

$$E_{Tx}(k,d) = E_{elec} \cdot k + e_{amp} \cdot k \cdot d^2$$

(1)

and to receive this message, the radio expends:
\[ E_{Rx}(k) = E_{Rx-elec}(k) \]
\[ E_{Rx}(k) = E_{elec} \times k \]

(2)

From above equation (2), we can see that receiving a message is not a low cost operation; the protocols should try to minimize not only the transmit distances but also the number of transmit and receive operations for each message.

In this paper, we make the assumption that the radio channel is symmetric such that the energy required to transmit a message from node A to node B is the same as the energy required to transmit a message from node B to node A for a given SNR. We assume that all sensor nodes are sensing the environment at a fixed rate and sending data when end-user has requirement.

2.2. Protocol EBCA

In the first section, we proposed several shortcomings of LEACH. In our new protocol, presents some improved methods to get over these disadvantages.

In initialization, BS selects randomly some sensors as a cluster head; other non-cluster head sensors will join to come into being a new cluster. Non-cluster head communicate with cluster head to determine their TDMA slots for data transmission and goes to sleep until it is time to transmit data.

Choosing new cluster head is triggered by energy event. Each sensor has a threshold of \( \text{Energy}_{\text{thres}}(i) \), \( i \) is number of being cluster head. When a sensor is cluster head and its residual energy drops below \( \text{Energy}_{\text{thres}}(i) \), and then it will send a \text{Reselect} packet to BS to trigger new operation of selecting cluster head. \( \text{Energy}_{\text{thres}}(i) \) is proportional to times of being cluster head \( i \).
$$\text{Energy}_{\text{thresh}}(i) = \begin{cases} \\ \text{Energy}_{\text{thresh}}(0), i = 0 \\ \text{Energy}_{\text{thresh}}(i - 1)/2, i = 1, 2, 3, \ldots \end{cases}$$

(4)

With this method, cluster is formed according to residual energy of cluster head that thus reduces broadcasting times. Then, sensor can increase energy utilization ratio and prolong network lifetime.

The next step is to pick out new cluster head by BS. In LEACH, the cluster head algorithm just uses a random number to choose cluster head without considering practical condition. In our approach, we consider the location and energy in cluster head algorithms.

When BS received \textit{Reselect} packet, it start reselecting operation of cluster head. All other non-cluster nodes send their current location and residual energy to BS. The BS figure out a \textit{Judge-value(k)} with residual energy and distance between sensors and center of cluster area,

\[
\text{Judge-value}(k) = \alpha \text{Energy}_{\text{residual}} + \beta (\text{Distance}_{\text{max}} - \text{Distance}_{\text{to-center}})^2
\]

(5)

\text{Energy}_{\text{residual}} is residual energy of non-cluster head sensor, \text{Distance}_{\text{to-center}} is distance between sensor of non-cluster head and center of cluster area, \text{Distance}_{\text{to-center}} is maximum value in the set of \text{Distance}_{\text{to-center}}. k is sensor ID of non cluster head, \alpha and \beta are weighting factors. Through a round computation, BS can achieve a set of \text{Judge-value}(k), then the BS picks out the sensor nodes with maximum \text{Judge-value}(k) as new cluster head. It means that sensor which has maximum value of residual energy and minimum value of distance square will be a cluster head.

The ID of new cluster head is \textit{ID}_{\text{new-clusterhead}} = \text{ID}(\text{MAX}\{\text{Judge-value}(k)\}), \text{ID}(\text{\_}) is a function which get the ID of corresponding sensors.

From equation (1), we can see the transmission energy is tightly relative to the distance \(d^2\). Thus in our approach, the distance from sensor nodes to cluster head is considered into selecting head algorithm that it can minimize the total sum of squared distances between sensor nodes and the closest cluster head.

Once new cluster head is found, BS broadcasts a \textit{allocate} packet that contains the cluster head ID to each sensor. If a sensor’s ID matches the new cluster ID of \textit{allocate} packet, the node is a cluster head; otherwise, the node determines its TDMA slot for data transmission and goes to sleep until it is time to transmit data. Anyway, the operation of selecting new cluster head is always carried out into same cluster. Once a sensor joins a cluster, it is not permitted to join another cluster later. It can reduce complexity of cluster head algorithm.
3. ANALYTIC EVALUATION

In this paper, cluster head algorithm is consider residual energy and distance. We know energy consumption is relative to data length and transmission distance. From the first radio model, trying to minimize total sum of distance is vital to control energy consumption.

If we assume cluster area is a circle and \( N \) sensors are deployed uniformly in cluster. There are one cluster head and \( N - 1 \) non-cluster sensors. The distance between each non-cluster sensor and cluster is \( d_i \). We want to minimize transmission energy of non-cluster sensors that means to minimize \( \sum d_i^2 \). We let center point of cluster area be zero point of coordinate. The coordinate of cluster is \((x, y)\) and arbitrary non-cluster sensor is \((x_i, y_i)\), so \( d_i^2 = (x_i - x)^2 + (y_i - y)^2 \). The expected squared distance from the non-cluster sensor to the cluster head,

\[
E[d_i^2] = \int \int [(x_i - x)^2 + (y_i - y)^2] \rho(x_i, y_i) dx_i dy_i
\]

(6)

If we assume the radius is \( R \) and \( \rho(r, \theta) \) is constant for \( r \) and \( \theta \), (6) simplifies to

\[
E[d_i^2] = \rho \int_0^{2\pi} \int_0^R [r^2 + (x^2 + y^2) - 2(xrcos\theta + yrsin\theta)] r dr d\theta
\]

\[
= \rho \left[ \frac{\pi R^4}{2} + \pi R^2 (x^2 + y^2) \right]
\]

(7)

As all sensors are deployed uniformly, then \( \rho = \frac{1}{\pi R^2} \) and

\[
E[d_i^2] = \frac{R^2}{2} + (x^2 + y^2)
\]

(8)

On account of \( N - 1 \) non-cluster sensors, the \( \sum d_i^2 = (N - 1) \left[ \frac{R^2}{2} + (x^2 + y^2) \right] \).

If we want to obtain the minimum of \( \sum d_i^2 \), must minimize \( x^2 + y^2, x \to 0, y \to 0 \).

That means, BS should let cluster head to close to center point of cluster area as nearly as possible.

In figure2, we suppose that two clusters are square. Each cluster has 16 sensors and distance between two sensors is \( r \). BS selects one from these sensors as a cluster head in each round. The bigger black point is cluster head and grey point is normal sensors. In addition, we mark the smaller black point as center point of every cluster. As following, we will set forth how the location of cluster head to affect transmission.
energy.

We suppose the residual energy of each sensor is same in reselect phase for analysis, thus the only factor which affects result is $Distance_{to\text{-}center}$. (in this scheme, $Distance_{\text{max}}$ is a constant).

From equation (1), $E_{\text{Tx}}(k, d) = E_{\text{elec}} \cdot k^2 + \epsilon_{\text{amp}} \cdot k \cdot d^2$, we induce that minimizing $\sum d^2$ will get minimum of transmission energy. In other words, if we want to obtain minimum of transmission energy, we must minimize $\sum Distance_{\text{to\text{-}center}}$.

In example (a), cluster head is located nearly to center point of cluster. If every sensor send $k$ bit data to cluster head each time, transmission energy of all sensors in cluster is

$$E_{\text{Tx}}(k, R) = \sum_{i=1}^{15} E_{\text{Txi}}(k, R)$$

$$= 15(E_{\text{elec}} \cdot k) + \sum_{i=1}^{15} \epsilon_{\text{amp}} \cdot k \cdot R_i^2$$

$$= 15(E_{\text{elec}} \cdot k) + 44\epsilon_{\text{amp}} \cdot k \cdot r^2$$

(9)

![Diagram](a) ![Diagram](b)

Figure 2. Different location of cluster head will take different affection to transmission energy

In example (b), cluster head is located farly to center point of cluster. If every sensor send $k$ bit data to cluster head each time, transmission energy of all sensors in cluster is

$$E_{\text{Tx}}(k, R) = \sum_{i=1}^{15} E_{\text{Txi}}(k, R)$$
\[ = 15(E_{elec} * k) + \sum_{i=1}^{15} e_{amp} * k * R_i^2 \]

(10)

From comparison between (a) and (b), we draw a conclusion: the nearest cluster head to center point of cluster, the little transmission energy is consumed. Thus for \textit{Judge - value}(k), maximizing it means picking out the sensor which is nearest to center point as a cluster head. Through this method, we can minimize total sum of distance for transmission.

In addition, taking residual energy into consideration helps to choose sensor, which has much more energy that thus can reduce selecting cluster head times. In fact, each round selecting cluster head will consumes energy. Then, reduction of selecting cluster head times can save much energy and prolong lifetime of sensor networks.

4. SIMULATION RESULT

In this experiment, each node begins with only 1J of energy and an unlimited amount of data to send to the BS. In the beginning, BS assigns randomly some cluster heads and forms cluster. In each round, cluster will send Reslect packet to BS to trigger operation of selecting new cluster head after its residual energy dropping below energy threshold. Then, BS uses the equation (5) to determine new cluster head and broadcasts result to all sensors in this cluster. When the node uses up their limited energy during the course of the simulation, they can no longer transmit or receive any data.

TDMA is applied to communication between sensors and cluster head that it can reduce probability of collision. After choosing cluster head, other sensors will communicate with cluster head in order to get their sending slot. In own slot, sensor sends its data to cluster head; other time, it enters into sleeping phase.

Figure3. BS received data size

Figure4. Total energy consumed by transmitting data
In this experiment, we deployed uniformly 50 sensor nodes in 500-meter×500-meter area. The number of cluster head is five that can get best outcome. Any sensor in same cluster can communicate mutually. We make a comparison between three protocols, transmit packet directly to BS, LEACH and EBCA.

Figure 3 shows the plot of the data size of the BS received vs time. Each packet send by sensor is 2000bits. The simulation result shows that data size is observed to increase with time going. We can see the performance of LEACH and EBCA is better than direct transmission. The EBCA saves energy more efficient; sensors can transmit much data than LEACH. Therefore, BS in EBCA can receive much more data than that in LEACH and direct transmission.

Figure 4 shows the plot of the total energy of transmission data vs time. The simulation is stopped when all sensors died. Each packet send by sensor varied from 2000bits to 8000bits. We can see the networks that transmit data directly to BS using much energy in transmission data. It is obvious that it almost has no other controlling packet; thus, almost all energy is expended on transmission data. But in figure 3, we notice that BS of direct transmission manner receives much less data. It also shows the efficiency of transmitting data directly is lowest. In additional, network-using EBCA consumes more energy than LEACH in aspect of transmission data. From figure 3 and figure 4, we notice that with same total energy of network, BS of EBCA received more data, thus consumed more energy. The benefit owes to two aspects, the first is reducing the number of broadcasting; the second is minimizing the total distance which data routing in transmission data. It shows that sensors use more energy in aspect of transmission data and the sensor networks using EBCA has higher ratio of energy utilization than that using LEACH.

Figure 5 shows the plot of the total energy of networks vs time. Each packet send by sensor varied from 2000bits to 8000bits. At the beginning, the network has 50J energy, simulation com-

![Figure 5. Total energy consumed by networks](image-url)
5. CONCLUSION

In this paper, we present a clustering protocol-EBCA in ad-hoc sensor networks. EBCA uses residual energy and distance from non-cluster head to cluster head in cluster head algorithm that it reduces broadcast times and transmission energy. The simulation result also proved our analysis. Improvement of sending data size is about 10% and improvement of lifetime is about 34% in networks using EDCA.

Cluster architecture is an efficient approach for sensor networks. LEACH is a dynamic randomly clustering protocol for sensor networks. It presented a solution, which organize a number of sensors to cooperation. Our new protocol is based LEACH and adopts event-triggered scheme. The networks using EDCA can adjust adaptively by practical condition. Through these improved measures, EDCA gets over shortcomings of LEACH and increases performance.

REFERENCES
