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An Energy-Efficient Protocol with Static Clustering for Wireless Sensor Networks

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***Abstract*—**A wireless sensor network with a large number of tiny sensor nodes can be used as an effective tool for gathering data in various situations. One of the major issues in wireless sensor networks is developing an energy-efficient routing protocol which has a significant impact on the overall lifetime of the sensor network. In this paper, we propose a novel hierarchical with static clustering routing protocol called Energy-Efficient Protocol with Static Clustering (EEPSC). EEPSC, partitions the network into static clusters, eliminates the overhead of dynamic clustering and utilizes temporary-cluster-heads to distribute the energy load among high-power sensor nodes; thus extends network lifetime. We have conducted simulation-based evaluations to compare the performance of EEPSC against Low-Energy Adaptive Clustering Hierarchy (LEACH). Our experiment results show that EEPSC outperforms LEACH in terms of network lifetime and power consumption minimization.

***Keywords*—**Clustering methods, energy efficiency, routing protocol, wireless sensor networks.

I. Introduction

A wireless sensor network is a collection of sensor nodes interconnected by wireless communication channels. Each sensor node is a small device that can collect data from its surrounding area, carry out simple computations, and communicate with other sensors or with the base station (BS). Such networks have been realized due to recent advances in micro electromechanical systems and are expected to be widely used for applications such as environment monitoring, home security, and earthquake warning [1].

Despite the infinite scopes of wireless sensor networks, they are limited by the node battery lifetime. Once they are deployed, the network can keep operating while the battery power is adequate. This is critical point to be considered as it is almost impossible to replace the node battery once deployed over an inaccessible area. Such constraints combined with a typical deployment of large number of sensor nodes, have posed many challenges to the design and management of sensor networks and necessitate energy-awareness at all layers of networking protocol stack [2], [3].

In this paper we assume a sensor network model, similar to those used in [4]–[6], with the following properties:

- All sensor nodes are immobile and homogeneous with a limited stored energy.
- The nodes are equipped with power control capabilities to vary their transmitted power.
- None of the nodes know their location in the network.
- Each node senses the environment at a fixed rate and always has data to send to the base station.
- Base station is fixed and not located between sensor nodes.

In this paper, we propose EEPSC (Energy-Efficient Protocol with Static Clustering), 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 lifetime. In each cluster, EEPSC chooses the sensor node with maximum energy as the cluster-head (CH); thus, not only there is always one CH for each cluster, but also the overhead of dynamic clustering is removed. EEPSC is a modified version of the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol presented in [7].

LEACH uses the paradigm of data fusion to reduce the amount of data transmitted between sensor nodes and the base station. Data fusion combines one or more data packets from different sensors in a cluster to produce a single packet. It selects a small number of CHs by a random scheme which collects and fuses data from sensor nodes and transmits the result to the base station. LEACH uses randomization to rotate the CHs and achieves a factor of 8 improvement compared to the direct approach before the first node dies [7].

The main difference between EEPSC and LEACH are described below:

- EEPSC benefits a new idea of using temporary-CHs and utilizes a new setup and responsible node selection phase.
- EEPSC utilizes static clustering scheme, therefore eliminates the overhead of dynamic clustering.

The rest of the paper is organized as follows. Section II describes the proposed method. In Section III simulation

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results are presented, and finally the conclusions are presented in section IV.

II. EEPSC Protocol Architecture

EEPSC is a self-organizing, static clustering method that forms clusters only once during the network action. The operation of EEPSC is broken up into rounds, where each round consists set-up phase, responsible node selection phase and steady-state phase. In the following sub-sections we discuss each of these phases in details.

A. Setup Phase

According to the static clustering scheme which is used in EEPSC, cluster formation is performed only once at the beginning of network operation. For this aim, base station broadcasts k-1 different messages with different transmission powers, which k is the desired number of clusters (specified a priori). By broadcasting the $k=1$ message all the sensor nodes which hear this message (are in the radio range of this message) set their cluster ID to k and inform the base station that they are member of the cluster k via transmitting a join-request message (Join-REQ) back to the base station. Similarly, by broadcasting the $k=k$-1 message, all the sensor nodes which are not joined to any clusters yet and hear this message set their cluster ID to k-1 and inform base station with a Join-REQ message. Later, all sensor nodes which are not joined to any clusters set their cluster ID to k and inform base station. Fig. 1 shows how the network area is divided into $k=4$ clusters with broadcasting k-$1=3$ different messages from base station.

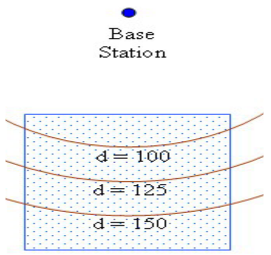

Fig. 1 Network area is divided into 4 clusters with broadcasting 3 different messages from base station

These messages are small messages containing node's IDs and a header that distinguishes them as announcement messages. Like LEACH, in order to reduce the probability of collision among joint-REQ messages during the setup phase, CSMA (Carrier Sense Multiple Access) is utilized as the MAC layer protocol [7].

Afterward, the base station selects randomly one temporary-CH for each cluster and advertises these rules to the whole network. In addition, base station (based on the number of each cluster) sets up a TDMA (time-division multiple-access) schedule and transmits this schedule to the nodes in each cluster. Once the TDMA schedule is known by all nodes in the cluster, the set-up phase is complete and the next phase can begin.

B. Responsible Node Selection Phase

After the clusters are established, network starts its normal operation and responsible nodes (temporary-CH and CH) selection phase begins. At the beginning of each round, every node sends its energy level to the temporary-CH in it's time slot. Afterward, temporary-CH choose the sensor node with utmost energy level as CH for current round to collect the data of sensor nodes of that cluster, perform local data aggregation, and communicate with the base station; and the node with lowest energy level as temporary-CH for next round and sends a round-start packet including the new responsible sensor IDs for the current round. This packet also indicates the beginning of round to other sensor nodes. Since every sensor node has a pre-specified time slot, changing the CHs has no effect on the schedule of the cluster operation.

C. Steady-State Phase

The steady-state phase is broken into frames where nodes send their data to the CH during pre-allocated time slots. These data contain node ID and the measure of sensed parameter. We show in the next section that the total energy expended in the system is greater using multi-hop routing than direct transmission to the base station; thus, we use direct transmission approach among CH and base station.

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.

To reduce energy dissipation, the radio of each non-cluster head node is turned off until its allocated transmission time, but the CHs must be awake to receive all the data from nodes in the cluster.

III. Simulation Results

To validate the performance of EEPSC, we simulate EEPSC and utilize a network with 100 nodes randomly deployed between (x=0, y=0) and (x=100, y=100) and base station at (50,175). The bandwidth of channel is set to 1 Mb/s, each data message is 500 bytes long, and the packet header for each type of packet is 25 bytes long. The initial power of all nodes is considered to be 2J and duration of each round is 20s. Authors in [7] has revealed analytically that the number of clusters for above assumptions is optimized for $1 < k < 6$. So for the rest of the experiment, we set $k=4$.

We assume a simple model for the radio hardware energy dissipation where the transmitter dissipates energy to run the radio electronics and the power amplifier, and the receiver dissipates energy to run the radio electronics [7, 8], as shown in Fig. 2. For the experiments described here, both the free space (d^2 power loss) and the multi path fading (d^4 power loss) channel models were used, depending on the distance between the transmitter and receiver. If the distance is less than a threshold, the free space (fs) model is used; otherwise, the multi path (mp) model is used. Thus, to transmit an l-bit message a distance d, the radio expends:

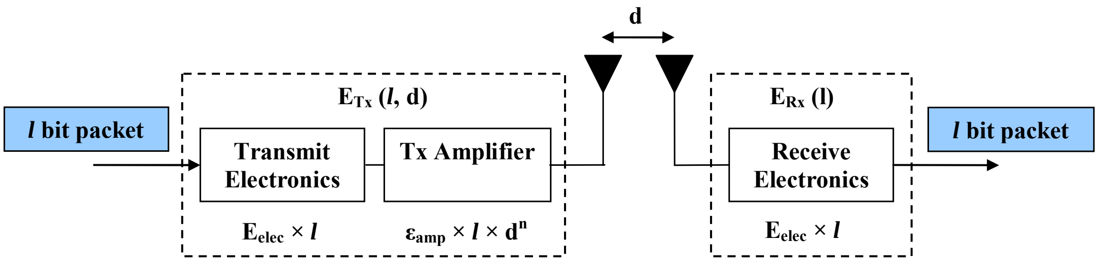

Fig. 2 Radio energy dissipation model

$$E_{TX}(l,d) = E_{TX-elec}(l) + E_{TX-amp}(l,d)$$
$$= \begin{cases} lE_{elec} + l\varepsilon_{fs}d^2, & d < d_{\circ} \\ lE_{elec} + l\varepsilon_{mp}d^4, & d > d_{\circ} \end{cases} \qquad (1)$$

Where $d_{\circ}$ is:

$$d_{\circ} = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \qquad (2)$$

The electronics energy (E_{elec}) depends on factors such as the digital coding, modulation, filtering, and spreading of the signal, whereas the amplifier energy, $\varepsilon_{fs}d^2$ or $\varepsilon_{mp}d^4$, depends on the distance to the receiver and the acceptable bit-error rate. For the experiments described in this paper, the communication energy parameters are set as: $E_{elec}=50nJ/bit$, $\varepsilon_{fs}=10pJ/bit/m^2$, $\varepsilon_{mp}=0.0013pJ/bit/m^4$ and the energy for data aggregation is set as $E_{DA}=5nJ/bit/signal$. As well, to receive an *l*-bit message, the radio expends:

$$E_{RX}(l) = E_{RX-elec}(l) = lE_{elec} \qquad (3)$$

CHs can send their data via just one (high-energy) transmit of data to the base station or via a multi-hop scheme where each data message must go through *n* (low energy) transmits and *n* receives. Depending on the relative costs of the transmit amplifier and the radio electronics, the total energy expended in the system might actually be greater using multi-hop routing than direct transmission to the base station.

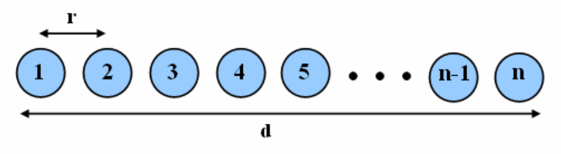

Fig. 3 Simple linear network

To illustrate this point, consider the linear network shown in Fig. 3, where the distance between the nodes is *r*. If we consider the energy expended transmitting a single *l*-bit message from a node located a distance *nr* from the base station using the direct communication approach via one hop and Equations 1 and 3, we have:

$$E_{TX} = l\varepsilon_{fs-amp}\left(\frac{n-1}{\beta}r\right)^2 + lE_{elec} \qquad (4)$$

Where β is the number of hops. Thus, the total energy is:

$$E_{tot} = \beta E_{TX} + \beta E_{RX}$$
$$= 2l\beta E_{elec} + l\varepsilon_{friss-amp}\frac{(n-1)^2 r^2}{\beta} \qquad (5)$$

And the optimum number of hops is computed as below:

$$\frac{dE_{tot}}{d\beta} = 2lE_{elec} - l\varepsilon_{friss-amp}\frac{d^2}{\beta_{opt}^2} = 0$$
$$\Rightarrow \beta_{opt} = d\sqrt{\frac{\varepsilon_{friss-amp}}{2E_{elec}}} = \frac{d}{100} \qquad (6)$$

This shows that, when transmission energy is on the same order as receive energy, which occurs when transmission distance is short, direct transmission is more energy-efficient than multi-hop routing. Thus we use direct transmission communication among CHs and the base station.

The improvement gained through EEPSC compared to LEACH is further illustrated by Figs. 4-7 which indicates the lifetime of network is extended and the overall number of messages received at base station is increased. With LEACH, all nodes remain alive for 220 seconds before the first node dies, while in EEPSC, all nodes remain alive for 320 seconds; which is 45% more than LEACH. Figs. 3 and 4 show that, the total number of data messages received at base station at the end of network lifetime is greater for EEPSC. Furthermore, Figs. 5 and 6 clearly indicate the advantages of EEPSC over LEACH in terms of network lifetime.

IV. Conclusion and Future Work

We introduce EEPSC; a novel energy-efficient routing protocol which partitions the network into static clusters, eliminates the overhead of dynamic clustering and utilizes temporary-cluster-heads (CHs) to distribute the energy load among high power sensor nodes; thus extends network

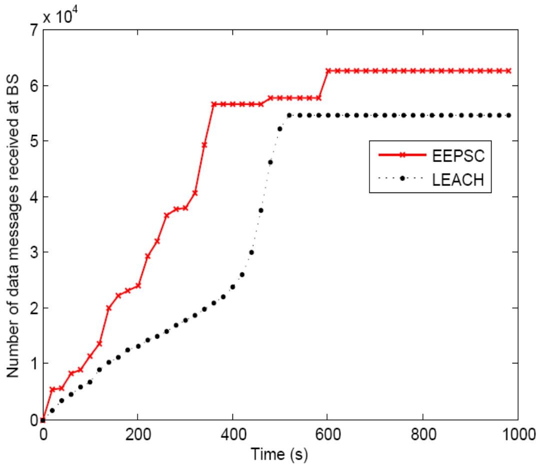

Fig. 4 Number of data messages received at base station over time

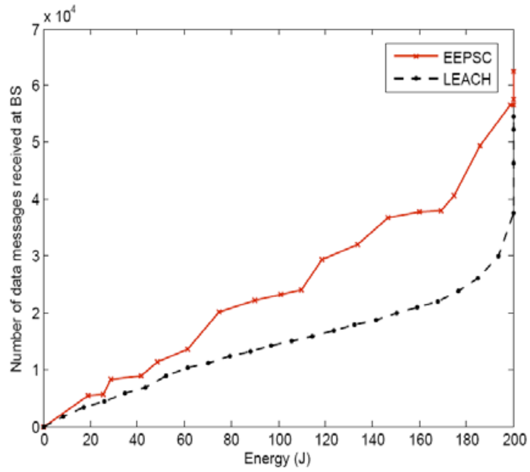

Fig. 5 Number of data messages received at base station over energy

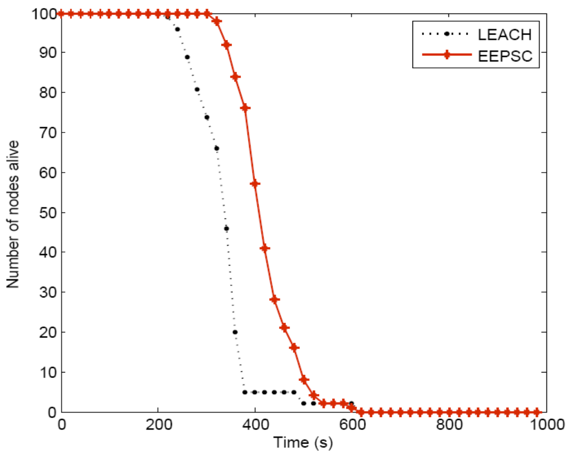

Fig. 6 Number of nodes alive over time

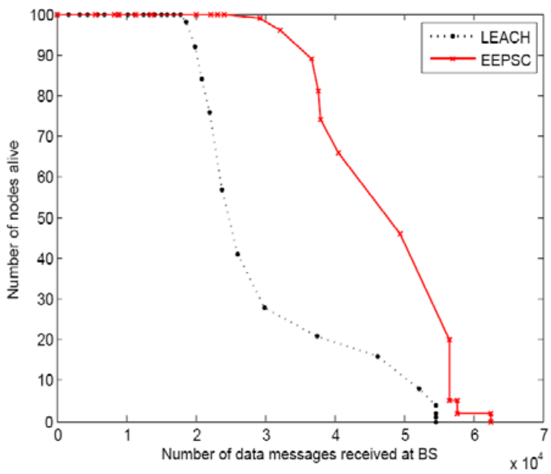

Fig. 7 Number of nodes alive per amount of data messages received at base station

lifetime. The energy efficiency and ease of deployment make EEPSC a desirable and robust protocol for wireless sensor networks. Simulation results show that EEPSC has a better performance than LEACH. For future work, a model with heterogeneous sensor nodes may be investigated.

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