An Energy-Efficient Distributed Unequal Clustering Protocol for Wireless Sensor Networks

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Abstract — The wireless sensor networks have been extensively deployed and researched. One of the major issues in wireless sensor networks is a developing energy-efficient clustering protocol. Clustering algorithm provides an effective way to prolong the lifetime of a wireless sensor networks. In the paper, we compare several clustering protocols which significantly affect a balancing of energy consumption. And we propose an Energy-Efficient Distributed Unequal Clustering (EEDUC) algorithm which provides a new way of creating distributed clusters. In EEDUC, each sensor node sets the waiting time. This waiting time is considered as a function of residual energy, number of neighborhood nodes. EEDUC uses waiting time to distribute cluster heads. We also propose an unequal clustering mechanism to solve the hot-spot problem. Simulation results show that EEDUC distributes the cluster heads, balances the energy consumption well among the cluster heads and increases the network lifetime.

Keywords—Wireless Sensor Network, Distributed Unequal Clustering, Multi-hop, Lifetime.

I. Introduction

Recent advances in MEM-based sensor technology and wireless networks have enabled the deployment of large scale wireless sensor networks. Wireless sensor networks (WSNs) are composed of thousands to millions of wireless sensors. Sensor node is tiny in size and low in cost. Also it has low computational ability and small memory constraint. These small sensor nodes are capable of sensing the environment, storing and processing the collected sensor data, and interacting and collaborating within the network. Considering the characteristics of WSNs, energy resource of node should be managed wisely to extend the lifetime of sensors. This is very important to prolong the lifetime of entire sensor networks.

In order to guarantee low energy consumption and a uniform load distribution over the network, there have been many schemes that sensor nodes are organized into clusters. From clustering organization point of view, previous research has shown that multi-hop communication between source and base station is usually more energy efficient than direct transmission because of the characteristics of wireless sensor networks. Nowadays in Many WSNs applications, the traffic pattern that the cluster head closer to base station relay more messages than the other cluster head because of the hotspot problem when using the multi-hop forwarding model. Therefore, how to select appropriate forwarding cluster head to relieve the load imbalance becomes the key issue. Although many schemes proposed from the previous researches reduce energy consumption of the cluster heads which is on forwarding paths, they do not necessarily extend network lifetime due to the continuous many-to-one traffic pattern.

In this paper, we present the idea of solving the hotspot problem in WSNs. This is a mechanism for periodical data gathering applications in wireless sensor networks. It is suitable for WSN using EEDUC, where cluster heads are chosen by localized competition, which is unlike LEACH[2][5], and with no iteration, which differs from HEED[3]. In the literature of WSNs, the hotspot problem has been formulated in various ways with different assumptions and objectives. Especially EEUC[10] was suggested as a solution that clusters closer to the base station are expected to have smaller cluster sizes, thus they must be consume lower energy during the intra-cluster data processing, and can preserve some more energy for the inter-cluster relay traffic. However it has a defect that a cluster head chooses a relay node from its adjacent cluster heads without considering the relay traffic balances. So we focus on relay traffic balancing and distributed clustering. We solve the hotpot problem with considering the number of neighbor's node and the residual energy of node. Simulation results show that EEDUC successfully balances the energy consumption over the network, and achieves a remarkable network lifetime improvement.

The rest of this paper is organized as follows: Section II covers related work in this area; Section III presents the Distributed Unequal Clustering algorithm and inter-cluster multihop routing protocol in detail; Section IV analyzes some properties of the EEDUC algorithm; Section V concludes this paper with directions for future work.

II. Related work

There are many clustering algorithms used in wireless sensor networks, and new ideas for clustering are announced in recent years. In this section, we review some of the most effective algorithm.

LEACH uses randomized rotation of the cluster-heads to

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evenly distribute the energy load among the sensor nodes in a network [2], [5]. Once the clusters are constructed, the cluster heads broadcast TDMA schedules providing the order of transmission for members in the cluster. Each node has its own time slot. It transmits data to the cluster head within its exclusive time slot. When the last node in the schedule has transmitted its data, the cluster head will be randomly elected in the next round. It employs localized coordination to improve the scalability and balance the energy usage of the network among all the nodes. In PEGASIS(Power-Efficient Gathering in Sensor Information Systems), author tried to foster the past technique [4], [6]. This new mechanism is a chain-based power efficient protocol based on LEACH. It assumes that each node must know location information about all other nodes at first. PEGASIS starts with the farthest node from the base station. The chain can be constructed easily by using a greedy algorithm. The chain leader aggregates data and forwards it to the base station. In order to balance the overhead involved in communication between the chain leader and the base station, each node in the chain takes turn to be the leader. In HEED, author introduces a variable known as cluster radius which defines the transmission power to be used for intra-cluster broadcast [3]. The initial probability for each node to become a tentative cluster head depends on its residual energy, and final heads are selected according to the intra-cluster communication cost. HEED terminates within a constant number of iterations, and achieves fairly uniform distribution of cluster heads across the network. All these methods require re-clustering after a period of time because of cluster heads' higher workload.

Almost all these methods, however, have no consideration about the hot spots problem when multi-hop forwarding model is adopted during cluster heads transmitting their data to the base station. To solve this problem, unequal clustering model is appeared [7]. This model focuses on a heterogeneous network where cluster heads are deterministically deployed at some pre-computed locations. But cluster heads farther away from the base station have to transmit packets over longer distance than those of cluster heads closer to the base station. Because of this, a similar problem of unbalanced energy exists in single hop wireless sensor networks. EECS extends LEACH and HEED by choosing cluster heads with more residual energy [11]. It also achieves a well distribution of cluster heads. In EECS, a distance-based cluster formation method is proposed to produce clusters of unequal sizes. Clusters farther away from base station have smaller sizes, thus some energy could be preserved for long-haul data transmission to base station.

Furthermore, multi-hop routing protocol for energy efficiency has also been proposed for wireless sensor networks. Directed diffusion that focuses a scalable and robust communication paradigm is based on data-centric routing [8]. A sensor sends the data along the aggregation tree to the sink when it has data for the interest. And GBR(Gradient-Based Routing) is also proposed as a variant of directed diffusion [9]. The key idea in GBR is to memorize the number of hops when the interest in diffused through the whole network. In GBR, three different data dissemination techniques have been discussed (i) Stochastic Scheme, where a node picks one gradient at random when there are two or more next hops that have the same gradient, (ii) Energy-based scheme, where a node increases its height when its energy drops below a certain threshold, so that other sensors are discouraged from sending data to that node, and (iii) Stream-based scheme, where new streams are not routed through nodes that are currently part of the path of other streams. The main objective of these schemes is to obtain a balanced distribution of the traffic in the network, thus increasing the network lifetime. Simulation results of GBR showed that GBR outperforms directed diffusion in terms of total communication energy.

In EEUC(An Energy-Efficient Unequal Clustering), to address the hot spot problem, author proposed an unequal clustering mechanism to balance the energy consumption among cluster heads [10]. Clusters closer to the base station have smaller sizes than those farther away from the base station, thus cluster heads closer to the base station can preserve some energy for the purpose of inter-cluster data forwarding. And an energy-aware multi-hop routing protocol is proposed for the inter-cluster communication in EEUC mechanism.

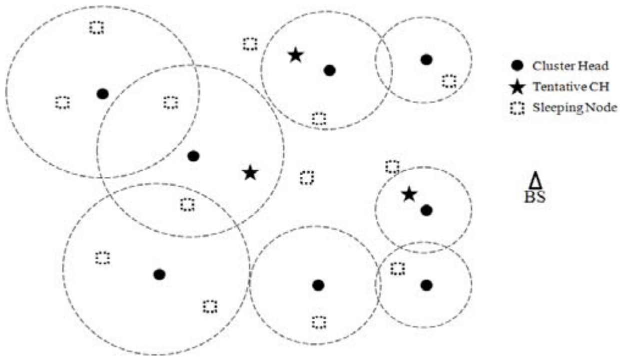


Fig. 1 The overview of the EEUC mechanism

III. PROPOSED ALGORITHM

When the wireless sensor network initialized, the Base Station synchronizes with all sensor nodes to an advertisement message. The Base Station broadcasts an advertisement message to each node. A received node calculates a distance from the Base Station to itself by strength of message. Each sensor node broadcasts advertisement message to count the number of neighborhood nodes in 1-hop range. Also, the Base Station assigns a random value to each node and decides a time unit for clustering. Each sensor node decides a waiting time in the range of a clustering time unit. The waiting time is set as:

$$[(1-\alpha)\times N_i/N_{MAX}]+[\alpha\times V_{random}] \quad (1)$$

Where N_i is the number of neighborhood nodes of node i, N_{MAX} is the number of total sensor nodes, V_{random} is a random number between 0 and 1, α is a constant coefficient between 0 and 1. During round 0, each node has same energy with other nodes.

Figure 1 shows an overview of the EEUC mechanism. When cluster heads cooperate with each other to forward their data to the Base Station, the cluster heads closer to the Base Station are burdened with heavy relay traffic and tend to die early. To address this problem, the EEUC provides an unequal clustering mechanism. But the EEUC can't cover whole network. This uncovered area causes the imbalance of the networks. So we consider the number of neighborhood nodes of node i to cover whole network.

After initialize phase, each sensor node decreases its waiting time which is synchronized with a node timer. When the waiting time becomes 0, a node determines itself to be a cluster head. And the cluster head broadcasts a HELLO message to the neighborhood nodes. The competition radius of HELLO message is decided by the function. This function is made by the distance to the base station, the number of neighborhood nodes and the residual energy of cluster head. The competition radius R_{comp} is set as:

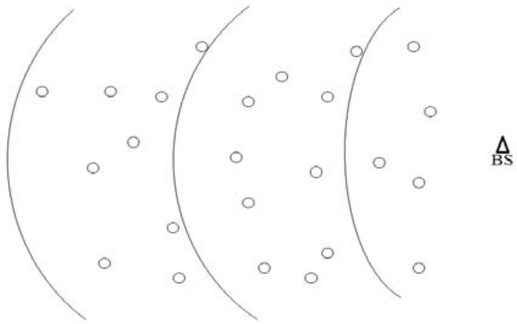
$$R_{comp} = \begin{bmatrix} 1 - w_1(1 - TS_i/TS_{MAX}) - \\ w_2(1 - E_i/E_{MAX}) - w_3\, N_i/N_{MAX} \end{bmatrix} R_{MAX} \qquad (2)$$

where TS_i denote the distance between node i and the Base Station, TS_{MAX} is the maximum distance between sensor node and the Base Station, E_i is the residual energy of node i, E_{MAX} is the maximum energy of sensor node, R_{MAX} is the maximum cluster size, w_1 and w_2, w_3 are a constant coefficient between 0 and 1.

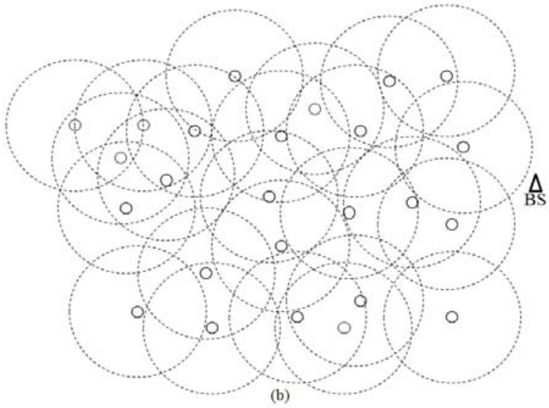
If the mode of neighbor nodes which receive a message from the cluster head is same as Initial, they store their node table with a cluster head information and change their node mode as a cluster member. The member nodes send a reply message about their information to the cluster head. When re-clustering to the next round, each node decides a waiting time. The waiting time is set as:

$$\left[\left(1 - \beta - \gamma\right) \times N_i/N_{MAX}\right] + \\ [\beta \times E_i/E_{MAX}] + [\gamma \times V_{random}] \qquad (3)$$

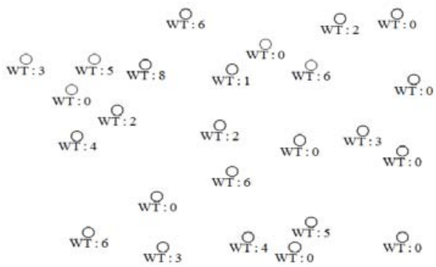
where β and γ are a constant coefficient between 0 and 1. Using this waiting time, each cluster head will be distributed in the sensing field well.



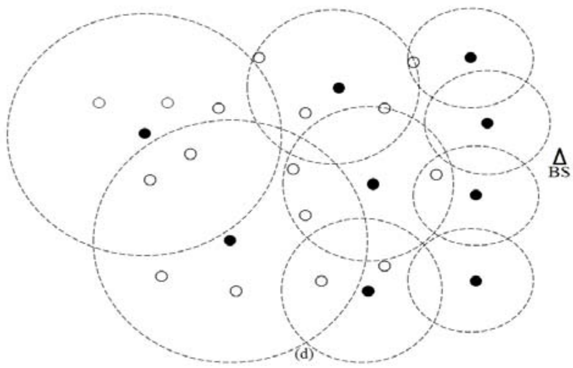
(a)



(b)



(c)



(d)

Fig. 2 Clustering phase: (a) BS broadcast advertisement message (b) Each sensor node broadcasts advertisement message (c) Each sensor node decreases its waiting time (d) Complete clustering

Figure 2 shows a clustering phase for our proposed scheme. When the cluster head delivers their data to the Base Station, each cluster head first aggregates the data from its cluster member and sends the packet to the Base Station via multi-hop communication. In some proposed algorithms like LEACH, the cluster head sends directly the packet to the Base Station via 1-hop communication. But this method increases the consumption of cluster head. In PEGASIS, each cluster head can aggregate the incoming data from other cluster head together with its data. This method uses multi-hop communication, but is unpractical because the sensed data correlation between different clusters is relatively low. In this paper, each cluster head doesn't aggregate the incoming data. Also each cluster head communicates with the Base Station by multi-hop routing protocol. The cluster head chooses a next cluster head to forwarding its data from its neighborhood cluster heads.

IV. SIMULATION

We have implemented our proposed protocol in NS-2(ver. 2.31). Simulation experience is measured in following environments.

TABLE I
BASIC PARAMETERS CONFIGURATION

Wireless Sensor Network Node Environment	
MAC Protocol	MAC / 802_15_4
Traffic Pattern	CBR
Interface Queue Type	Default : 5~100
Topology Configuration Mode	Drop-Tail, Priority Queue
Size of Data Packet	70 Bytes
Initial Energy	1 J
Simulation Environment	
Simulation Area	50m x 50m
Simulation Time	150 seconds
Number of Node	Default : 50

For measuring, we have compared EEDUC with LEACH and EEUC.

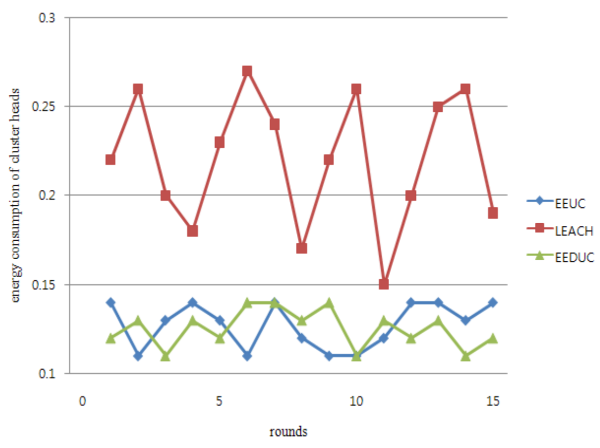


Fig. 3 The amount of energy consumption by CHs

In Figure 3, we compare the amount of energy consumption by cluster heads in three protocols for 15 rounds. The energy spent by cluster heads per round in EEDUC is much lower than that in LEACH, and is about the same as that in EEUC. Because cluster heads send their data to the Base Station via 1-hop communication in LEACH, the energy consumption is much higher. In EEDUC and EEUC, cluster heads send their data to the Base Station via multi-hop communication. Thus cluster heads a considerable amount of energy consumption is decreased. In EEDUC and EEUC, the amount of energy consumption by cluster heads is almost the same in each round.

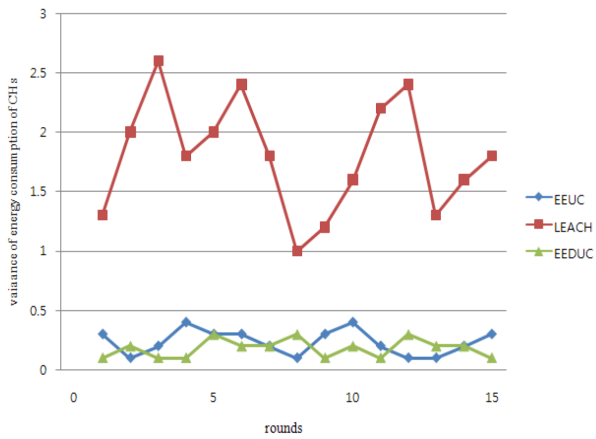


Fig. 4 The variance of amount of energy consumption by CHs

Figure 4 shows the variance of amount of energy consumption by cluster heads in three protocols for 15 rounds. In EEDUC and EEUC, the unequal clustering scheme and the energy-aware multi-hop routing scheme balance the energy consumption among cluster heads. Also the variance of two methods is almost the same in each round.

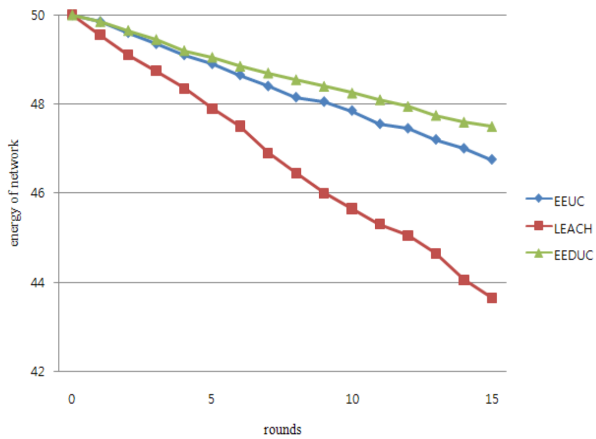


Fig. 5 The total remaining energy of the network

Figure 5 shows the total remaining energy of the network in three protocols for 15 rounds. It shows that EEDUC balances the energy consumption among cluster heads best. In EEUC, cluster heads can't cover the whole network perfectly. Thus cluster heads increase the overhead to communication with the Base Station.

V. Conclusion

In the paper, we present an energy-efficient distributed clustering mechanism for wireless sensor networks. We think that both of the energy-aware multi-hop routing protocol and the unequal clustering mechanism are not sufficient to balance the energy consumption. To solve this problem, we propose an Energy-Efficient Distributed Unequal Clustering algorithm for Wireless Sensor Networks. At first we introduce a distributed clustering mechanism. The cluster heads are selected based on the number of neighborhood nodes with their residual energy. In other words, each node sets the waiting time to start broadcasting its HELLO message. This waiting time is considered as a function of residual energy, number of neighborhood nodes. And we present an unequal clustering algorithm to solve the hot-spot problem. The competition radius of cluster head where closer to the Base Station has smaller size than those of far away Base Station. Simulation results show that EEDUC obviously improves performance over LEACH and EEUC. In EEDUC, the performance of energy consumption is improved 24.2% compared to EEUC.

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