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A New Energy Efficient Multiple Cluster Head (EEMCH) Protocol for Wireless Sensor Networks

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Abstract: Wireless sensor networks are composed of a large number of inexpensive power-constrained wireless sensor nodes, which detect and monitor physical parameters around them through self-organization. Energy of sensor nodes is a scarce resource in wireless sensor network. It is vital to reduce energy consumption to improve the overall lifetime of wireless sensor network. In this paper, a simple modification in clustering algorithm of the LEACH protocol is proposed to design EEMCH (Energy Efficient Multiple Cluster Head) protocol to prolong network lifetime. In the proposed EEMCH method, the sensor nodes are organized into clusters. In lieu of selecting a single cluster-head, our protocol selects Mini CH and Super CH in each cluster based on residual energies of sensor nodes. Due to the broadcast nature of wireless transmission, cluster-heads are able to receive data from sensor nodes simultaneously. Every Super CH can aggregate data within each cluster and transmit data to the base station by multi-hop communication. The Mini CH takes its role as a cluster head in case of Super CH fails in its purpose. Simulations are carried out using MATLAB environment. The simulation results obtained using the EEMCH protocol with multi-hop data aggregation shows that the new protocol reduces the total energy consumption in the network. Also, the number of live nodes in the network and packet delay in the proposed method are calculated and compared with the LEACH.

Keywords: Energy consumption, life time, clustering, wireless sensor network.

1. INTRODUCTION

In recent years, wireless sensor networks (WSNs) have received significant attention of researchers due to their wide range of applications such as environmental monitoring (e.g., humidity, temperature), disaster and health care areas providing relief, conferencing, file exchange, commercial applications including controlling product quality, military applications and managing inventory [1]. A WSN is a self-organized network that consists of a large number of sensor nodes deployed on the ground, in the air, in vehicles, on bodies, under water or inside of buildings etc. Each sensor node is a tiny device that includes three basic units: a sensing unit for data acquisition from the physical environment, a processing unit for local data processing and storage, and a wireless communication unit for data transmission to a central collection point called sink. Most of these sensor devices are equipped with limited energy supplies (batteries), and it is inconvenient to recharge the batteries because nodes may be deployed in a hostile environment. So, one of the critical challenges in WSNs are limited energy of sensor nodes.

A lifetime of the sensor network is determined by the residual energy of each sensor node. The most important challenge in WSN is the efficient use of energy resources. Clustering is one of the various ways to improve resource utilization in the network due to its advantages of energy saving, network scalability and network topology stability [2]. Adjacent nodes organize a cluster and one of the nodes in the cluster is chosen as a cluster head. The cluster head aggregates data from other nodes and transmits them to the base station. Cluster heads shorten the distance for transmission. Without clustering, all the nodes should communicate with the base station directly. Nodes far from the base station consume much energy when transmitting data. However, with clustering, the distance of transmission decreases.

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By considering all the functional properties of WSNs, routing protocols become necessary in WSNs. There are several routing algorithms in wireless sensor networks and they can be divided into flat routing and hierarchical routing in the network structure. All sensor nodes generally have the same function in the flat routing protocol. The nodes in the hierarchical routing usually play different roles. In hierarchical routing, the high energy node is used to process and send messages. The nodes having low energy levels are used to sense the target area information.

The main contribution of this paper is to extend the traditional routing protocol LEACH (Low Energy Adaptive Clustering Hierarchy) [3] to EEMCH (Energy Efficient Multiple Cluster Head). Instead of selecting a single cluster head, EEMCH selects Mini CH and Super CH in each cluster based on residual energies of sensor nodes. EEMCH not only inherits the advantage of LEACH but also extends network lifetime and improves the network throughput.

The outline of the paper is organized as follows. Section 1 introduces basic concept of WSNs and the research area attempted in this paper. Section 2, related researches are covered. The proposed protocol and its implications are explained in Section 3. In Section 4, we evaluate the performances of LEACH and EEMCH by simulations under MATLAB environment. Finally, Section 5 concludes the paper detailing the findings.

2. RELATED WORKS

Many different approaches have been carried out to design feasible WSNs. Energy conservation is crucial to prolong the network lifetime of WSNs. Several energy efficient routing algorithms have been proposed to reduce energy consumption.

One of the most popular clustering algorithms for WSN is LEACH [2]. It is a hierarchical, distributed, probabilistic protocol that uses one hop routing. The main objective is to maximize the network lifetime by evenly distributing the energy consumption among all the nodes of the network. Based on the received signal strength, the clusters are formed within the network and the CH nodes are used as routers to the base station. The entire data processing task such as data fusion and aggregation are locally performed by the CH. A node becomes a CH for the current round rotation if the number is less than the threshold and T(i) is given below in (1).

$$T(i) = \begin{cases} \dfrac{p}{1 - p*[r \bmod (1/p)]} & \text{if } i \in G \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

Where G is the set of nodes that have not been CHs in the last rounds, r is the current round number and p is the desired percentage of CH nodes.

In [4], a distributed, randomized Energy Efficient Hierarchical Clustering Algorithm is proposed. The algorithm generates the hierarchy of cluster heads. It has been shown that the energy saving increases with the number of levels in the hierarchy.

Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [5] is an improvement of the LEACH protocol. Instead of forming multiple clusters, PEGASIS forms chains from sensor nodes so that each node transmits and receives to/from a neighbor and only one node is selected from that chain which can transmit to the base station.

Similar to LEACH, another protocol TEEN (Threshold Sensitive Energy Efficient) protocol is proposed in [6]. It starts with a set-up phase and forms clusters in a network. It is efficient in terms of energy consumption and response time and is suitable for time critical sensing applications. By broadcasting the new attributes, the user can change the threshold values during the time when the clusters are changed.

To extend the lifetime of cluster head, a cluster-based routing protocol is proposed in [7]. In this approach, sensors can vote for their neighbors to elect the cluster heads. For the reduction of the transmission energy, this protocol combines the cluster architecture with multi-hop routing.

Distributed energy-efficient clustering [8] approach selects cluster heads based on their residual energy. Communication cost is minimized by joining the sensor nodes into clusters. The approach exploits the availability of multiple transmission power levels at sensor nodes. In [9] U-LEACH is proposed to address the problem in LEACH and to extend lifetime. The protocol uses uniform distribution technique for selecting CHs in the network.

In this paper, we propose a lifetime extension of wireless sensor network using two cluster heads and hierarchical routing. A new protocol, named EEMCH with two cluster heads is proposed to improve the lifetime. The use of two cluster heads analogy reduces the overhead of single cluster head, avoids packet collision and improves reliable data transmission.

3. PROPOSED PROTOCOL EEMCH

One of the most important factors to improve the lifetime of wireless sensor network is the design of the network. The network is partitioned into different clusters of sensor nodes by the clustering mechanism. Sensor nodes send data to the cluster head and cluster head in turn to the base station. Failure in cluster head requires re-clustering and may change the topology of the sensor network. Figure 1 shows the proposed approach to extend the lifetime of cluster by selecting Mini CH and Super CH in each of the clusters' based on residual energies of sensor nodes. Clustering in wireless sensor network can be divided into three phases; initialization, setup phase and steady state phase as in LEACH. Our proposed approach is explained using these three phases:

A. Initialization

1. ***Base Station:*** It is the central processing unit and trans-receiver station. There is no power limitation with this node. This node is connected to the sensor nodes with the proposed sensor network architecture. It gathers data from the nodes and processes that data for other uses. It maintains the statistics of the network and the sensor nodes.
2. ***Sensor nodes:*** In wireless communication, attenuation of transmitted power decreases exponentially with the increasing transmission distance. In [10], two types of channel transmission models are proposed (i) free space model and (ii) multi-path attenuation model. When the distance between transmitting node and receiving node is smaller than a certain value, the free space model is applied so that the sending power decreasing exponentially by d^2. Otherwise, the multi-path attenuation model is employed with sending power decreasing exponentially by d^4.

B. Setup phase

In EEMCH, nodes are periodically select Mini CH and Super CH in each cluster. At the beginning of each round, the sink broadcasts a message to declare the start of the set-up phase, which is divided into two steps: cluster formation and cluster head selection.

1. ***Cluster Formation:*** Once the sensor nodes are deployed on the flat surface, the whole network is divided into clusters of different size. Every cluster will have a sufficient number of high energy nodes in each cluster.
2. ***Cluster head selection:*** In this mode, EEMCH elects both Mini CH and Super CH in each cluster based on their residual energy. Super CH gathers and aggregates information from its members and sends

messages between the adjacent CHs or to sink node at regular intervals. The Mini CH takes its role as a cluster head in case of Super CH fails in its purpose. Mini CH turns to Super CH based on remaining energy and optimum distance from the existing Super CH.

C. Steady State

In this phase, sensor nodes will always communicate with the Super CH within each cluster. The responsibility of the Super CH is to communicate with all the sensor nodes within that cluster and gather the sensed data. This data is then communicated to the base station over multi hop. Once the energy of Super CH goes below the threshold, then Mini CH takes the action of Super CH in the particular cluster. The role of CH is rotated among the nodes which will allow balancing of the energy consumption among the cluster heads.

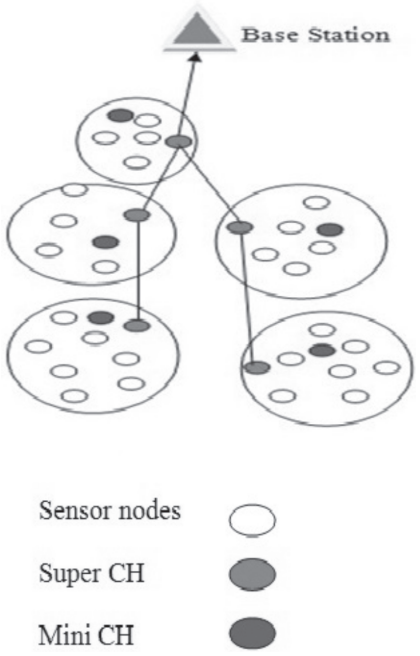

Figure 1: Clusters with multiple CH

4. EXPERIMENTAL SETUP AND EEMCH PERFORMANCE EVALUATION

A. Experimental Set-up

Simulations are conducted with a sensing area of size 100 m × 100 m and with 250 sensor nodes deployed randomly. Table 1 indicates the parameters for performance evaluation. Deployment of sensor nodes is achieved by choosing the locations of the sensor nodes randomly within the sensing area. The base station location is fixed in the sensor network. The initial energy of each node is 0.5 J and the length of message is 4000 bit. Clusters are formed such that each cluster has at least two high energy nodes as CHs. P is the probability to choose a node as a cluster head in the LEACH protocol. EDA means the amount of energy dissipation in aggregating the messages in the cluster heads. Sensor nodes within each cluster communicate with the cluster heads and cluster heads communicate with the base station over multi hop communication.

Energy levels of sensor nodes are evaluated over a time period using LEACH and EEMCH protocols for a cluster with a single cluster head and a cluster with multiple cluster heads respectively.

Simulation experiments have been carried out under MATLAB environment. After performing the above evaluations, the effectiveness of the clustering algorithms stated above are discussed. For a fair

comparison with other protocols, performances are evaluated using both types of clusters under the same experimental setup. Simulation parameters are given in Table I.

B. Performance Evaluation

Simulations are carried out and the performance results obtained are discussed.

1. ***Comparison of residual energy:*** Figure 2 shows the amount of energy dissipated per round in the LEACH protocol as well as in EEMCH over a period of time. Simulation results indicate that the cluster with multiple CHs performs marginally better in the case of residual energy.

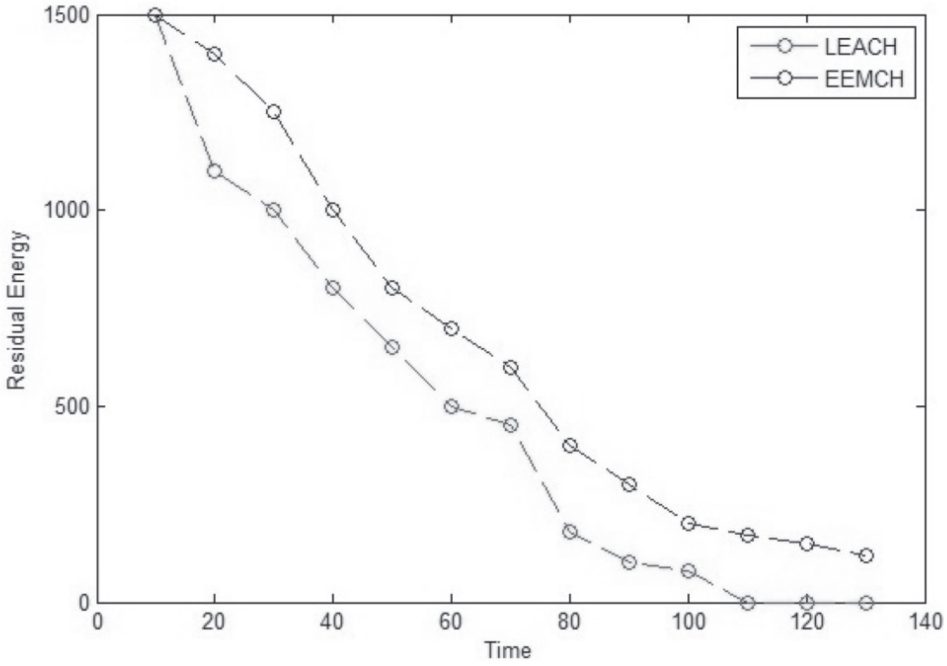

Figure 2: Comparison of residual energy per time

Table I
Parameters for performance evaluation

Parameter	*Symbol*	*Values*
Tx/Rx electronic constant	E_{elec}	50 nJ/bit
Amplifier constant	E_{fs}	10 pJ/bit/ m^2
	E_{amp}	0.0013 pJ/bit/ m^4
Initial Energy	E_0	0.5 J
Energy for Data aggregation	E_{DA}	5 nJ/bit/signal
Minimum threshold energy	E_{THMIN}	10^{-4} J
Length of message	EDA	50 nJ/bit

When we increase the number of rounds (and hence time increase), LEACH fails to perform well in terms of energy consumption. The energy gain in EEMCH is mainly achieved because of the selection of two CHs instead of single CH as in LEACH. EEMCH achieves a balance of energy consumption among the CHs and extends the life span of the whole network.

2. ***Comparison of number of nodes alive per each time:*** Figure 3 shows the comparison of the number of nodes alive per round. Considering 250 nodes in the network, we first calculate the effective number of nodes per cluster. In the case of LEACH, the nodes die out rapidly even within the first few rounds,

whereas in the proposed method EEMCH, the nodes sustain energy for a longer period of time or for larger rounds.

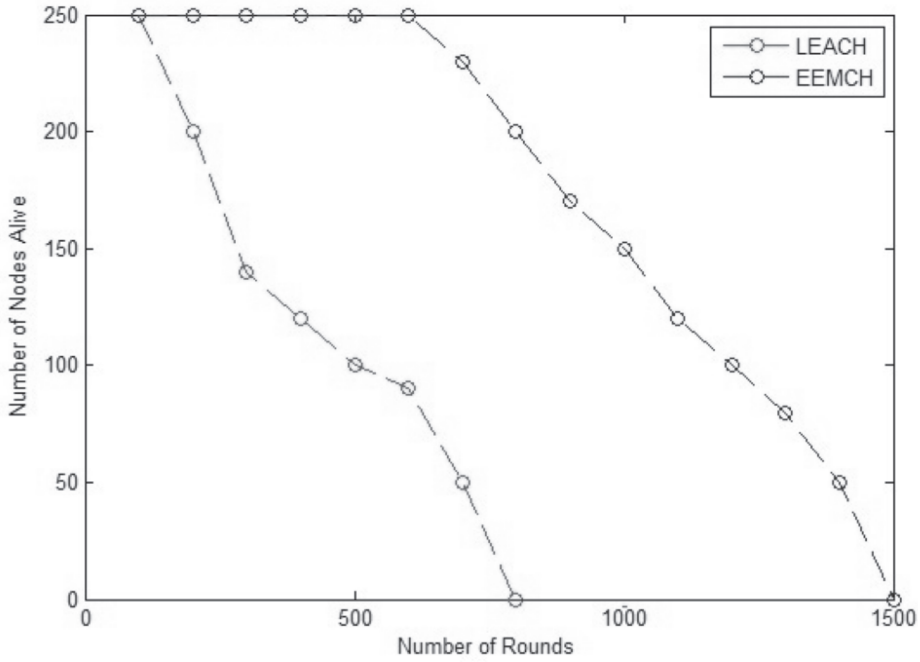

Figure 3: Comparison of number of nodes alive per round

3. ***Comparison of delay per rounds:*** Figure 4 shows the superiority of EEMCH in attaining less delay than in LEACH. The network delay depends on the number of nodes in the cluster. If the cluster size is bigger, the delay is also high. Clusters having unequal number of nodes and high traffic flow in the network can induce significant delays in LEACH protocol. EEMCH with two CHs can significantly reduce delay in the network by selecting Super CH and Mini CH. If Super CH fails within a cluster, Mini CH can take its role as CH. If the network is based on EEMCH, there is no need of re-clustering and change in topology.

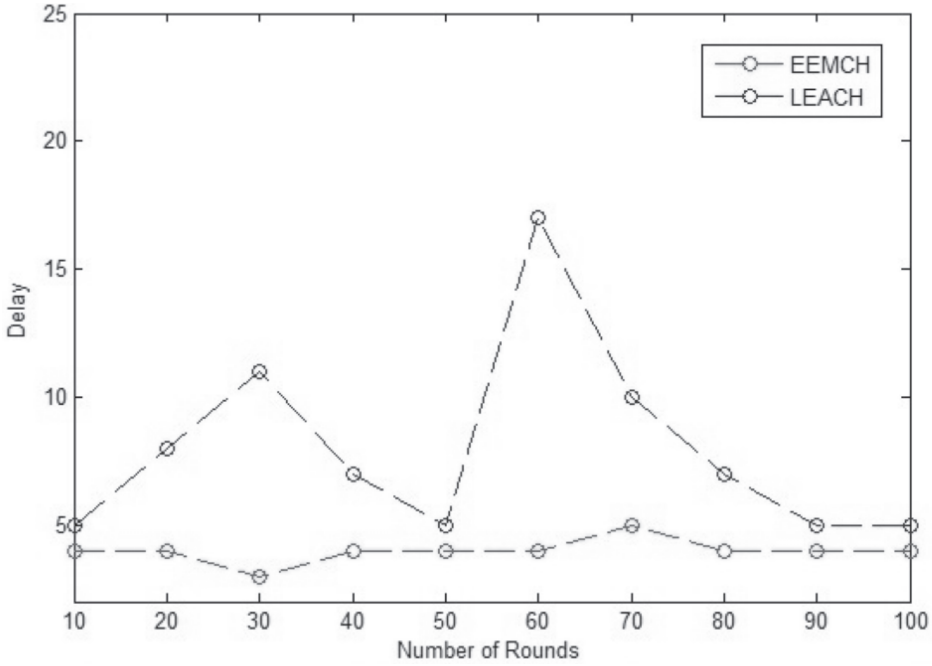

Figure 4: Comparison of delay per rounds

5. CONCLUSION

To limit the energy of sensor nodes in wireless sensor network, we proposed a clustering based protocol EEMCH which is an enhancement of the existing LEACH protocol. Instead of selecting a single CH in each cluster as in LEACH, EEMCH elects two cluster heads (i) Mini CH and (ii) Super CH in each cluster based on residual energies of sensor nodes to improve the lifetime of wireless sensor network. Energy consumed by each of the sensor nodes is evaluated by using (i) cluster with a single cluster head and (ii) cluster with multiple cluster heads. It has been shown that the proposed EEMCH can improve the network lifetime significantly as compared to that of LEACH protocol. Simulations are carried out using MATLAB environment. The simulation results show that the EEMCH protocol with multi-hop data aggregation can significantly reduce the total energy consumption in the network. Also, we have proved that EECMH gives better performance than LEACH in terms of number of live nodes in the network and the amount of delay.

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