Energy Balanced Fixed Clustering protocol for Wireless Sensor Networks

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Abstract— Wireless sensor networks (WSNs) is a collection of large number of tiny, limited battery powered sensor nodes. Minimizing energy consumption and maximizing network lifetime are the primary goals when designing applications and protocol for WSNs. Clustering sensor nodes proven to be an effective and energy efficient way to extend the lifetime of wireless sensor networks. One of the major challenging issues of a clustering protocol is selecting an optimal group of sensor nodes as cluster head (CH) to partition the network. In this paper, an Energy Balanced Fixed Clustering (EBFC) protocol is proposed and evaluated. The protocol creates a fixed number of clusters and maintained throughout the lifetime. Energy load have been distributed evenly among all the nodes by rotating the role of cluster heads. In EBFC protocol, cluster heads and next heads have been selected based on the residual energy and location of the nodes in advance. The results show that EBFC significantly increases the lifetime.
Keywords— Clustering, Cluster head, Energy consumption, Sensor nodes, Wireless sensor networks.

1. INTRODUCTION

Recent years have witnessed rapid advances in micro-electro-mechanical systems (MEMS) technology that enabled the development of extremely small, battery operated, low power and relatively low cost communication devices called sensor nodes. Sensor nodes are generally equipped with antenna, radio and transceivers which are used to transmit/receive the information from interested nodes or the central base station/sink. Sensing circuitry is capable of measuring the desired parameters (such as temperature, humidity, etc.) from surrounding medium and translates them to electrical signal for further processing [1-2]. Each sensor nodes has low computational power on board processor for data processing.

A wireless sensor network (WSN) is an autonomous and self organizing system consists of large number of tiny sensor nodes which are densely deployed throughout a physical space. These sensor nodes gather sensor information, perform data processing and communicate with each other. Data to the sink is transmitted using multihop communication. WSNs are quite different from the mobile ad hoc networks (MANETs), in which sensor nodes are less mobile, less capable and more densely deployed.

WSNs are widely used for systematic gathering of useful information from hundred or even thousands of nodes related to the surrounding environment and transmission of the gathered information to a base station for further processing. WSN has attracted the researcher's community attention and find use in a wide range of real-world applications, such as target tracking [3], habitat monitoring [4], disaster management [5], and so on.

Node's energy is depleted due to useful operations, such as transmitting/receiving data, processing queries, and forwarding queries or data to interested nodes. The energy is also consumed due to wasteful operations like, sensing and listening to the media continuously, and retransmission of packets, etc. Sensor nodes run with small, low power batteries, and it cannot be rechargeable or replaceable. Since most of the applications require an unattended use of these networks over a longer duration of time. Energy conservation is one of the key challenges in the operation of WSN. This necessitates the development of energy aware protocol for extending the lifetime of the network.

Energy conservation is achieved by efficient network organization [6], in which the sensor nodes in the field are divided into small groups called clusters. Each cluster has a coordinator node called a cluster head (CH). The cluster heads often lose more energy than member nodes in the network. Because, cluster heads are responsible for collection of data from each node in the cluster, perform data aggregation, and send the aggregated data to the base station directly or using multihop communication. The uniform distribution of load among the sensor nodes is achieved by rotating the role of the cluster head periodically.

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In the past few years, a good number of hierarchical clustering protocols [7-14] for WSNs had been dealt with the common issue of energy conservation. In most of these published works, the researchers propose to reduce the energy consumption of sensor nodes by minimizing the inter node communication, and increasing the node sleeps times.

In this paper, we propose a novel distributed clustering protocol, which has the following primary goals:

- Cluster creation is initiated by central base station and proceeds in a distributed manner.
- Protocol maintains a fixed number of clusters throughout the lifetime of the network.
- Cluster heads are evenly distributed over the network.

The remainder of the paper is organized as follows. Section 2 briefly discusses an overview of related work on a cluster based protocols. In section 3, we describe the network and radio model used in our protocol. A detailed description of the proposed protocol is presented in section 4. We present the result obtained from our simulation study in Section 5. Finally, we conclude this paper in Section 6.

2. RELATED WORK

In the past few years, many energy-efficient clustering protocols for WSNs have been proposed. Hierarchical or cluster based routing protocols perform energy-efficient routing using innovative techniques. In hierarchical architecture, higher-energy sensor nodes can be used to collect and transmit the information, while other nodes used to sense the proximity of the target. The formation of clusters greatly contributes to overall network lifetime, scalability, and energy efficiency. Hierarchical routing is a two-layer routing, in which one layer is used to select high-energy nodes as cluster heads and the other for routing. Few of these clustering protocols have been discussed here.

LEACH [9] is an application specific hierarchical clustering protocol proposed to increase the network lifetime. Cluster heads are selected randomly and this role is rotated to evenly distribute the energy load among the sensor nodes in the network. In cluster setup phase, node selects a random number between 0 and 1. If the random number is lower than a threshold value, the node becomes a cluster head for the current round otherwise it becomes a member node of the cluster. The threshold value is related to the desired percentage of cluster heads (p), current round, and the set of nodes that have not been cluster heads for the last $(1/p)$ rounds. After cluster setup, the cluster head nodes broadcast TDMA time slot for each node in the cluster to send data. In steady state phase, the cluster head nodes collect data from each node in the cluster, perform data aggregation, and transmit data to sink.

HEED [11] protocol uses probabilistic approach for the election of cluster head based on residual energy of a node as the primary parameter. If there is any tie between two cluster heads, it uses node degree or average distance to neighboring nodes as secondary parameter. The HEED does not make any assumptions about the network, such as, density and size. Every node runs HEED individually.

Threshold-Sensitive Energy Efficient Sensor Network Protocol (TEEN) [12] and Adaptive Periodic TEEN (APTEEN) [13] are proposed for time-critical applications. In TEEN, the cluster head node broadcast two threshold values (hard threshold and soft threshold) into the network. The node transmit only when the sensed attribute is greater than hard threshold or the difference of current and previously transmitted sensed attribute is greater than soft threshold. APTEEN is an extension to TEEN and it is designed to suit both proactive and reactive networks. In this protocol, nodes sense the environment continuously, and only those nodes that sense a data value greater than hard threshold transmit. The drawbacks of TEEN and APTEEN approaches are the overhead and complexity associated with forming clusters at multiple levels.

Energy-balanced unequal clustering (EBUC) [14] protocol operation is based on a centralized control mode. In EBUC, the base station collects the position and energy level of each node in the network. Based on these information base station selects the cluster heads for the network and broadcast them into the network. The cluster heads collects the data from their member nodes, performs data fusion, and sends the data to the base station via inter-cluster multihop routing.

3. PRELIMINARIES

3.1 Network model

We assume that a sensor network can be composed of thousands of nodes. Also:

1) Nodes are dispersed in a 2-dimensional space and cannot be recharged after deployment.
2) Nodes are quasi-stationary.
3) A fixed base station is located either inside or outside of the sensor fields.

4) Nodes are location-aware, which can be defined using GPS, signal strength or direction.
5) All nodes are energy constrained and perform similar task.
6) Each sensor nodes in the network assigned a unique identifier (ID).

3.2 Radio Energy Dissipation model

We assume a simple model for radio hardware energy dissipation as used in ref [10]. In this model, the transmitter has power control abilities to dissipate minimal energy to send data to the receiver. Transmitter dissipates the energy to run transmit electronics and power amplifier, and receiver expends energy to run radio electronics. Thus, to transmit a *k-bit* message to a distance *d*, radio expends

$$E_{Tx}(k,d) = \begin{cases} E_{elec}k + E_{fs}kd^2 ; & d < d_o \\ E_{elec}k + E_{mp}kd^4 ; & d \geq d_o \end{cases} \quad (1)$$

and to receive this message, the radio expends:

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

where, E_{elec} is the energy dissipated per bit to run the transmitter or the receiver circuit, and E_{fs}, E_{mp} is the amplifier energy dissipated per bit to run the transmit amplifier depending on the distance between the transmitter and receiver. If the distance is less than a threshold (d_o), the free space $(d^2$ power loss$)$ model is used; otherwise, the multipath $(d^4$ power loss$)$ model is used.

For the protocol described in this paper, the communication energy parameters are set as given in the Table.1.

Table 1. Simulation parameters

Parameter	Symbol	Value
T_x/R_x electronic constant	E_{elec}	50 nJ/bit
Amplifier constant	E_{fs}	10pJ/bit/m^2
	E_{mp}	0.0013 pJ/bit/m^4
Initial Energy	E_o	2 joule
Energy for Data aggregation	E_{DA}	5 nJ/bit/signal

4. EBFC PROTOCOL OPERATION

EBFC is designed for application, where periodic monitoring of WSNs is required. It is used to collect data from randomly deployed sensor nodes and transmit data to a base station, which is located far from the sensor nodes. Partitioning the entire network into clusters would reduce the energy consumed for data communications. Fig. 1 gives an overview of the EBFC protocol, where circles represent our clusters and arrows indicates data forwarding using multihop communication.

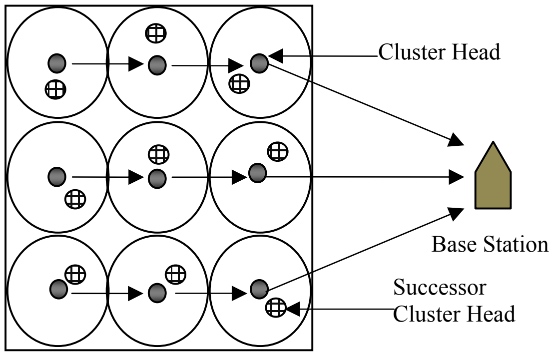


Fig.1 An overview of the EBFC protocol

EBFC is a clustering protocol for WSNs, which maintain the fixed number of cluster heads throughout the lifetime of the network. The protocol operation is begun with central control mode at base station and continues in distributed control mode. The EBFC operates in three phases: central cluster setup phase, steady-state phase, and distributed cluster setup phase as shown in Fig. 2.

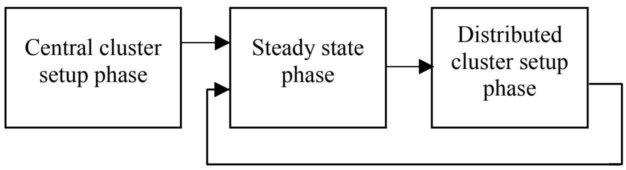


Fig. 2 EBFC operations

During the Central cluster setup phase, the base station creates fixed number of clusters, and selects cluster heads based on the energy status and location information received from sensor nodes. The central cluster setup phase consists of these stages: cluster formation stage, cluster head broadcast stage, and advertisement stage

4.1. Central Cluster Setup Phase

During the Central cluster setup phase, the base station creates fixed number of clusters, and selects cluster heads based on the energy status and location information received from sensor nodes. The central cluster setup phase consists of these stages: node information stage, cluster head broadcast stage, and advertisement stage

4.1.1. Node information stage

In this stage base station collects the information from all the nodes in the network. The base station broadcast a message requesting each node in the network to send their location, ID and energy status. The sensor nodes get their current location either by using global positioning system receiver or localization techniques. In response to the request from base station, all the nodes in the network send the location, ID, and energy level information to the base station.

4.1.2. Cluster head broadcast stage

Upon receiving information from nodes, the base station creates fixed number of clusters decided by the protocol and fixes the centre of each cluster. The protocol selects the energy abundant nodes as cluster head for each cluster. If more than one node is eligible to become cluster head, node which is near to the centre of the cluster is selected as cluster head.

Once the clusters and cluster heads have been selected, the base station broadcast cluster head ID into the network.

4.1.3. Advertisement stage

During this stage, each node extracts the ID from the message broadcasted from the base station. If the node ID matches with the cluster head ID, the node becomes cluster head, otherwise the node wait for the cluster head advertisement.

The cluster head node broadcast cluster head advertisement message into the network. The member node decides whether it would like to join the cluster or not based on the received signal strength of the advertisement signal. The member node join the cluster by sending join message signal to the nearest cluster head along with their ID and current energy level.

4.2. Steady-state phase

The cluster head select next head and distribute the time division multiple access (TDMA) schedule, which specifies the time slots allocated for each member of the clusters. Upon gathering data from all the member nodes, the cluster head transmits fused data to the base station. The steady-state phase is broken into following stages: Next head selection stage, schedule creation stage, and data transmit stage.

4.2.3. Next head selection stage

During this stage, the cluster heads select a set of sensor nodes as next heads based on the energy level and location of member nodes. The cluster head node selects the higher-energy level node as next head. The next head takes the role of the cluster head in the next round. The main aim of selecting the next cluster heads in advance is to reduce communication overhead incurred in the selection of new cluster heads.

4.2.2. Schedule creation stage

In this stage, the cluster head sets up a TDMA schedule for its members to avoid collisions among data messages. Based on the number of nodes in the cluster, the cluster head node creates a TDMA schedule telling each node when it can transmit. The TDMA time is divided into a set of slots, the number of slots being equal to the number of nodes in the cluster. Each node is allocated a unique time slot during which it can transmit its data to the cluster head. Once the TDMA time slot is defined, the cluster head broadcast TDMA time slot and its next head node ID into the network.

4.2.3. Data transmit stage

During this stage, the cluster head node gathers the information, performs data aggregation and sends the aggregated data to the base station. To minimize energy dissipation, each member node uses power control to set the amount of transmit power based on the received signal strength of the cluster head advertisement message. Furthermore, transceiver of each member node is turned off until its allocated TDMA time slot.

The cluster head node must keep its receiver on to gather all the data from the member nodes in the cluster. Once the cluster head gathers all the data, it performs data aggregation by eliminating any redundant data. The resultant is transmitted to the base station. This stage consumes more energy, since the base station may be far away and the data messages are large.

4.3. Distributed cluster setup phase

Cluster head is responsible for collecting all the data from member nodes within the cluster, aggregating this data, and transmit the aggregated data to the base station. The energy load is uniformly distributed among the sensor nodes by periodically rotating the role of the cluster head. Otherwise, the cluster head node would quickly deplete its limited energy and die. The activities in this phase are broken into two stages: new cluster formation stage, and advertisement stage.

In new cluster formation stage network is re-clustered. The next heads selected in the previous round become cluster heads, and old cluster heads become a member node. Negotiation among the sensor nodes is not required, when the next head becomes new cluster head. The new cluster head broadcasts an advertisement message signal into the network for re-clustering. When the advertisement stage explained in the central cluster setup phase is complete, the steady-state phase can begin.

The complete protocol activity is shown in Fig. 3.

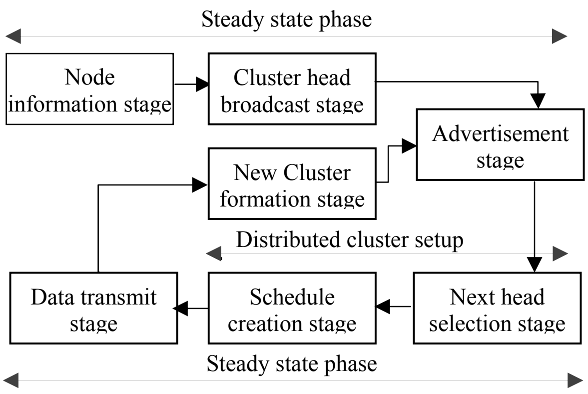


Fig. 3 EBFC protocol activity

5. Simulation Results and Discussion

In this section, we evaluate the performance of the EBFC protocol, simulated using MATLAB. The performance of the protocol is examined with Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol in terms of network lifetime, and energy efficiency.

We simulate the EBFC protocol by deploying 100 nodes in a 100 m X 100 m network area. The sensor nodes are randomly deployed in a sensing field as shown in Fig. 4. The number of cluster heads is set to be 8% of the total nodes, and is fixed throughout the network lifetime. The base station is placed outside the sensor field, and located at (50, 175). The data packet size was fixed at 500 bytes, and packet header size was set to 25 bytes. The initial energy of the nodes was 0.5 joule. Table 1 summarizes parameters used in our simulation.

In LEACH, the first node dies earlier than EBFC as shown in Fig. 5. Since the sensor nodes in EBFC can switch to the next head without negotiation with the base station. This reduces the energy consumption among sensor nodes and extends the network lifetime.

We examine the energy efficiency of two protocols by examining the network lifetime. Fig. 6 shows the nodes with EBFC protocol remain alive for longer time than that of LEACH.

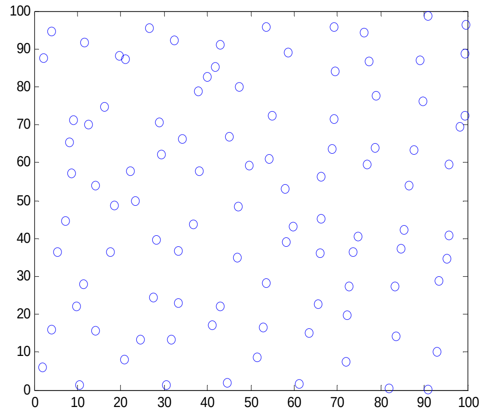


Fig. 4 Random deployment of sensor nodes

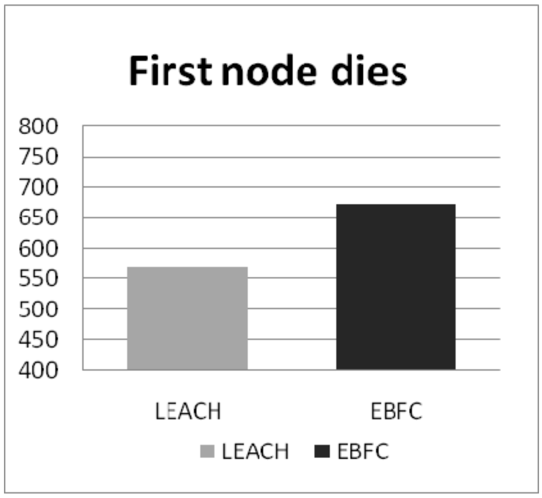


Fig. 5 First dead node

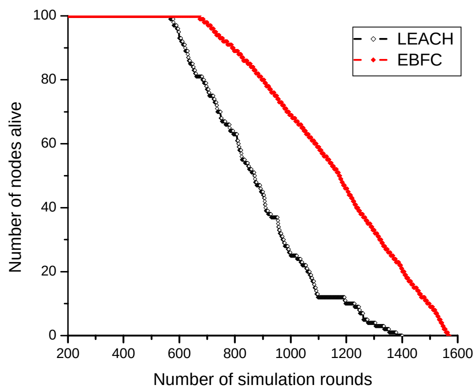
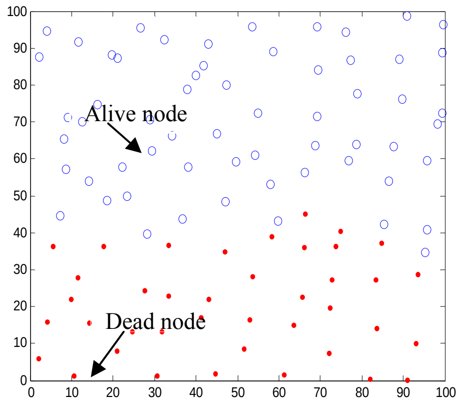


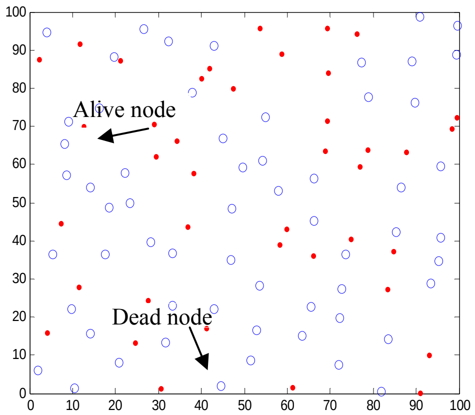
Fig. 6 The number of alive nodes over simulation time

In EBFC protocol the sensor nodes can switch directly to next heads without communicate with the base station. Thus, it reduces a large number of communication overheads and consumes the least amount of energy thereby decreasing the sensor node's death rate in EBFC than that in LEACH. EBFC protocol performs much better than LEACH in extending the network lifetime for all the metrics.

EBFC clearly improves the network lifetime (both the time until the first node dies and the time until 40% nodes die) over LEACH. Since simultaneously adopted the fixed clustering mechanism and inter-cluster multihop routing, EBFC effectively balance the energy consumption for data transmission between the clusters close to the base station and the clusters far away from the base station. As it is showed in Fig. 8, the distribution of dead nodes (represented by small dots) of two protocols are quite different. In LEACH, the dead nodes are concentrated in the region far away from the base station; while the dead nodes of the proposed protocol were evenly distributed over the entire sensor field.



(a) LEACH



(b) EBFC

Fig. 8 Distribution of dead nodes until 40% nodes die

6. CONCLUSION

In this paper, we have presented a fixed clustering protocol for WSNs. The selections of cluster heads and next heads in advance are weighted by remaining energy of sensor nodes and the centre of the cluster. Simulations results indicate that the proposed protocol can effectively balance the energy consumption of the entire network, slow down the dead speed of the sensor nodes, and prolong the network lifetime efficiently.

Sensor nodes can reach the base station either using single hop or multihop communication. The sensor nodes located far away from the base station using single hop communication have highest energy load due to long range communication. The sensor nodes closer to the base station using multihop communication have higher load for delivering the packets. In our future work, we will design an energy efficient protocol to determine optimum mode of communication in each cluster.

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