Energy Efficient Adaptive Protocol for Clustered Wireless Sensor Networks

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Abstract

Wireless Sensor Networks (WSNs) is a network of an inexpensive low coverage, sensing, and computation nodes. The foremost difference between the WSN and the traditional wireless networks is that sensors are extremely sensitive to energy consumption. Energy saving is the crucial issue in designing the wireless sensor networks. Many researchers have focused only on developing energy efficient protocols for continuous-driven clustered sensor networks. In this paper, we propose a modified algorithm for Low Energy Adaptive Clustering Hierarchy (LEACH) protocol. Our modified protocol called "Energy-Efficient Adaptive Protocol for Clustered Wireless Sensor Networks (EEAP)" is aimed at prolonging the lifetime of the sensor networks by balancing the energy consumption of the nodes. EEAP makes the high residual energy node to become a cluster-head. The elector nodes are used to collect the energy information of the nearest sensor nodes and select the cluster-heads. We compare the performance of our EEAP algorithm with the LEACH protocol using simulations.

Keywords: E*nergy efficiency, LEACH, Wireless SensorNetworks.*

1. Introduction

Wireless Sensor Networks (WSNs) consists of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions such as temperature, sound, vibration, pressure, motion or pollutants, at different locations. The development of wireless sensor networks was originally motivated by military applications for battlefield surveillance. Therefore, wireless sensor networks are used in many civilian applications, including environmental and habitat monitoring, health-care applications, home automation and traffic control. This network contains a large number of nodes which sense data from an impossibly inaccessible area and send their reports toward a processing center which is called "sink". Since sensor nodes are power constrained devices, frequent and long-distance transmissions should be kept to minimum in order to prolong the network lifetime [1]. Thus direct communication between nodes and the base station are not encouraged. Several communications Protocols have been proposed to realize power-efficient communication in these networks. One efficient approach is to divide the network into several clusters, each electing one node as its cluster head. The cluster-head collects data from sensors in the cluster which will be fused and transmitted to the base station. Thus only some nodes are required to transmit data over a long distance and the rest of the nodes will need to do only short distance transmission. Then more energy is saved and overall network lifetime can be prolonged. Much energy efficient routing protocols are designed based on the clustering structure where cluster-heads are elected periodically [2]. To model energy consumption, three basic states of a node can be identified: sensing, data processing and data communication. Experimental measurements have shown that data transmission is very expensive in terms of energy consumption, while data processing consumes significantly less. Minimizing the number of communications by eliminating or aggregating redundant sensed data saves much amount of energy. In a homogeneous network, cluster head uses more energy than non cluster head nodes [3]. As a result, network performance decreases since the cluster head nodes go down before other nodes do. Thus dynamic, adaptive and energy efficient cluster head selection algorithm is very important issue in clustered WSNs.

Generally, there are three basic data delivery models, i.e., event-driven, query-driven, and continuous delivery models [4]. In continuous delivery model, the sink is interested in the conditions of the environment at all times and every node periodically sends data to the sink. In event-driven delivery model, the sink is only interested in hearing from the network when certain events occur. Query-driven data delivery model is similar to the event- driven model except that the data is pulled by the sink while the data is pushed to the sink in the event driven model. Configuring the network as event-driven is an attractive option for a large class of applications since it typically sends far fewer messages [5]. This is translated into significant energy saving, since message transmissions are much more energy intensive when compared to sensing and (CPU) processing. Also some existing energy-saving solutions take that into consideration and switch some nodes off, leading the nodes to an inactive state, these are waken up only when interest matches the events "sensed" [6]. Therefore, event driven protocols are used to conserve the energy of the sensor nodes. Most research so far assumed that all nodes collect and send data at the same rate and network's energy consumption is uniform, so that they regulate the run-time of each round. However, in event-driven sensor network applications, events occur randomly and transiently, and accompanied by the burst of large numbers of data, therefore, network energy consumption is uneven. Energy-efficient Event Driven Clustering (EDC) [7] algorithm can decide which nodes will become cluster head nodes according to the maximum remainder energy of nodes.

Fig.1. Wireless Sensor Network Structure

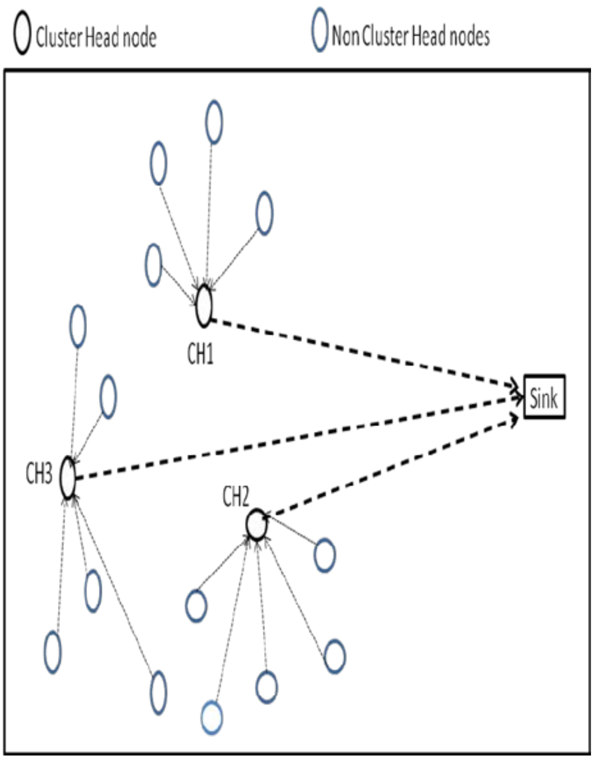

Fig.1. extracted from [8] describes the architecture of wireless sensor networks structure. In this paper, we focus on the energy efficient clustering algorithm for event-driven wireless sensor network. We propose a modified algorithm of LEACH called "Energy efficient Adaptive protocol for clustered Wireless sensor networks". Our proposed protocol facilitates the nodes with more residual energy have more chances to be selected as cluster head. In order to extend the lifetime of the whole sensor network, energy load must be evenly distributed among all sensor nodes so that the energy at a single sensor node or a small set of sensor nodes will not be drained out very soon.

In Section 2 related works for our protocol is described. Section 3 describes the proposed system model. Simulation results are shown in Section 4. Finally, we give concluding remarks in Section 5.

2. Related Works

Many clustering algorithms were developed and used in wireless sensor networks. A detailed survey of energy efficient clustering algorithms for wireless sensor networks is presented in [9]. Low Energy Adaptive Clustering Hierarchy (LEACH) is the first energy efficient routing protocol for hierarchical clustering. It reduces the energy significantly [10]. The LEACH protocol forms clusters in the sensor networks and randomly selects the Cluster-heads for each cluster. The non cluster-head nodes sense the data and transmit to the cluster-heads. The cluster-heads aggregate the received data and then forward the data to the sink. This aggregation process reduces the transmission of duplicate data.

There are two phases in LEACH protocol: i) Setup phase ii) steady-state phase. In the setup phase the clusters are formed and the cluster-heads are selected. In the steady-state phase, the data from non cluster heads are transmitted to the sink. The sensor nodes communicate to the cluster-heads using TDMA schedule. The nodes communicate to the cluster-head only in their allotted slots. It avoids collision. The cluster-heads are selected randomly for every round. The Power Efficient Gathering in Sensor information systems (PEGASIS) is a chain based power efficient protocol based on LEACH. The chain is formed on the basis greedy algorithm [11]. The chain starts from the farthest node to the nearest node to the sink. The node nearest to the sink is selected as a chain leader and aggregated and forwarded the received data to the base station. Each node in the chain selected as chain leader to balance the energy consumption.

Enhanced Low-energy Adaptive Clustering Hierarchy (E-LEACH) proposes a cluster head selection algorithm for sensor networks that have non-uniform starting energy level among the sensors. It also determines that the required number of cluster heads has to scale as the square root of the total number of sensor nodes to minimize the total energy consumption. LEACH-Centralized (LEACH-C) uses a centralized clustering algorithm and same steady-state protocol. During the set-up phase of LEACH-C, each node sends information about current location and energy level to base station (BS)[13]. The BS will determine clusters, CH and non-CHs of each cluster. The BS utilizes its global information of the network to produce better clusters that require less energy for data transmission. The number of CHs in each round of LEACH-C equals a predetermined optimal value.

Multi-hop LEACH (M-LEACH) modifies LEACH allowing sensor nodes to use multi-hop communication within the cluster in order to increase the energy efficiency of the protocol [13]. This work extends the existing solutions by allowing multi-hop inter-cluster communication in sparse

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WSNs in which the direct communication between CHs or the sink is not possible due to the distance between them. Thus, the main innovation of the solution proposed here is that the multi-hop approach is followed inside the cluster and outside the cluster. CHs can also perform data fusion to the data receive, allowing a reduction in the total transmitted and forwarded data in the network. Among the hierarchical routing protocols, LEACH is the most popular cluster-based routing protocol. A node becomes a CH for the current rotation round if the number is less than the following threshold:

$$T(n) = \frac{p}{1-p}[r \bmod (1/p)],\ n \in G \quad = 0, \text{ otherwise}$$

Where p is the percentage of nodes that Can become CHs, r is the current round and G is the set of nodes that have not served as cluster head in the past 1/p rounds [8].

As long as optimal energy consumption is concerned, it is not desirable to select a cluster head node randomly and construct clusters. However, repeating round can improve the total energy dissipation and performance in the sensor network. There are some problems with the LEACH protocol. The main problem is the residual energy of a node is not considered for cluster formation. The nodes are started with the same initial energy. The cluster-heads are randomly selected rotationally. The proposed protocol selects the cluster-heads based on their residual energy.

3. EEAP System Model

The proposed system assumed with the following properties:

- The sink located very far from the cluster-heads.
- All the sensor nodes are stationary with limited energy.
- All the sensor nodes are equipped with power control capabilities to vary their transmitting power.
- The network is assumed to be continuous data delivery model.

Assume that there are N sensor nodes randomly deployed into M x M region. It is assumed that M=100 and the base station locates very far from the sensing area. Then the distance from the cluster nodes to the base station is very long. Also, we assumed that clusters are equally sized. Thus there are average N/k nodes per clusters and (N/k)-1 non cluster head nodes. The EEAP involves three main phases: the Initial phase, the clustering phase, and the data transmission phase. The initial phase is performed only once in the beginning of network operation.

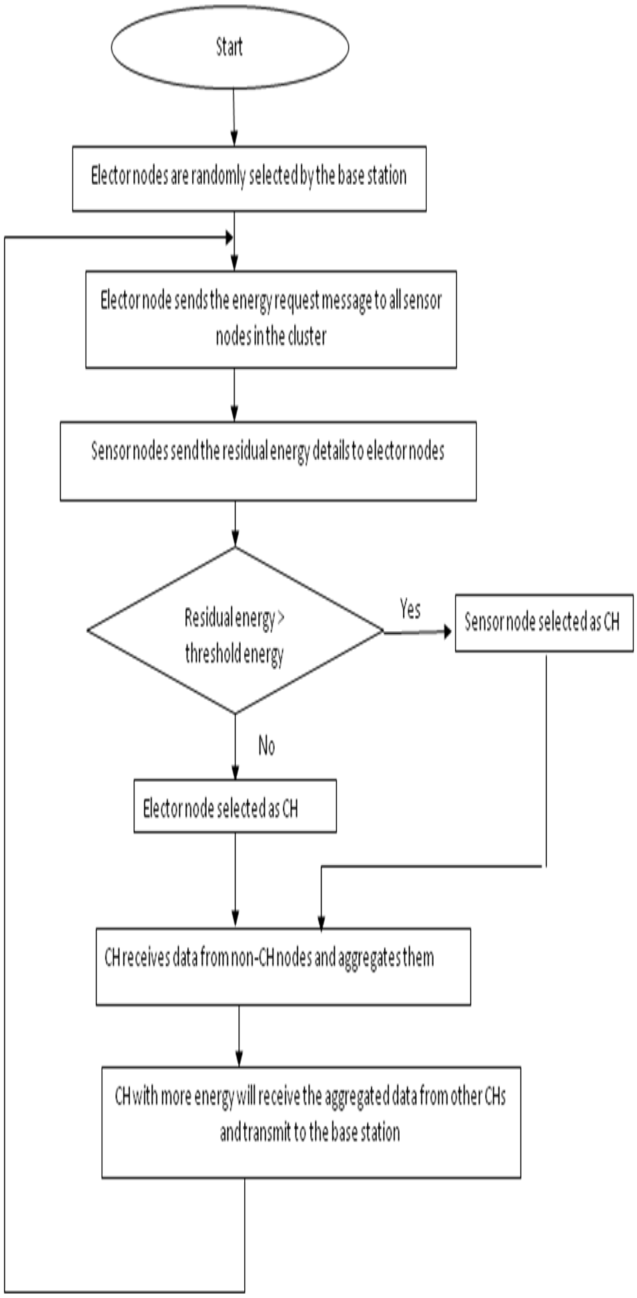


Fig.2. Flow chart for proposed protocol

As in the LEACH protocol, the EEAP is divided into rounds, where each round consists of the clustering phase and the data transmission phase. Each round begins with the clustering phase when the clusters are organized, followed by a data transmission phase when data are transferred from the nodes to cluster head and on to the base station.

3.1 Initial Phase

The sink selects most separated k optimal number of elector nodes, then the sink broadcasts and elector advertisement message in initial phase.

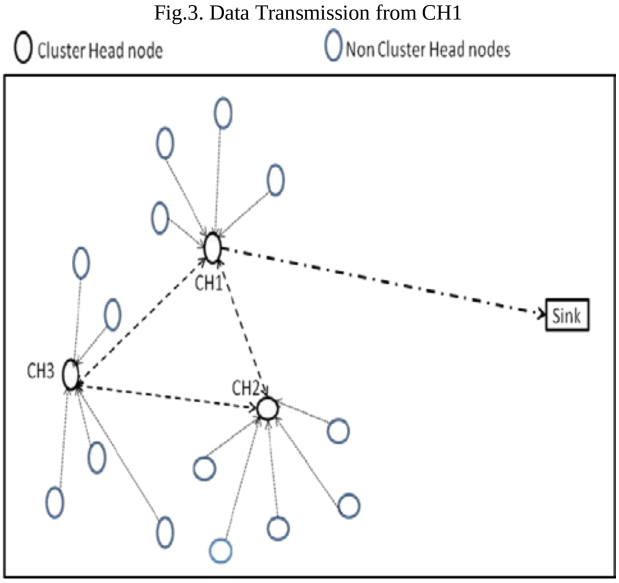
3.2 Clustering Phase

The clustering phase involves the cluster formation and cluster head selection. In the LEACH protocol, the cluster head is selected randomly. But in the proposed algorithm, the elector node selects the cluster head based on the residual energy of each sensor node within the cluster. Elector nodes take responsibility for collecting nearest sensor's information and energy is greater than others. After the cluster head node is selected by elector node, the cluster head node broadcasts a cluster head advertisement message containing cluster head ID. Non – cluster head nodes then select the most relevant cluster head node according to the signal strength of the advertisement message from the cluster head nodes. Each member node transmits a join request message.

3.3 Data transmission phase

The cluster head node collects and aggregates the data from the non-cluster head nodes. Once the cluster head node receives the join request message from member nodes, the cluster head setup a TDMA schedule according to their active member nodes. In LEACH approach, when cluster heads have aggregated data from the nodes, they send it to the Base Station. In our proposed protocol, the cluster heads of all clusters exchanging their aggregated data between them. On rotational basis, one cluster head collects all the data from other cluster heads and transmit to the base station. Each cluster head takes the responsibility of transmitting data to the base station as shown in Fig.3. Once the data transmission phase ends, network reforms the cluster head selection procedure in a new round.

Fig.3. Data Transmission from CH1



In Fig.3, the Cluster-head CH1 received the data from the cluster-heads CH2 and CH3. CH1 will aggregate the data received from other cluster-heads and the sensor nodes in its cluster, and transmit the aggregated data to the sink which far from the cluster-heads. Instead of all the cluster-heads sending the aggregated to the sink, one cluster-head collects, aggregates, and transmit the data the sink. Many research works proved that the transmission will consume more power than the sensing and reception. This approach will reduce the battery usage and saves extend the life time of network.

Fig.4. Data Transmission from CH2

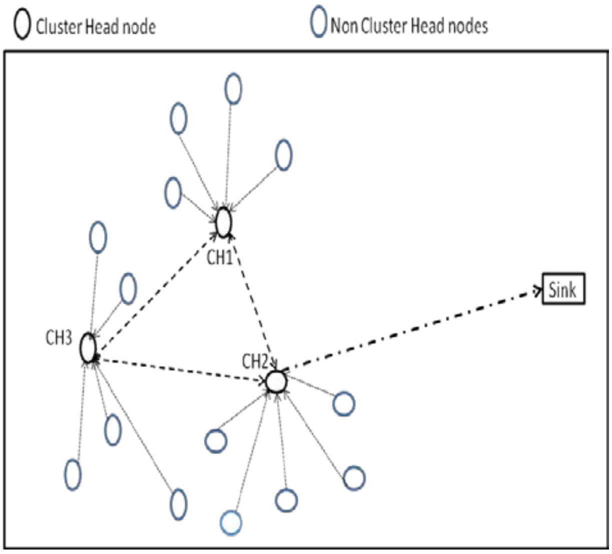


Fig.4. shows that the cluster-head CH2 collects the data from the cluster-heads CH1 and CH3 and from its own sensor nodes. It will aggregate the collected data and transmit to the sink.

Fig.5. Data Transmission from CH3

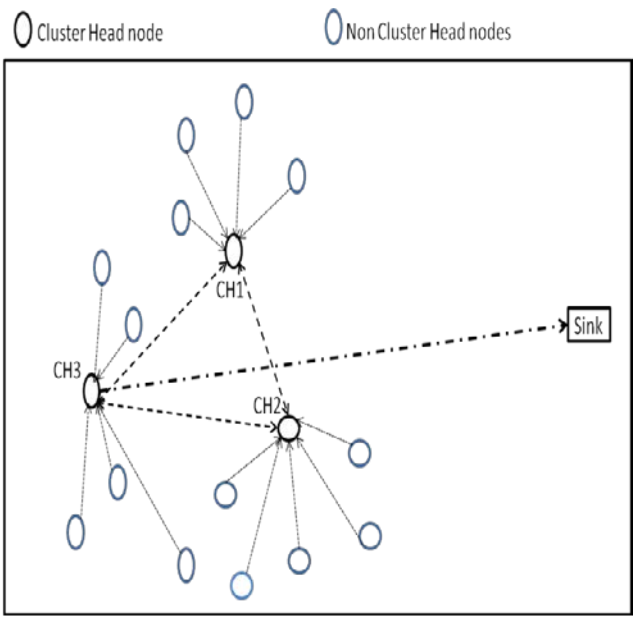


Fig.5. shows that the cluster-head CH3 collects the data from the nodes in its cluster and also from the cluster-heads CH1 and CH2. The collected data is aggregated and transmitted to the sink.

4. Performance Analysis

4.1 Energy Consumption and Simulation parameters

In this simulation, energy is decreased whenever a node transmits or receives data and whenever it performs data aggregation. The carrier sense operation consumes less energy. Table.1. shows simulation parameters.

Table.1. Simulation parameters

Description	***Value***
Simulation Area	100x100
Number of sensor nodes	150 and 300
Sink node location	Far from the network
Initial energy	0.2 J
Energy of data aggregation	5nJ/bit
Data packet size	500bytes
Optimal cluster number	10

4.2. Simulation Result and Analysis

In the simulation, we compared the performance of our proposed EEAP algorithm and with LEACH protocol in under the continuous delivery model. We simulated the model for the equal initial energy (0.2J) in each node. The size area was considered with small (100x100) situation. Our performance criteria are total residual energy per round in the network and total network lifetime. Network lifetime is the number of round from the start of operation until the death of the last alive node. The network connectivity which depends on the time of the first node failure is a meaningful measurement in the sense that a single node failure can make the network partitioned and further services be interrupted. When a sensor node is depleted of energy, it will die and be disconnected from the network which may impact the performance of the application significantly.

When the nodes start with the same initial energy and the total number of nodes in a network is 150 and 300, the number of living nodes per round is shown in Fig.6 and Fig.7 respectively. Fig.6 shows that the total network lifetime of our algorithm is longer than that of LEACH. During most of the network lifetime, our algorithm EEAP runs with much more living nodes than LEACH. Fig.7 is the case for the number of nodes in a network of 300. The result is similar with Fig.6. In case of LEACH protocol, the round first dead node appears is very fast and linearly decreases until last round. EEAP shows the round of first dead node and network lifetime is almost same regardless with the increase of network size. Simulation shows our algorithm can balance the energy consumption of the entire network compared to LEACH protocol.

Fig.6. Number of Living nodes in each round with same initial energy

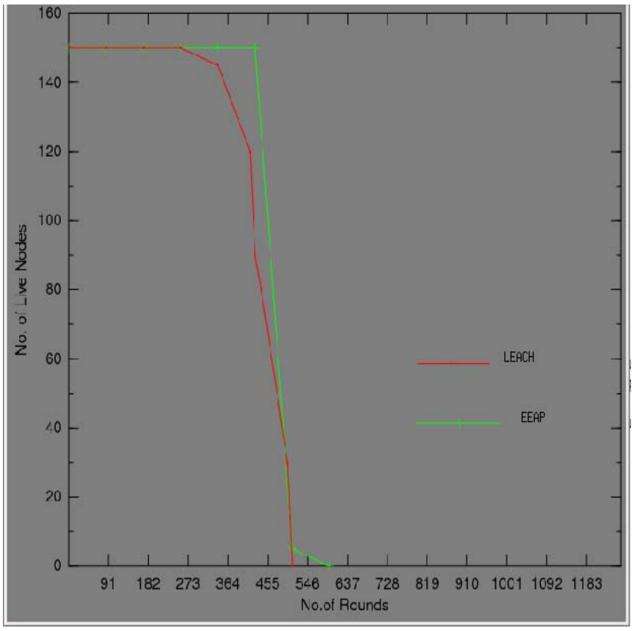
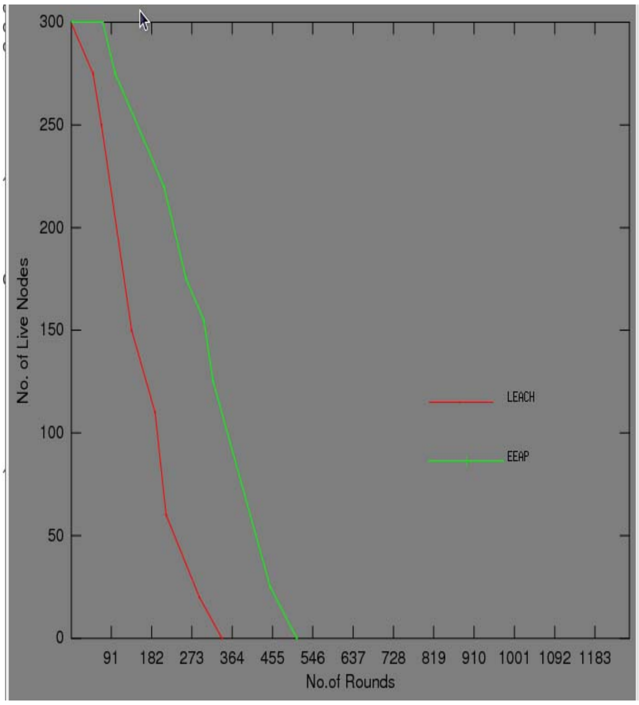


Fig.7. Number of Living nodes in each round with same initial energy with increased senor nodes



5. Conclusion

Wireless sensor networks are increasingly being used for health care, transportation, manufacturing, and much more. In this paper, we proposed an "Energy Efficient Adaptive Protocol for Clustered Wireless Sensor Networks" (EEAP), to extend the lifetime of a sensor network by balancing energy usage of the nodes. Our algorithm ensures that the nodes with more energy should be cluster heads more often than the nodes with less energy. We showed that in many cases our algorithm is more energy efficient than LEACH. The results show that the proposed algorithms can maintain a balanced energy consumption distribution among nodes in a sensor network and thus prolong the network lifetime.

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