

UDCA: An Energy Efficient Clustering Algorithm for Wireless Sensor Network

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Abstract—In the past few years, the use of wireless sensor networks (WSNs) potentially increased in applications such as intrusion detection, forest fire detection, disaster management and battle field. Sensor nodes are generally battery operated low cost devices. The key challenge in the design and operation of WSNs is to prolong the network life time by reducing the energy consumption among sensor nodes. Node clustering is one of the most promising techniques for energy conservation. This paper presents a novel clustering algorithm which maximizes the network lifetime by reducing the number of communication among sensor nodes. This approach also includes new distributed cluster formation technique that enables self-organization of large number of nodes, algorithm for maintaining constant number of clusters by prior selection of cluster head and rotating the role of cluster head to evenly distribute the energy load among all sensor nodes.

Keywords—Clustering algorithms, Cluster head, Energy consumption, Sensor nodes, and Wireless sensor networks.

I. INTRODUCTION

RAPID technological progress in micro-electro-mechanical systems (MEMs), digital electronics and wireless communications have led to the development of low cost, low power, multifunctional sensor nodes which are small in size and communicate over short distances. These sensor nodes are generally equipped with sensing, data processing and communicating component[1]. The sensing circuitry measures the ambient conditions in the surrounding environment and transforms these measurements into electrical signals that can be processed to reveal some properties about the phenomena happening in the vicinity of the sensors. A wireless sensor network consists of hundreds or thousands of low cost sensor nodes which could either have a fixed location or randomly deployed either inside the phenomenon or very close to it to monitor the environment. These networks are widely used for systematic gathering of useful information related to the surrounding environment(e.g. target field imaging, intrusion detection, weather forecasting and detecting ambient

conditions such as temperature, humidity, seismic and acoustic data, etc.) and for the transmission of the gathered data to base station(BS), i.e sink for further processing[2].

One of the main advantages of WSNs is their ability to operate unattended in environments in which human intervention is impossible. Therefore, sensor nodes can be deployed randomly by dropping from a plane or delivering in an artillery shell, rocket or missile, and to collectively form a network in an adhoc manner. Given the large area to be covered, the low power battery operated sensors and the possibility of having damaged nodes during deployment, dense population of sensor nodes are required in most applications. Designing and operating such large size network would require scalable architectural and management strategies. In addition, sensors are energy constrained and their batteries cannot be recharged/replaced in such environments. Therefore energy/power conservation is commonly recognized as the key challenging factor in the design and the operation of large scale WSNs, consisting of hundreds or even thousands of sensor nodes. Therefore, designing energy-aware algorithms becomes an important factor for extending the lifetime of sensors.

In many WSN applications only an aggregate value to be reported to the BS. In this case, sensors in different regions of the sensing area can collaborate to aggregate their data and provide more accurate reports about their local regions. For example, in battle fields where radiation or chemical activity is measured, the maximum value may be required to alert the troops. Data aggregation improves the fidelity of the reported measurements and reduces the communication overhead in the network, leading to significant energy saving.

In order support data aggregation through efficient network organization, nodes can be partitioned into a number of small groups called clusters[3]. Each cluster has a leader, referred to as a cluster head (CH), and number of member nodes. Clustering results in two-tier hierarchy, in which CHs form higher tier and member nodes form lower tier. The member nodes send their data to their immediate CHs. The CHs perform data aggregation and send them to the BS directly or using multihop communication using other CHs. Because CHs often transmit data over long distances, they loose more energy compared to member nodes. The network may be reclustered periodically in order select higher-energy nodes to serve as CHs.

The rest of the paper is organized as follows. Section II gives a short overview of some clustering algorithms proposed in the literature while section III describes the most widely

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used radio energy model adopted by the algorithms. The section IV explains proposed novel clustering algorithm. Simulation results of this protocol are presented in section V. Finally, section VI concludes this paper.

II. RELATED WORK

Energy efficiency is the primary challenge of WSNs. Clustering schemes strive to reduce power consumption in order to prolong the network lifespan. In literature, a number of clustering algorithms have been specifically designed for WSNs[4-10]. These proposed clustering techniques widely vary depending on the node deployment, the pursued network architecture, the characteristics of the CH nodes and the network operation model. A CH may be elected by the sensors in a cluster or pre-assigned by the network designer. A CH may also be just one of the sensors or a node that is richer in resources. The cluster membership may be fixed or variable. CHs may form a second tier network or may just ship the data to interested parties.

In clustered WSNs, a CH has a higher burden than that of member nodes making it drain energy much more quickly than member nodes. Rotating the CH role distributes this higher burden among the nodes, thereby preventing the CH from dying prematurely.

LEACH [9] operations are divided into set up phase (cluster organization, CH role rotation) and steady state phase (data collection, data aggregation and data forwarding). During the set up phase, each node locally determines whether it will become a CH or not. The CH selection is based on the residual energy of the node. Those with higher residual energy have the advantage during the CH competition. Clusters are created by non-CH nodes choosing to join a CH based on the signal strength of advertisements received from CHs. It has been shown that LEACH reduces energy consumption and improves network lifetime compared to fixed CH schemes.

Liu and Lin [10] proposed the Cluster Head Election Protocol (CHEP) that select CH based on the remaining energy of member nodes. Once a cluster has been created with a nominal CH, each member node will send the value of its remaining energy to the CH, which will select the node with the highest remaining energy to be its successor. This node will be the CH for a cluster cycle. At the end of each cycle the current CH will select the node with the most remaining energy to be its replacement. HEED [7] is distributed clustering scheme in which CH nodes are picked from the deployed sensors. HEED considers a hybrid of energy and communication cost when selecting CHs. Only sensors that have a high residual energy can become CH nodes.

III. RADIO ENERGY MODEL

The energy model used in this paper is similar to that used by most existing energy-efficient clustering algorithms [9] is shown in figure 1.

Let E_{elec} is the amount of energy dissipated to run transmitter or receiver by the transceiver and E_{amp} be the

energy required for the transmit amplifier to achieve an acceptable E_p/N_0 . To transmit a k-bit message to a distance of d meters using this radio model, the transceiver expends:

$$E_{Tx} = E_{elec} * k + \epsilon_{amp} * k * d^2 \quad (1)$$

and to receive this message, the transceiver expends

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

The parameters of the transmission/receiver circuitry and the path-loss exponent are listed in Table I.

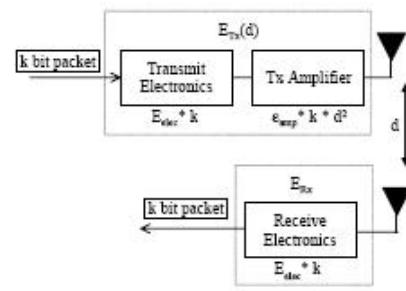


Fig. 1 Radio model

TABLE I
SIMULATION PARAMETERS

Parameter	Symbol	Value
T_x/R_x electronic constant	E_{elec}	50 nJ/bit
Amplifier constant	ϵ_{amp}	10 pJ/bit/m ²
Path-loss exponent	n	2
CH energy threshold	E_{th}	10 ⁻⁴ J
Packet size	k	30 bytes

IV. PROPOSED CLUSTERING ALGORITHM

This section presents a network model, desired aim of clustering, and detailed description of the proposed algorithm.

A. Network Model

Consider a sensor field consisting of set of randomly deployed sensors in a rectangular field. In this network, the sensing tasks and data reporting are periodic. The algorithm assumes the following properties about the sensor network model:

- Sensor nodes are densely deployed and are static.
- Sensor nodes have similar capabilities for sensing, processing and communication.
- All sensor nodes have unique ID.
- Sensor nodes transmit data to its immediate cluster head in the allotted time slots.
- The BS is fixed and located far from the sensors.
- Each node can communicate with the BS directly.
- All nodes are energy constrained and perform similar task.

B. Clustering Aim

The main aim of the algorithm is energy minimization, which is obtained by reducing the amount of communications among the sensor nodes. The algorithm has been designed with the following principles in mind:

- Cluster formation is initiated with the BS and maintained in distributed manner, through self organization of sensor nodes.
- Constant number of cluster are created and maintained throughout the lifetime of the network.
- CHs should be evenly distributed throughout the network.
- Clustering process should terminate within a finite interval.
- Energy consumption should be well distributed among sensor nodes by rotating the role of the CH.

C. UDCA: Uniform Distributed Clustering Algorithm

UDCA combines the system parameters such as cluster size, transmission power, and energy level of nodes and maintain constant number of clusters throughout the lifetime of the network. In this proposed algorithm, only nodes with higher energy are selected as CHs, while those with low energy extend their lifetime by performing sensing tasks that require low energy. Further, each cluster member nodes sense the similar data, which are aggregated by the CH, limiting the amount of data that needs to be sent to the BS.

The main activities of this algorithm are broken up into rounds, where each round begins with a cluster setup phase, followed by a steady state round. They are i) Central cluster setup round, ii) Steady state round, and iii) Distributed cluster setup round.

1) *Central cluster setup round:* In this round, clusters and CHs selection is initiated at the time of system activation by the central BS.

Step I: Node information

- BS broadcast *REQ* signal into the network requesting location, node ID, and energy level of each node.
- In response to the REQ signal, all the nodes in the network send *LOC_ID_EL* message, which consist of location information, node ID, and energy level to the BS.

Step II: Cluster Head selection

- BS selects fixed number (*m*) of energy abundant nodes as CHs for the network.
- If more than one nodes have same energy level, the BS uses smallest/largest node ID to break the tie.
- The BS broadcast *CH_ID* message signal, which contains CHs node ID into the network.

Step III: CH Announcement

- Each node extracts node ID from the message. If the ID matches with the node ID, the node becomes

CH, otherwise the node will wait for the cluster head advertisement message (*CH_ADV*) signal from other nodes.

- CH node broadcast a *CH_ADV* message to the non cluster head nodes. This is a short message which contains cluster head node ID, message header (used to differentiate messages) and unique direct sequence spread spectrum code, which is used to avoid the inter cluster interference.
- Based on the received *CH_ADV* signal strength, each of the non cluster head node bases its decision whether it would like to join the cluster or not by sending the *JOIN_CH* message which includes its energy level and node ID to the desired cluster head.
- All CH nodes receives the *JOIN_CH* messages from the member nodes, and the CH node selects the probable cluster head (*CH_{prob}*) for the next round.

2) *Steady state round:* The CH node receives all the messages from the nodes that would likely to be included in the cluster. The CH node creates time schedule and initiates the data transmission.

Step I: Schedule creation

- After deciding the *CH_{prob}*, the CH node creates TDMA time slot for all the nodes.
- The CH node sends out *CHPROB_SCH* message into the network. This message contains CHprob node ID and time slot telling when it can transmit the data.

Step II: Data reporting

- The radio of each of the member nodes can be turned off until the nodes allocated TDMA slot, thus minimizing the energy in these nodes. The CH nodes must keep their receiver on to receive all the member nodes data.
- After receiving data from all member nodes, the cluster heads performs data aggregation. The aggregated data is send to the BS by using multihop communication through intermediate CHs.

3) *Distributed cluster setup round:* After certain time, which is determined a priori, the next round begins with the formation of new clusters. This is initiated by the CHprob nodes, which was selected by the CHs of previous round. This begins with the announcement round as described in the step III of central cluster setup round. The network operation then continues with the Steady state round followed by Distributed cluster setup round and continues.

V. OBSERVATION AND RESULTS

In this paper, the environment is simulated by deploying 50 nodes randomly in an area of 100x100 units. From the results obtained, it is observed that UDCA reduces the number of communication among the sensor node by selecting the probable cluster head CHprob for next round, in advance by the current CHs. This avoids fresh negotiations among sensor

nodes to form new clusters and CH. Thus, the UDCA greatly reduces the communication burden during every round, and significantly minimizes the energy consumption. The simulation result shows that, UDCA greatly increases the network lifetime. Figure 2 shows the creation of number of CHs by the UDCA over a given period. Since the algorithm is developed to create a constant number clusters, which maintains the uniform distribution of CHs in a network. Thus, minimizes the energy consumption by reducing the number of inter node communication.

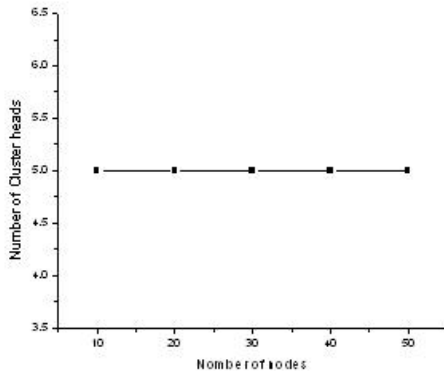


Fig. 2. Constant number of cluster heads

The metric Number of nodes alive is used in Figure 3, which indicates the overall lifetime of the network. More importantly, it gives an idea of the area coverage of the network over time. Figure 4 shows the average dissipation of energy per node over the time in the network as it performs various functions such as receiving, transmitting, sensing, and aggregation of data.

VI. CONCLUSION

This paper presented a novel clustering algorithm UDCA that effectively combines some system parameters to organize the nodes into non overlapping clusters. UDCA attempts to minimize the energy consumption by creating constant number of clusters and by selecting the probable cluster head for the next round in advance. UDCA is completely distributed except for the first round. Energy cost is more during the first round, since all the nodes needs to communicate with the BS. But, for subsequent rounds, energy cost is very much reduced due to probable cluster head selection in advance for the next subsequent round.

In our future work, we will compare the performance of our algorithm with the existing clustering algorithms in the literature.

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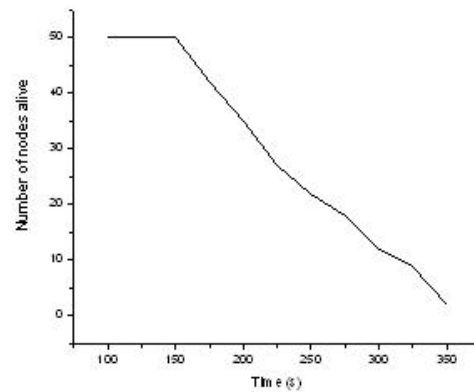


Fig. 3. Number of nodes alive

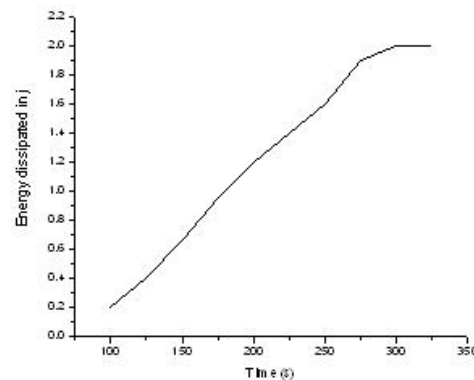


Fig. 4. Energy dissipation

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