An Enhanced Energy Efficient Unequal Layered Clustering Algorithm for Large Scale Wireless Sensor Networks

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Abstract -- Organizing wireless sensor networks into clusters ensures the effective utilization of limited energy resources of the sensor nodes. The problem of unbalanced energy consumption and hot-spots problem remain unavoidable. To solve this problem, we propose an Enhanced Energy Efficient Unequal Layered Clustering Algorithm (EEEULCA), which leads to the uniform energy dissipation among the cluster heads. Layer close to the base station will have smaller size than from the outer, which can preserve more energy for data forwarding. Data-aggregated Unequal Layered clustering protocol is used for inter-cluster communication. Simulation result shows that, our proposed algorithm effectively balances the energy consumption and increases the network lifetime.

Index Terms -- hot-spots, network lifetime , unequal layered clustering, Wireless sensor networks.

I. INTRODUCTION

Wireless sensor networks are of tiny, battery powered sensor nodes with limited processing power and capabilities. To overcome this problem and to achieve higher energy efficiency, sensor nodes are grouped into clusters, where each cluster heads collects all the data and process them before being sent to the base station. To achieve network scalability, clustering is the best solution .Communication within a cluster (intra-cluster) and communication between different clusters (inter-cluster) can be done by single-hop and multi-hop communication. In single-hop communication, every sensor node will directly transmit the data to the base station, so the nodes furthest away from the base station are the most critical nodes.In multi-hop communication, due to the limited transmission range, data's are forced to route over several hops until they reach the final destination nodes that are closest to the base station are burdened with heavy relay traffic and they die first (i.e., the "hot-spots" problem).

In this paper, Enhanced Energy Efficient Unequal Layered Clustering Algorithm (EEEULCA) is proposed to solve hot-spots problem. Under EEEULCA, network model is divided into unequal layers, where the width of the inner layer is smaller than the outer layer. Here the node's competition radius changes with respect to its hops. Data-aggregated Unequal Layered Clustering protocol is used for inter-cluster communication. Here Main Cluster Head (MCH) is selected. All the cluster heads will send data to the Main Cluster Head (MCH), which will aggregate all the data's and check for redundancy before being sent to the base station.

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Simulation result shows that EEEULCA efficiently balances the energy consumption and increases the network lifetime.

The paper consists of the following sections. Sections II presents related works. Section III describes the network model, enhanced energy efficient unequal layer clustering algorithm and data-aggregated inter-cluster routing protocol. Section IV gives the simulation results and analysis. Finally, Section V concludes this paper.

II. RELATED WORK

Now days, many clustering algorithms have been proposed to facilitate communication and data processing in sensor networks. But the problem of unbalanced energy consumption exists in wireless sensor networks. We mention the most related papers to energy efficient unequal layered clustering.

In [1] the authors propose a multi-hop communication between the data source and base station which is more energy efficient than single-hop communication. But the hot-spots problem remains unavoidable in inter-cluster communication. So the cluster heads close to the base station are overloaded with heavy relay traffic and they will die first.

In [2] the authors investigate the problem of prolonging the lifetime of a network, by considering the optimal cluster size. Based on this, they propose a transmission scheme, which further increases the network lifetime. In [3], the problem of unbalanced energy consumption is solved by unequal layered clustering model. The network model is divided into two rings of unequal sizes. The authors conclude that unequal layered clustering is better than equal clustering in multi-hop model. In LEACH [4], single-hop clustering algorithm for wireless sensor network is proposed. Each node will have certain probability to become a cluster head. Each cluster head collects the entire aggregated packet and forwards them to the base station by single-hop.

In EEUC [5], the authors propose Energy Efficient Unequal Clustering protocol. Nodes are distributed into clusters of unequal size. So the cluster heads close to the base station have smaller sizes than those from the furthest away. The overhead of cluster setup in EEUC is very high. In ULCA [6] is a well known unequal layered clustering approach to mitigate the hot-spots problem. In ULCA local competition and member join mechanism is adopted which reduces the overhead than EEUC [5].

In [7] the authors propose an Improved Energy Efficient Unequal Clustering (IEEUC) algorithm.

The nodes competition radius will be adjusted based on the hops to base station. Energy consumptions are better in IEEUC compared to EEUC.Paper [8] proposes a Data–aggregated Unequal Clustering (DUC) routing protocol, where main cluster head (MCH) are elected. All the cluster heads aggregate the data and check for redundancy and finally forward them to the base station.

In [9], Energy Balancing Unequal Clustering Protocol (EB-UCP) is proposed. Network model is divided into many rings. The rings close to the base station have higher probability than that are further away from the base station. HEED [10] extends LEACH [4] by considering the residual energy and intra-cluster cost information. Tentative cluster heads are elected and finally cluster heads are elected.

III. THE EEEULCA MECHANISM

A. Network Model

The network consists of a set of sensors which are uniformly deployed over a vast rectangular field to continuously monitor the environment. We make some assumptions about the sensor nodes and the network model.

- All the nodes are alike and each node is assigned with a unique identifier (ID).
- Base station is located at the center of the monitor field. Sensors and the base station are all stationary after deployment.
- A node can compute the approximate distance to another node based on the received signal strength.
- Node can transmit in different power levels to achieve different communication range.

The monitored field is divided into multiple annuli with different width [6]. The number of annulus and width of each annulus depends on the radius of the innermost circle and the expanding factor (α). The width of the inner annulus is smaller than the outer annulus.

We use a simplified model presented in [7]. Either the free space (d^2 power loss) or the multi-path (d^4 power loss) channel is used based on the distance between the transmitter and the receiver. The energy spent for transmitting h-bit packet over distance d is:

$$E_{TX}(h,d) = \begin{cases} hE_{elec} + h\varepsilon_{fs}\, d^2 \ldots\ldots d \le d_0 \\ hE_{elec} + h\varepsilon_{mp}\, d^4 \ldots\ldots d > d_0 \end{cases} \quad (1)$$

Where d_0 is the critical distance beyond which multi-path channel mode is used. Energy spent for receiving h-bit packet is

$$E_{RX}(h,d) = hE_{elec} \quad (2)$$

All the cluster head can always aggregate the data coming from its member into a single length-fixed packet.

B. Enhanced Energy Efficient Unequal Layered Clustering Algorithm

The key idea of EEEULCA is to utilize different layer width to mitigate the hot-spots problem. The algorithm consists of six phases, i.e. calculation of no of hops of each node, calculation of limit of node degree, determination of communication radius, choice of candidate cluster head, selection of formal cluster head and clustering phase. In the calculation of hops of each node from the base station, EEEULCA uses the hops of the node to the base station to determine their location in the network and to measure their distance from the base station. In the second phase, calculation of the limit of the node degree is done. We adjust the upper and lower limit of each node. The maximum node degree upper limit value is set to D_{0_Max}, with which we adjust the upper limit of each node degree D_{i_max}.

$$D_{i\_max} = \left[1 - c \cdot \frac{hop_{max} - S_i.hop}{hop_{max} - hop_{min}}\right] D_{0\_max} \quad (3)$$

Where hop_{max} and hop_{min} denote the maximum and minimum hops to the BS. S_i.hop is the hops between S_i and the BS; c is a constant between 0 and 1.

Third phase is the determination of communication radius of each node. The process is as follows:

(1) In the beginning, each node broadcasts a LifeMsg containing its own ID.
(2) The nodes that receive the messages will send a response message LifeAckMsg.
(3) Each node determines its node degree D_i after receiving LifeAckMsgs.
(4) If D_i is less than the lower limit D_{i_min}, node increases its communication radius as (4).
(5) If D_i is larger than the upper limit D_{i_max}, the node decreases its communication radius as (5).

$$R_i = \min\{B_{max} * R_0, A_{inc} * (D_{i\_min} - D_i) * R_0\} \quad (4)$$

$$R_i = \max(B_{min} * B_0, A_{dec} * (1-(D_i - D_{i\_max})) * R_0 \quad (5)$$

Paper [7], gives the node degree range from 4 to 12, A_{inc} =10%, A_{dec} =2%, B_{max}= 1, B_{min}=1/4.

In the choice of candidate cluster head sub-phase, the node with smallest probability is selected as the candidate cluster head.

$$P_{min} = n/N = 2A_{AREA}/\sqrt{27}\, NR_0^2, \ (R_0 < d_0/2) \quad (6)$$

$$\text{Where } n = 2A_{AREA}/\sqrt{27}\, R_0^2 \quad (7)$$

The probability P is calculated as

$$P = a\, P_{min}, \ (1 \le a \le 1/p_{min}). \quad (8)$$

In order to ensure the network connectivity, threshold T (n) can be expressed as:

$$T(n) = \begin{cases} \dfrac{P}{1 - P*[r \bmod (1/P)]}, & n \in G \\ 0, & n \notin G \end{cases} \quad (9)$$

Where P is the percentage of cluster head in all the nodes, r is the election round, [r mod (1/P)] is the no of cluster head elected before, G is the group of the nodes that have not yet been elected.In the fifth formal cluster head sub-phase, each candidate cluster head broadcast the COMPETE_Message (ID, HOPCOUNT, ENERGY, R_i) to all the nodes and maintains a timer. The candidate cluster head whose energy is maximum become the formal cluster head and sends FORMAL_Message (ID, HOPCOUNT) in its radius R_i. In the sixth clustering sub-phase, each node joins to its appropriate cluster by sending Join_Message (ID, Head ID).

C.Data-Aggregated Unequal Layer Inter-Cluster Routing

There is a large number of redundant data among different clusters in practical application. In this paper, Data-aggregated Unequal Layer Inter–cluster routing protocol is proposed to solve this problem. Cluster heads from outer layer forward to the next inner layer and finally reach the base station. We will select the MCH (Main Cluster Head) in layer 0 whose distance are smaller to base station as less than TD_MAX. The algorithm is as follows.

1) Suppose there are many cluster heads $CH_1, CH_2 \ldots CH_n$, whose distances are less than threshold TD_MAX, each cluster head sends their residual energy $E_1, E_2, \ldots E_n$ and values of data size $K_1, K_2, \ldots K_n$ to base station.
2) Base station calculates the total size of data packet as

$$K_{sum} = K_1 + K_2 + \ldots + K_n \qquad (10)$$

3) In order to transmit a K-bit message , the radio expends

$$E_{TX}(k,d) = E_{elec} * k + \varepsilon_{amp} * k * d^2 \qquad (11)$$

Where E_{elec} and ε_{amp} are the fixed values. In order to send the data packets from CH_1 and CH_2, the base station expends:

$$E_{T1} = E_{elec} * K_{sum} + \epsilon_{amp} * k_{sum} * d_1^2 \qquad (12)$$

and

$$E_{T2} = E_{elec} * K_{sum} + \epsilon_{amp} * k_{sum} * d_2^2 \qquad (13)$$

Where d_1 and d_2 are distances from CH_1 and CH_2 to base station.

4) Base station calculates the difference value between cluster head CH_1 and CH_2 as

$$\Delta E_T = \varepsilon_{amp} * K_{sum} * (d_1^1 - d_2^2) \qquad (14)$$

And the difference value between the residual energy of cluster head CH_1 and CH_2 is:

$$\Delta E = E_1 - E_2 \qquad (15)$$

5) Compare ΔE with ΔE_T, if ΔE is greater than ΔE_T, CH_1 is chosen as the preliminary main cluster head (PMCH). Final PMCH will become the main cluster head (MCH).

MCH will collect all the data and it will check for redundancy, before being sent to the base station. Thus it efficiently balances the energy consumption and increases the network lifetime.

IV. SIMULATION RESULTS AND ANALYSIS

We evaluate the performance of EEEULCA mechanism via simulation by NS-2. An ideal MAC layer and error-free communication links are assumed. The simulation parameters are given in table 1.

Table I: Simulation Parameters

Parameter	Values
Network coverage	(0,0)~(600,600) m
Base station location	(300,300)m
Nodes	400
Initial Energy	2J
E_{elec}	50nJ/bit
ε_{fs}	10pJ/bit/m^2
ε_{mp}	0.0013pJ/bit/m^4
d_0	87 m
EDA	5nJ/bit/signal
Eidle	1mW
Data Packet Size	4000 bits
TD_MAX	150

A. Energy Efficiency

We investigate the energy efficiency of EEEULCA. The ULCA is simulated by NS-2 with some parameters as those in [6]. First We Compare the Energy Consumption of CH's and normal nodes in clustering phase. 20 rounds of simulations are sampled and the result is shown in Fig.1 and Fig. 2.

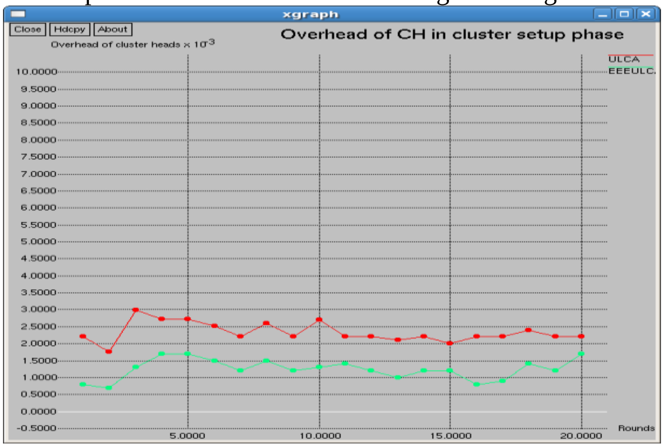

Fig. 1: The overhead of CH in cluster setup phase

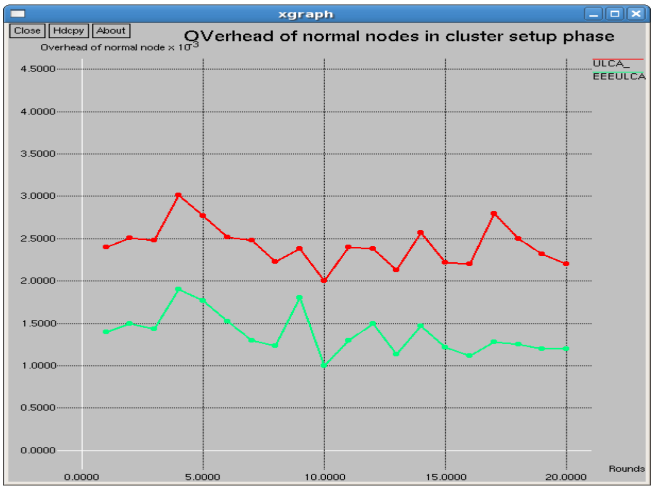

Fig. 2: The overhead of normal nodes in cluster setup phase

We observe from Fig.1 and Fig.2, that the energy consumed by CH's and normal nodes in ULCA is greater than EEEULCA. Because the hops distance and nodes competition radius are taken into account in EEEULCA, which effectively balances the energy consumption.

B. Network Lifetime

Next we compare the network lifetime of two protocols ULCA and EEEULCA. Fig.3 shows the number of alive nodes over simulation rounds.

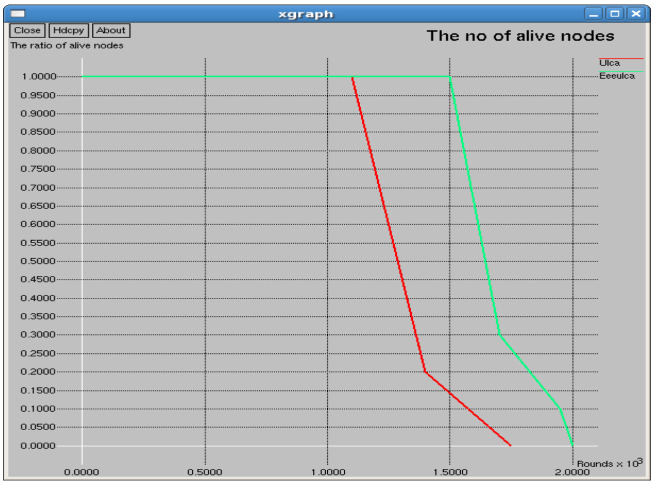

Fig. 3: The number of alive nodes over rounds

We can see that the span of time from the first node dies to the last node dies is greater in EEEULCA compared to ULCA. Thus EEEULCA clearly improves the network lifetime.

V. CONCLUSION

In this paper, we proposed Enhanced Energy Efficient Unequal Layered Clustering Algorithm (EEEULCA) for large scale wireless sensor network. It mitigates the hot-spots problem and efficiently balances the energy consumption. Layers close to the base station have smaller width than those far away from the base station. In addition Data-aggregated unequal layer inter-cluster routing is done, where all the data's are checked for redundancy and finally sent to the base station. Simulation results show that our EEEULCA effectively balances the energy consumption and improves the network lifetime.

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