Energy Optimization in Heterogeneous Clustered Wireless Sensor Networks

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Abstract ***Wireless sensor network is one of the mostly used networks in the world. It has been applied in many fields to improve the productivity and reduce the wastage. Wireless Sensor networks consist of small sized and inexpensive sensor nodes. The wireless sensor nodes are restricted with limited energy. Energy efficiency in wireless sensor nodes is an important task. Many researches focus on energy optimization in wireless sensor nodes. The proposed system attempts to reduce the energy usage in the wireless sensor nodes. The result shows that the energy optimization is higher in the proposed system.***

Keywords: *Energy efficient, clustering, heterogeneity*.
BS location

1. Introduction

The sensors are inexpensive and small in size, with limited processing and computing capabilities. These sensor nodes sense the information from the deployed area and transmit the sensed information to the user [1]. Sensor nodes are low power devices equipped with one or more sensors, a processor, memory, a power supply, a radio, and an actuator. Battery provides power to all the components in a sensor node. WSNs are used in many applications such as monitoring battle fields, factory manufacturing flow control, home appliance automation, traffic controls, and medical equipment coordination, etc. [2].

The environment determines the size of the network, the deployment scheme, and the network topology. The indoor environment requires fewer nodes but outdoor environments may require more nodes to cover a larger area. A random deployment of nodes is preferred over uniform deployment when the field is inaccessible or the network is large. There are three data delivery models in Wireless Sensor Networks. They are continuous, event-driven, and query-driven delivery models [3]. In continuous delivery model, all the nodes periodically send the data to the BS. The nodes always have data and continuously transmit to BS. In event-driven delivery model, the nodes sense the data and transmit to BS when there is a need. The node transmits the data only when the specified event occurs. Otherwise, the node senses the environment, but does not transmit to BS. In the query-driven data delivery model the data is pulled by the BS while the data is pushed to the BS in the event driven model. The BS extracts the data from the nodes when there is a need.

The nodes sense the environment but transmit the data only when the BS makes a query. Event-driven data delivery model performs well in large-scale networks and sends only fewer messages than continuous data delivery model [4]. Many research so far assumed that all nodes gather and transmit data at the fixed rate and network's energy consumption is homogeneous, so that they regulate the run-time of each round. But, in event-driven sensor networks, events occur randomly and rapidly, and accompanied by the bursts of large numbers of data, therefore, network energy consumption is uneven [5].

Typically, wireless sensor networks consists of homogeneous sensor nodes, i.e, all the sensor nodes in the network have same capacity in computing and initial energy, but, in recent years, heterogeneous networks exist in most of the applications. In heterogeneous sensor networks, the sensor nodes with different capabilities have been performing aggregation and transmission. The sensor nodes in the heterogeneous networks will have different levels of energy, memory, and resources. The heterogeneous networks will be the combination of more number of homogeneous sensor nodes and few numbers of heterogeneous nodes. The main objective of the heterogeneous sensor network is to improve the lifetime and the reliability. Heterogeneous wireless sensor network performs well and provides reliable data to the researchers.

The following are some of the advantages of using heterogeneous sensor nodes.

- Network lifetime – energy consumptions is reduced in the heterogeneous networks. So the network lifetime can be improved
- Throughput – the data rate transmitted in the network will be more than the homogeneous network
- Response time – computational resource and link resource can reduce the processing time and waiting time.

The researches show that the communication unit consumes more energy in the wireless sensor network. Transmission consumes more energy than the reception. Many researches have been carried out to reduce the energy consumption by reducing the number of transmission [6]. The sensors can transmit the data to the sink either directly or through the intermediate nodes. In the direct transmission, the node which is far away from the sink has to spend more energy than the node which is nearest to the sink. In multi-hop routing protocol, the data is transmitted to the sink through the intermediate nodes. In this, the node which is nearest to the sink will drain out its energy very quickly [7].

Various routing protocols have been proposed to improve the network life-time. In order to extend the lifetime of the whole sensor network, energy load must be evenly distributed among all sensor nodes [8] so that the energy at a single sensor node or a small set of sensor nodes will not be drained out very soon.

2. RELATED WORKS

Heinzelman *et al*. [9], introduced the first hierarchical clustering algorithm for WSNs, called LEACH. It is one of the most popular protocols in WSNs. The main idea is to form clusters of the sensor nodes. LEACH outperforms classical clustering algorithm by using adaptive clustering and rotating CHs. This saves energy as transmission will only be performed on that specific CH rather than all the nodes. LEACH performs well in homogeneous environment. However, its performance deteriorates in heterogeneous environment.

S. D. Muruganathan et al. [10] proposed Base Station Controlled Dynamic Clustering Protocol (BCDCP), which utilizes a high-energy base station to set up clusters and routing paths, perform randomized rotation of cluster heads, and carry out other energy-intensive tasks. The key ideas in BCDCP are the formation of balanced clusters where each cluster head serves an approximately equal number of member nodes to avoid cluster head overload, uniform placement of cluster heads throughout the whole sensor field, and utilization of cluster-head-to-cluster-head (CH-to-CH) routing to transfer the data to the base station. Threshold-sensitive Energy Efficient Network (TEEN) proposed by A. Manjeshwar et al. [11] is a reactive protocol for time critical applications. The CH selection and cluster formation of nodes is same as that of LEACH. In this scheme, CH broadcasts two threshold values i.e. Hard Threshold (HT) and Soft Threshold (ST). HT is the absolute value of an attribute to trigger a sensor node. HT allows nodes to transmit the event, if the event occurs in the range of interest. Therefore, this not only reduces transmission to significant numbers but also increases network lifetime. Stable Election Protocol (SEP) proposed by G. Smaragdakis et al. [12], does not require any global knowledge of the network. The drawback of SEP is that it does not consider the changing residual energy of the node hence, the probability of advanced nodes to become CH remains high irrespective of the residual energy left in the node. Moreover, SEP performs below par if the network is more than two levels. Li Qing et al. [13] proposed Distributed Energy Efficient Clustering (DEEC) protocol for WSNs. DEEC is a clustering protocol for two and multilevel heterogeneous networks.

The probability for a node to become CH is based on residual energy of the nodes and average energy of network. The epoch for nodes to become CHs is set according to the residual energy of a node and average energy of the network. The node with higher initial and residual energy has more chances to become a CH than the low energy node. Otgonchimeg Buyanjargal et al., [5] proposed a modified algorithm of LEACH called Adaptive and Energy Efficient Clustering Algorithm for Event-Driven Application in Wireless Sensor Networks (AEEC). This protocol makes the nodes with more residual energy have more chances to be selected as cluster head by balancing energy consumption of the nodes. 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.

3. NETWORK MODEL

We proposed Energy optimized heterogeneous clustered wireless sensor networks (EEHC) for improving the network lifetime by reducing the energy consumption of the nodes. The heterogeneous wireless sensor network consists of few special nodes and more number of ordinary nodes. The special nodes may have more initial energy than the ordinary nodes. The proposed system has two phases: Cluster Formation Phase and Data Transmission Phase. The proposed system assumes the following properties:

1. Nodes are stationary.
2. The BS is fixed and located at the centre of the network
3. All the nodes have the capability to control their transmission power.
4. Each node senses the field and sends the data when the specified events occur.
5. Few nodes have more initial energy than the other nodes

3.1 Radio Model

In our proposed system, we use the same ordeal radio model proposed in [9]. The equation 1 denotes cost of energy for transmitting a *k*-bit data to the destination. The energy dissipation for reception of data is denoted by equation 2.

$$E_T(k,r) = E_{TX}k + E_{amp}(r)k \quad (1)$$

$$E_R(k) = E_{RX}k \quad (2)$$

Parameter *r* indicates the range of transmission. E_{TX} and E_{RX} specify the energy dissipated for the transmission and reception of *k*-bits. *Eamp*(*r*) is the energy required to amplify the data. The free space propagation and two-ray propagation models were used to path loss due to wireless transmission. The threshold value r_0 is used to determine the range of transmission. If $r \le r_0$ the free-space model is used. If $r > r_0$ the two-ray model is used.

$$E_{amp}(r) = \begin{cases} \varepsilon_{FS} r^4, r \le r_0 \\ \varepsilon_{TR} r^4, r > r_0 \end{cases} \quad (3)$$

Where ε_{FS} indicates the amplified energy for free space model and ε_{TR} denotes amplified energy for two-ray model. The threshold value r_0 is denoted by

$$r_0 = \sqrt{\varepsilon_{FS} / \varepsilon_{TR}} \quad (4)$$

All the nodes send the sensed information to the base station (BS) along with the location information and residual energy information. The BS, which has unlimited energy, can be utilized for the cluster formation and cluster Head (CH) selection. The BS calculates the average energy level of the network and selects a set of nodes (SN) for Cluster Heads. These selected nodes will have more energy level than the average energy level of the network. The set of nodes that have more connectivity will have more chances to be selected as cluster head. Then the BS divides the network into two clusters C1 and C2 based on the maximum separation and the connectivity of nodes. Then the clusters C1 and C2 are divided further into more sub-clusters. This process repeated until *k* number of clusters formed. Then the BS broadcasts the cluster-head details, spread code, and the transmission schedule to the Non-CH nodes. The iterative cluster splitting algorithm proposed in [14] is modified and used to form the cluster. Then the balanced clustering algorithm is used to make the clusters equal in size. All the clusters will have approximately the equal number of nodes. The BS also calculates the energy efficient route using Minimum Spanning Tree approach [15] to connect all the CHs. The BS selects the CHs which have more residual energy and the connectivity. Normally, the special nodes will have more energy than the ordinary nodes. So they will have more chance to become the CHs. The nodes which are having more connectivity will be having more priority. After the CH has been selected, the BS broadcasts a message to the nodes about the CH selection, spread spectrum code, and the transmission schedule. The non-CH (NCH) nodes send their sensed data to the respective CHs during their transmission slot. The proposed system uses the TDMA schedule for the data transmission. Only one node in the cluster will transmit its data during the slot. All other nodes in the cluster turn off their radios to minimize the energy consumption at the node level. To avoid the interference between the clusters during the transmission, the BS assigns different spread code to each cluster. The spread code avoids the collision and saves the energy. The new cluster head selection and cluster formation will begin when the CHs collect the data from the non-CH nodes and transmit to the BS.

The data communication phase consists of Intra-cluster communication and Inter-cluster communication. In the Intra-cluster communication, the sensor nodes transmit their data to the respective CHs. All the non-CH nodes transmit their data during its transmission slot. The TDMA schedule is created and assigned by the BS to all the nodes. All other nodes, except the transmitting node, will turn off their radios. This approach minimizes the energy consumption. The CHs turn on their receivers to collect the data from the member nodes. The CDMA approach is used to avoid the interference between the clusters. The BS assigns different spread code to each CH to avoid the collision. In Inter-Cluster communication, the CHs collect the data from the member nodes and perform data aggregation on the received data. The CHs received different signals from member nodes and combine into a single signal to avoid the redundant data and reduce the size of the combined data. The CH with more residual energy can be selected, using the Minimum spanning tree approach, to collect the aggregated data from other CHs and transmit to the BS. Transmitting data directly to the BS is the energy consuming task. To avoid the energy depletion, the CH node with higher residual energy will be transmitting the data to the BS. This approach will be useful to balance the energy level in the network.

4. EXPERIMENTS AND RESULTS

To assess the performance of our system, we simulate the system using Network Simulator. We have used 100 nodes for small scale network and 300 nodes for large scale network. The network size for small-scale was 100x100m and 500x500m for large-scale. The ordinary nodes are assigned an initial energy of 0.2J and the special nodes are assigned with an initial energy of 0.5J. The simulation is performed on both of the continuous data delivery model and event-driven data delivery model. The continuous data delivery model is considered first for the simulation. It is assumed that the nodes are always having data for transmission in continuous delivery model.

Table: 1: Simulation parameters

Parameters	Description	Values
M x M	Network field	100 x 100 m, 500x500 m
N	Number of nodes	100, 300
BS	BS Location	Centre of the Network
E_0	Initial energy	0.2J and 0.5J
E_{elec}	Electronics energy	50nJ/bit

In the event-driven delivery model, only few nodes will have the data to transmit. The nodes transmit packets only when they meet certain criteria on the data. The number of transmission on event-driven model is less compare with the continuous model. It saves energy by minimizing the number of transmissions between the nodes and the sink. We compared the performance of our EEHC model with LEACH and AEEC models.

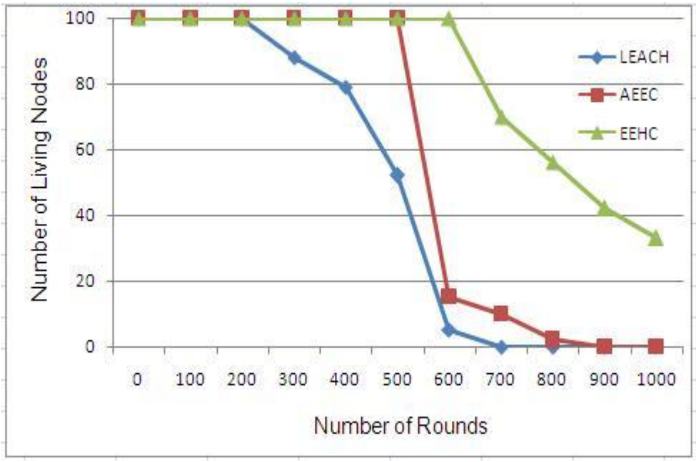

Fig-1: Network lifetime in continuous delivery in small area.

Performance is measured by Average energy dissipation, Network life-time, and the total number of messages delivered successfully. The network lifetime is measured on the total number of rounds until the death of last node. When a node depletes in energy, it is disconnected from the network and it affects the performance of the network. Figure 1 shows the network lifetime of different protocols. The EEHC method is compared with the LEACH and AEEC methods. The figure shows that the lifetime of the proposed EEHC model is longer than the LEACH and AEEC. The death of first node in LEACH and AEEC are prior to 400 and 700 rounds. But the nodes in the EEHC model starts to deplete after 700 rounds. Figure 2 shows that the number nodes depleted their energy very quickly and linearly decreases in LEACH. It leads to the loss of connectivity in the network. The network lifetime of AEEC is same as the small size network. The network size did not make any change in the network lifetime. The number of living nodes in the EEHC is more than the LEACH and AEEC model.

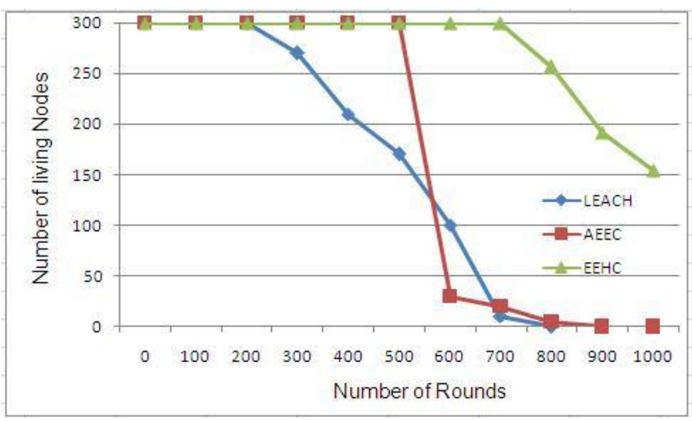

Fig-2: Network lifetime in continuous delivery in large area

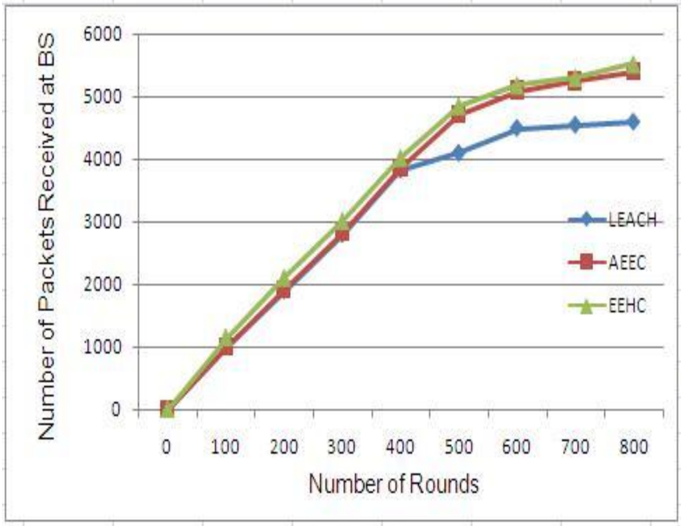

Fig-3: Number of packets received at the BS

Figure 3 shows that the number of packets received by the base station from the cluster head is more in the EEHC than the LEACH and AEEC. The Figure shows the event-driven delivery model in which only 50% of the nodes have sent the data to the sink. The nodes in LEACH and AEEC were depleted their energy at rounds 1100 and 1200 respectively. The EEHC method has life more than 1200 rounds. Our proposed EEHC method has performed better than the LEACH and AEEC approach in terms of longer lifetime.

5. CONCLUSION

In this paper, we proposed energy efficient event-driven wireless sensor networks for improving network lifetime. It utilizes the base station for performing energy related tasks. By using the base station, the sensor nodes are relieved of performing cluster setup, cluster head selection, routing path formation. Performance of the proposed system is assessed by simulation and compared to clustering-based protocols. The simulation results show that our proposed system outperforms its comparatives by uniformly placing cluster heads. It is also observed that the performance gain of the proposed system over its counterparts increases with the area of the sensor field. Therefore, it is concluded that the proposed system improves the network lifetime by minimizing the energy consumption at various levels.

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