Energy Aware Static Clustering Routing Protocol for Wireless Sensor Networks

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Abstract— Clustering in wireless sensor network (WSN) is an efficient approach to provide prolonged network life time, scalability and data aggregation. Clustering also conserves the limited energy resources, for this reason in this paper; we propose an energy aware static clustering routing protocol for WSN. The specificity of this work is that the network is partitioned into static clusters that contain a Primary Cluster Head (P-CH) and a Secondary Cluster Head (S-CH) and both of them are selected based on energy. The simulation results show that the new protocol proposed in this paper extends the network lifetime and balances the energy consumption of the network nodes.

Keywords— Cluster-based routing, EERP protocol, Energy efficiency, Wireless Sensor Networks.

I. Introduction

Wireless sensor network is composed of small sensing electronic actuators device and activate nodes [1]. They have the ability to collect information about the environment where they are deployed [2][3]. WSN are used to in monitoring real time environmental status. Sensors are small, practical, for sensing and collecting information. However, due to the small size their small size, they suffer from the limited energy capacity [4, 5, 6]. For this reason, advanced techniques that improve energy efficiency are highly required.

In WSN, once information is collected by sensors, they have to be transmitted to the base station. Data transmission in such network is very challenging task, because routing the information in WSN is the main source of energy consumption.

Several works are proposed to reduce the energy consumption by the network protocols within the communication stack (network and data link layers). Multi-hop transmission and structuring the network in clusters, is a possible solution [7], [8], [9]. Since the data bit forwarding cost is more important than the computation process in WSN [10], it is preferable to partition the network into clusters. In the clustered network, data gathered by the nodes is transmitted to the base station through cluster heads. As the nodes will communicate data over shorter distances, the energy consumed in the network is likely to be lower compared to when every sensor communicates directly with the base station.

In a clustering organization, the intra-cluster communication can be single hop or multi-hop, as well as inter-cluster communication [11]. Communication between a data source and a data sink is usually more energy efficient than direct transmission because of the characteristics of wireless channel [12]. However, the hot-spots problem arises when using the multi-hop forwarding model in inter-cluster communication. Because the cluster heads closer to the data sink are burdened with heavy relay traffic, they will die much faster than the other cluster heads, reducing sensing coverage and causing network partitioning. Although many protocols proposed in the literature reduce energy consumption on forwarding paths to increase energy efficiency, they do not necessarily extend network lifetime due to the continuous many-to-one traffic pattern [13], [14].

In this work, we propose *an energy aware static clustering routing protocol for WSN*, this protocol tries to eliminate the overhead of dynamic clustering and it engages high-powered sensor nodes for power-consuming tasks and thus extends the lifetime of the network. The proposed protocol chooses two cluster-heads (*CHs*): *Primary CH (P-CH)* and *secondary* (*S-CH*) for each cluster. For the inter-cluster communication, a cluster head chooses a relay node from its adjacent cluster heads according to the Energy-Efficient Routing Protocol for wireless sensor networks (*EERP*) [15].

In the proposed protocol, energy efficiency is distributed and improved by optimizing the selection of cluster-heads while taking into account the residual energy of the nodes and the total power consumption of the cluster; improving the number of nodes in the clusters according to the size of the networks and the total power consumption of the cluster; rotating the cluster heads roles to balance power consumption between cluster heads and cluster members.

The remaining part of this paper is arranged into following sections: Section II presents some related work. The proposed protocol is explained in detail in Section III. Section IV, gives an overview of the simulation results and discussion. And finally Section V concluded this paper.

II. Related work

A number of problems have been solved to address the challenge of sensor energy preservation. One of these issues is routing. To address the energy-aware routing needs, various clustering algorithms have been proposed [16], [17], [18]. However, almost all focuses on reducing the number of clusters formed, which may not necessarily entail minimum energy dissipation.

LEACH [19] is one of the most cited clustering routing protocols for wireless sensor networks. It uses randomized rotation of cluster heads to distribute energy consumption over

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all nodes in the network. In the data transmission phase, each cluster head forwards an aggregated packet to the base station directly. An energy-aware variant (*TL-LEACH*: for Two-Levels Hierarchy for Low-Energy Adaptive Clustering Hierarchy) of *LEACH* is proposed in [20]. *TL-LEACH* uses random rotation of local cluster base stations (primary cluster-heads and secondary cluster heads). This permits to better distribute the energy load among the sensors in the network especially when the density of network is higher. In [21], authors used mathematical battery model for implementation in *WSNs.*

With this battery model authors proposed a new Battery Aware Reliable Clustering (BARC) algorithm for WSNs. It improves the performance over other clustering algorithms by using *Z-MAC* and it rotates the cluster heads according to battery recovery schemes. In [22], Zarei et al. propose a novel Cluster Based Routing Protocol *(CBRP)* for prolong the sensor network lifetime. *CBRP* clusters the network by using new factors and then construct a spanning tree for sending aggregated data to the base station which can better handle the heterogeneous energy capacities. Diwakar et al. [23] propose an Energy-Efficient Level Based Clustering Routing Protocol for wireless sensor networks *(EELBCRP)*. *In EELBCRP*, Network partitioned into annular rings by using various power levels at base station and each ring having various sensor nodes. Also consider the residual energy of each node and distance from the Base Station of nodes as the principle of cluster-head election. In [24], Golam-Rashed et al. propose a two-layer hierarchical routing protocol *(CBHRP)*. They introduce a new concept called head-set, consisting of one active cluster head and some other associate cluster heads within a cluster. The head-set members are responsible for control and management of the network.

Our work is closely related to the Energy-Efficient Protocol with Static Clustering *(EEPSC)* presented in [25]. Where, Zahmati et al propose a hierarchical static clustering based protocol, which eliminates the overhead of dynamic clustering and engages high power sensor nodes for power consuming tasks and as a result prolongs the network life time.

III. The Proposed Protocol Details

The energy aware static clustering routing protocol for WSN proposed is a self-organizing, static clustering method that forms clusters only once during the network action. It is divided into rounds; each round is achieved in two phases: Cluster-heads election phase and data transmission phase. In the following sub-sections, we discuss each of these phases.

III.1 Cluster construction

According to the static clustering scheme used in EEPSC [25], cluster formation is performed only once at the start of network operation, the construction of clusters is performed only once at the start of network operation. Thus, the base station broadcasts *nbLV* different messages with different transmission powers. The *nbLV* represents the number of levels that we are looking for. i.e., the base station transmits a level-1 signal with minimum power level. All nodes, which hear this message, set their level as 1. Then, the base station increases its signal power to attain the next level and transmit a level-2 signal. All the nodes that receive the massage but do not set the previous level set their level as 2. This procedure continuous until the base station transmits corresponding massages to all levels. So, each sensor node in a WSN is assigned its own level from the external base station. A level is given as the form like a concentric circle using the signal strength of the base station as shown in figure 1.

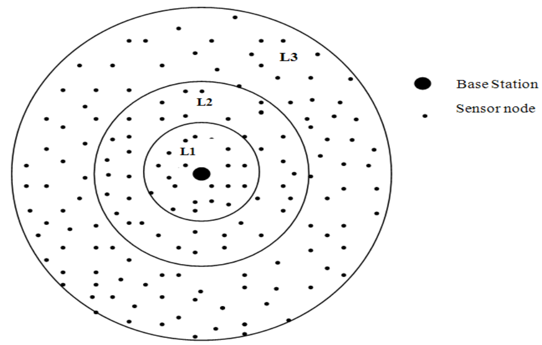

Fig. 1. Determination of the levels

By assuming that the battery of the base station is infinity, the all sensor nodes can receive the level information from the base station regardless of the distance between sensor nodes and itself. The number of these levels depends on the network size and the number of sensor nodes. Then, by using a bi-directional communication model to determine clusters, the network area is divided into ***C*** clusters by broadcasting different messages from the base station. In this proposed protocol the base station is able to communicate in omnidirectional and sectorized unidirectional way.

In order to overcome the hot spots problem, we introduce an unequal clustering mechanism to balance the energy consumption among cluster heads. Clusters closer to the base station have smaller sizes than those farther from the base station, thus cluster heads closer to the base station can preserve some energy for the purpose of inter-cluster data forwarding.

III.2. Clusters-head election

Once the clusters are established, the cluster head election phase is started. In this phase, two cluster heads are elected. The primary cluster-head (*P-CH*) and the secondary cluster head (*S-CH*).

A sensor node elects himself as a (*P-CH*) after evaluating its weight function P_i. In order to optimize energy management, this weight function should choose the highest energy capacity nodes, the biggest diameter of the network, and ones which have been less frequently cluster-head.

The weight P_i of a node *i* is based on the number of times that the node *i* is selected as *P-CH*, the distance between the node *i* and cluster center and the energy.

The *S-CH* is chosen from nodes in the same cluster , *S-CH* is the node which maximizes the objective function F of *P-CH* (see Eq. (1)).

Let *j* be the *P-CH* neighbor of the same cluster.

$$S-CH = \{ i / F_i = \max F_j \} (1)$$

The objective function F is based on energy parameter, the distance between the node *j* and the base station.

The objective function provides a good estimate of the communication cost. The F_i of a node *i* is a measure of the expected intra-cluster communication cost, between *P-CH* and S-CH, if this node becomes a *S-CH*.

A *P-CH* ensures the following tasks:

- *P-CH* sets up a TDMA (Time-Division Multiple-Access) schedule and transmits this schedule to its members during *bt*
- *P-CH* collects data from cluster members, aggregates the received data packets into a single data packet using data fusion technique. Then it transmits the compressed data to the *S-CH*. This latter, sends the received data to the base station (see Sec III.3.2).

The data packets consist of node *ID*, energy level and collected data.

- As the *P-CH* node consumes more energy than other nodes within the cluster, the current *P-CH* elects another node with the most residual power as the next *P-CH*. It chooses also the next *S-CH*, based on the objective function F, for the next round.
- During *wt*, cluster members have the information about the newly elected *P-CH* and *S-CH*. In others words, the current *S-CH* sends the Information Packet including the new responsible sensor IDs for the next round. Whereas, a *S-CH* ensures the following tasks:
- Each intermediate S-CH forwards the data to a chosen neighbor *S-CH* in its Neighbor Information Table *NIT*
- The main purpose of using the S-CH is to distribute the load among several nodes, thus avoiding the bottleneck caused by a single *CH*. Therefore, if the *P-CH* (of the same cluster) dies, the *S-CH* replaces it for completing the tasks of this *P-CH* (during the current round).

III.3. Data transmission

When the clustering is proceeded, the communication in the network is divided into communication from cluster members to the cluster head "intra-cluster communication" and communication from the cluster heads to the base station "inter-cluster communication".

III.3.1. Intra-cluster Communication

The communication phase operation is divided into frames, where nodes send their data to the P-CH at most once per frame during their allocated transmission slot. The duration of each slot in which a node transmits data is constant, so the time to send a frame of data depends on the number of nodes in the cluster.

We assume that nodes are all time synchronized and start the communication phase at the same time. This could be achieved, for example, by having the *BS* send out synchronization message to nodes during the waking time *(wt).* In order to reduce the energy dissipation, each cluster member uses power control to set the amount of transmits power based on the received strength of the *P-CH*.

Furthermore, the radio of each cluster member node is turned off until its allocated transmission time. Since we are trying to provide better performances for the situation when all the nodes have data to send to the P-CH, the use of a TDMA schedule is an efficient exploitation of bandwidth and represents a low-latency and energy-efficient approach. The P-CH must be awake to receive all the data from the nodes in the cluster.

Once the *P-CH* receives all the data, it performs data aggregation to improve the common signal and reduce the uncorrelated noise among the signals. The resultant data are sent from the *P-CH* to the *S-CH* during the break time *(bt).*

III.3.2. Inter-Cluster Communication

In this communication mode we adopt the multi hop mode to achieve the inter-cluster transmission. In inter-cluster communication the CHs transmit their aggregated data to the base station by passing several other CHs. In this work, we design an energy-aware multi-hop routing protocol for the inter-cluster communication based on our protocol *EERP* [15].

The base station initiates the connection by flooding the network in the direction of the source node and transmits "Global Information packet". At the beginning of this process (*wt*), each *S-CH* broadcasts this packet "*G-INFO-PK*" across the network at a certain power which consists of its node *ID*, residual energy and cost function *(f)*. The concrete scheme of choosing the best relay *S-CH* is explained as follows.

When a *S-CH* receives this broadcast message, it checks whether it has an entry in its *NIT* for the *S-CH* that transmitted the message. If not, it adds an entry that consists of Id, remaining energy, state (concerned, not concerned) that is determined according to an energy threshold alpha and cost function.

If the *G-INFO-PK* is sent from $S\text{-}CH_j$ to $S\text{-}CH_i$, $S\text{-}CH_i$ calculates the cost function f_i of the path as:

$$f_i = \min f_{ij} + 1/RE_i \quad (2)$$

Where:

RE_i : residual energy of the node *i*

Then $S\text{-}CH_i$ retransmits the *G-INFO-PK*, but changes the *id* field to its *id* and energy level field to its remaining energy level and f_j by f_i. Every *S-CH* in the network retransmits *the G-INFO-PK* once (during each *wt* in each round), to all its *S-CHs* neighbors. Thus, each node *S-CH* has a number of "*S-CHs*" neighbors through which it can route packets to the base station. An S-CH bases its routing decision on two metrics: state and cost function. A *S-CH* searches its *NIT* for all its *S-CHs* neighbors concerned with minimum cost function *f*. This is continued till the data packet reaches the base station.

After each round (during *wt*), new *P-CHs* and *S-CHs* are elected, and new relays are formed.

IV. SIMULATION RESULTS

In this section, a simulation is performed in order to evaluate the performance of the proposed protocol and we compare its performance with TL-LEACH and EEPSC protocols.

IV.1. Performance metrics

The performance of the proposed protocol is evaluated by using the following metrics

IV.1.1. The Average Energy Consumption (AEC)

The average cumulative energy consumption in the network is computed by estimating the energy required to relay data from each node to the base station through a multi-hop path.

IV.1.2. The Data Messages Received (DMR)

DMR represents the total number of data messages received by the base station over the number of rounds of activity.

IV.2. Radio energy dissipation model used

The energy costs for the various protocols discussed in the previous section were compared with those of the proposed protocol using the first order radio model [19], [26]. The transmitted and received energy costs for the transmission of a *k-bit* data message between two nodes separated by a distance of *d* meters are given by Eqs 3 and 4 respectively.

$$E_{tx} = k * E_{elec} + k * E_{amp} * d^2 \quad (3)$$

$$E_{rx} = k * E_{elec} \quad (4)$$

Where:
E_{elec}: the electronics energy.
E_{amp}: the amplifier energy.

IV.3. Results and Discussions

The proposed protocol was implemented in the *J-SIM* simulator [27], [28]. This section presents the results of simulation and discussion.
The improvement gained by the proposed protocol compared to *TL-LEACH* and *EEPSC* is illustrated by figures 2 and 3 which indicate the average energy consumed is decreased; overall number of messages received at base station is increased.

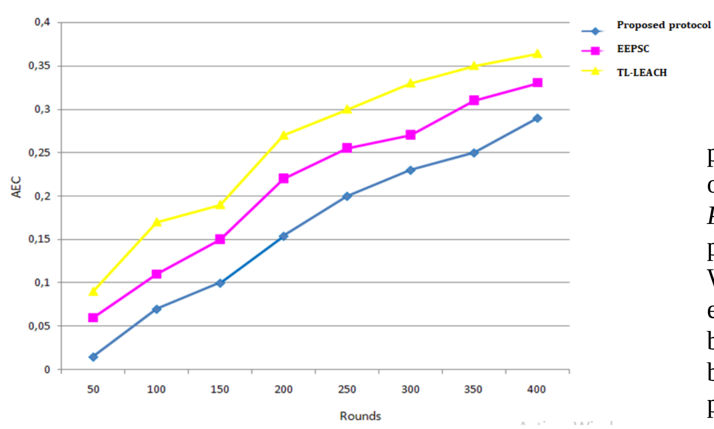

Fig.2. Average energy consumed in the network

Fig.2 presents the graph of average energy dissipation, the *proposed protocol* consumes energy more efficiently than the *TL-LEACH* and *EEPSC* protocols (this is due to fact that in *TL-LEACH* and *EEPSC*, *CHs* transmit their data directly to the *BS*). This may be due to the following reasons. First, alternating the role of *P-CH* and using two kinds of *CHs (P-CH, S-CH)* can balance energy consumption among cluster members. Second, *the proposed protocol* eliminates the overhead of dynamic clustering. Third, our protocol adopts the multi-hop communication among cluster heads during inter-cluster communications, based on the cost function, thus saving more energy in nodes.

Fig.3 illustrates the number of data messages received by the base station for the three routing protocols; it is shown in this figure that the total number of data messages received by the base station over the number of activity rounds, roposed protocol receives more data. This protocol uses multiple routes, based on *EERP*; hence the probability to reach the base station is better than *TL-LEACH* and *EEPSC*.
As can be noticed, *TL-LEACH* sends much more data to the base station than EEPSC. Such result can be justified by the fact that, in *TL-LEACH*, the nodes are forced to transmit to smaller distances.

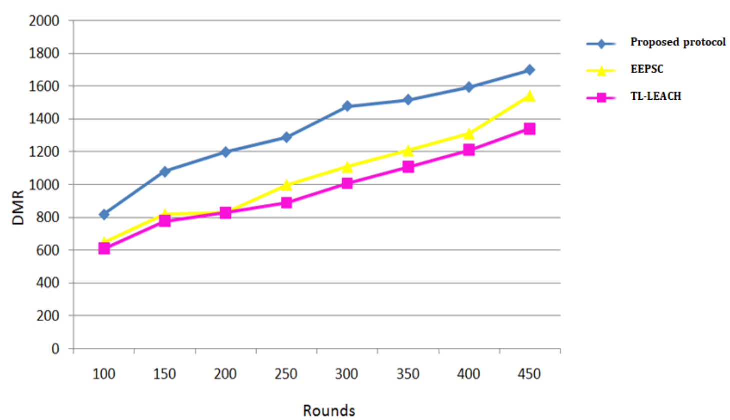

Fig.3. Number of DATA-PK received at base station.

V. Conclusion

In this work, a novel energy-efficient routing protocol which partitions the network into static clusters, eliminates the overhead of dynamic clustering and uses two kinds of *CHs* (*P-CHs and S-CHs*) to distribute the energy load among high power sensor nodes and extend the network lifetime.
We introduced an unequal clustering mechanism to balance the energy consumption among cluster heads. 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. Simulation results show that the proposed protocol has better performances than *TL-LEACH* and *EEPSC* protocols in context of energy consumption and the data message received.

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