Maximization of Lifetime for Wireless Sensor Networks Based on Energy Efficient Clustering Algorithm

Frodouard Minani

Abstract**—**Since last decade, wireless sensor networks (WSNs) have been used in many areas like health care, agriculture, defense, military, disaster hit areas and so on. Wireless Sensor Networks consist of a Base Station (BS) and more number of wireless sensors in order to monitor temperature, pressure, motion in different environment conditions. The key parameter that plays a major role in designing a protocol for Wireless Sensor Networks is energy efficiency which is a scarcest resource of sensor nodes and it determines the lifetime of sensor nodes. Maximizing sensor node's lifetime is an important issue in the design of applications and protocols for Wireless Sensor Networks. Clustering sensor nodes mechanism is an effective topology control approach for helping to achieve the goal of this research. In this paper, the researcher presents an energy efficiency protocol to prolong the network lifetime based on Energy efficient clustering algorithm. The Low Energy Adaptive Clustering Hierarchy (LEACH) is a routing protocol for clusters which is used to lower the energy consumption and also to improve the lifetime of the Wireless Sensor Networks. Maximizing energy dissipation and network lifetime are important matters in the design of applications and protocols for wireless sensor networks. Proposed system is to maximize the lifetime of the Wireless Sensor Networks by choosing the farthest cluster head (CH) instead of the closest CH and forming the cluster by considering the following parameter metrics such as Node's density, residual-energy and distance between clusters (inter-cluster distance). In this paper, comparisons between the proposed protocol and comparative protocols in different scenarios have been done and the simulation results showed that the proposed protocol performs well over other comparative protocols in various scenarios.

Keywords**—**Base station, clustering algorithm, energy efficient, wireless sensor networks.

I. Introduction

Wireless Sensor Networks have recently gained a lot of attention by scientific community and has become a leading area of research. Wireless Sensor Networks are increasingly being adopted in different application scenarios including environmental monitoring, target tracking and biomedical health monitoring. It is a wireless network that consists of base stations (BS) and numbers of nodes (wireless sensors). The service life of each node of WSNs serving as a new self-organizing network is relevant to the life cycle of topology and the entire network because of resource limit, battery power, and other factors, the energy consumption of the network is the core of Wireless Sensor Networks research.

As an effective scheme to save energy consumption of Wireless Sensor Networks, a reasonable clustering routing protocol is generally divided into three phases: cluster setup phase, Cluster Heads election phase, and data transmission phase. In the cluster setup phase, the sensor node groups in the detection area form clusters of different sizes. Based on a certain electoral mechanism, some nodes are selected as the Cluster Heads and the remaining nodes act as the member nodes in the Cluster Heads election phase. Finally, in the data transmission phase, the member nodes are responsible for collecting environmental information and then transmitting it to the CHs. After the aggregation and data fusion, the Cluster Heads send it to the Base Station. The latter transmits it to the control center (CC) via satellite, Internet, or a mobile communication network; eventually the center personnel makes decisions based on current environmental information. Fig. 1 shows a typical Wireless Sensor Network logical hierarchy diagram.

The LEACH protocol is the first protocol of hierarchical routing which proposed data fusion; it is of milestone significance in clustering routing protocol. A numbers of routing protocols have been proposed for Wireless Sensor Networks but most well-known protocols are hierarchical protocols like LEACH. Hierarchical protocols are defined to reduce energy consumption by aggregating data and to reduce the transmissions to the BS [1]. Wireless Sensor Networks consist of sensor nodes equipped with their own battery having limited lifetime, which makes the operations of network available only within a limited amount of time [2]. In Wireless Sensor Network field, various clustering techniques are used such as Hierarchical clustering, Partitioned clustering [3].

The rest of this paper is organized as follows: Section II introduces the related works and summary of identified gaps. Section III proposes a method for determining the optimal number of clusters. Section IV describes the simulation results and analysis of the protocol. Finally, Section V summarizes the conclusion and further works.

II. Related Works

In recent years, researchers in various countries have proposed various kinds of clustering protocols for WSNs. There

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are several classical protocols, such as LEACH [4], [5], SEP (Stable Election Protocol) [6], DEEC (Distributed Energy-Efficient Clustering) [7], and HEED (Hybrid Energy Efficient Distribution) [8]. A new group-based cluster-based hierarchical partitioning scheme that minimizes the number of hops in a cluster is proposed in [9] and a hybrid clustering method combining static and dynamic clustering is proposed in [7].

A Chain Based Cluster Cooperative Protocol (CBCCP) is proposed in [9] and Markov model is considered in [10]. Wang, Q. et al. [11] propose a new network structure model, then according to the original energy consumption model [12], the formula for determining the optimal cluster number of WSNs in the region is proposed. In addition, the proposed protocol introduces some common algorithms, such as ant colony optimization (ACO) [13], [14], particle swarm optimization (PSO) [15], [16], principal component analysis (PCA) [17], harmony search algorithm (HSA) [17], [18].

It is not difficult to find that the protocols have been improved in the following aspects: (1) intra-cluster data transmission path [19], (2) inter-cluster data transmission path, (3) data transmission amount compression [20], (4) implementation of mobile BS or relay node [21], (5) data security consideration [23], (6) increase in the number of sink nodes [17], (7) CHs selection mechanism optimization [22], [23]. As the Wireless Sensor Networks works continuously, the nodes will eventually die due to the continuous loss of energy. The problems faced by energy consumption in WSNs mainly include two aspects: (1) The large total energy consumption; (2) The unbalanced energy consumption. (1) will cause the average energy consumption of the nodes in the network to be too large, resulting in a decline in the overall performance of WSNs. (2) will cause a large difference in the death time of the node groups in WSNs, which will adversely affect the stability of the network and the efficiency of information transmission. From the perspective of efficient energy and balanced energy consumption, this paper proposes an energy-efficient clustering routing protocol in WSNs. The basic premise is as follows: To maximize the total energy consumption of WSNs, the researcher proposes a new network structure model and derives the optimal number of clusters according to the former and the original energy consumption model.

The clusters generated by traditional clustering routing protocols tend to be of different sizes, resulting in unbalanced energy consumption (i.e., the energy consumption of CHs in large clusters is often much larger than that in small clusters.). To alleviate this problem, based on the distance, the variance is introduced to reduce the difference in the distance between the nodes within the clusters in the cluster setup phase. Then in the CHs election phase, we implement the D-CHs division of the energy balance strategy and the node dormancy mechanism for the large cluster area before and after the death of the first node, respectively. In terms of optimal CHs election, we take the position of the node into account apart from the residual energy, which is obviously different from traditional protocols considering only the residual energy.

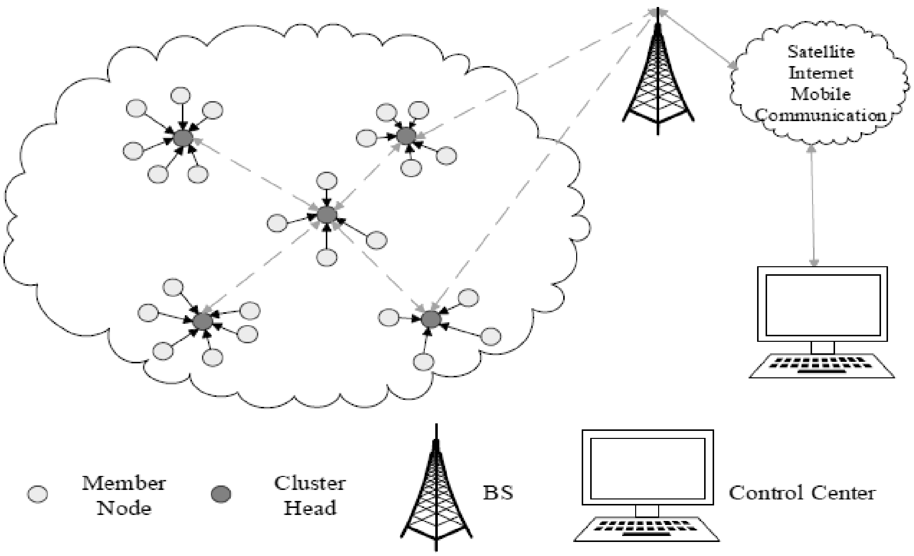

Fig. 1 Typical WSN logical hierarchy diagrams

In [24], the CH is elected based on the value assigned by the weighted factor to the CMs in the cluster. A new cluster formation is started when the value of the original CH drops below a certain threshold. Hierarchical cluster control (HCC) was proposed to improve various parameters in clustering. These are cluster size, connectivity between CHs and cluster joining. However, the entire network must be traversed before it can be computed.

A. Summary of Identified Gaps

The LEACH which is an energy-conserving routing protocol for WSNs and sensor nodes form clusters and the CHs acting as routers to the sink, this has to save energy since the transmissions is only done by CHs rather than all sensor nodes. Because of its probabilistic nature which is not much efficient in cluster formation, it might choose a node as CHs whose remaining energy is not sufficient to sustain the cluster and thus lead nodes dying earlier. The proposed solution improves the LEACH by taking into account the remaining energy of the nodes and comparing with the threshold average energy, but still there is a problem of uniform distribution of CHs within WSNs. There is no way of eliminating the probability factor of the existing algorithm and it has to take into consideration the node-degree, remaining battery level and distance from base-station (BS) as criteria to select node as Cluster Head (CH).

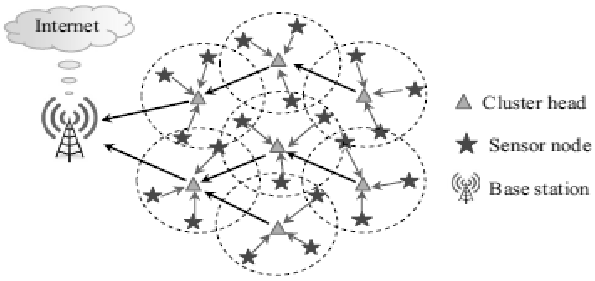

Fig. 2 Wireless Sensor Network model

III. Network Model and Optimal Cluster Number Calculation

A. Network Model

The network model used in this paper is a WSN model in which N sensor nodes are evenly arranged in a circular area of diameter M. The BS in the center of the network area has strong computing power. Because the BS energy can be self-replenished, the energy loss of the BS is not considered in this work. On this basis, we can make the following assumptions about the WSN: (1) all sensor nodes are static, nodes transmit data to each other in single or multiple hops, and the node energy cannot be supplemented. (2) the idealized simulation environment does not consider the influence of natural factors such as temperature, humidity, light, and wind on the sensor nodes.

B. Energy Consumption Model

This paper quotes the energy consumption model proposed in [25]. According to the actual transmission distance from the CHs to the BS, the free space model and the multipath fading channel model both need to be comprehensively analyzed, which is different from [26] considering only the multipath fading channel model. Therefore, the expression of the total energy consumption of the model will undergo some changes.E_T (e,d) indicates the energy consumed by the wireless transmitter to transmit a set of e bits of information. The expression is as follows:

$$E_T(e,d) = \begin{cases} e \times \left(E_{elec} + \varepsilon_{fs} d^2\right), & d < d_0 \\ e \times \left(E_{elec} + \varepsilon_{mp} d^4\right), & d \geq d_0 \end{cases} \quad (1)$$

E_R(e) indicates the energy required to receive the information of the e bit. The expression is as follows:

$$E_R(e) = e \times E_{elec} \ . \quad (2)$$

In (1) and (2), E_{elec} is the energy consumed per bit by the transmitter or receiving circuit and d is the distance between the transmitter and the receiver. In (2), when d < d_0, we use the free space model and ε_{fs} acts as the energy factor per bit. Otherwise, the multipath fading channel model is used, and ε_{mp} acts as the energy factor per bit. In addition, d0 is used as the distance threshold. As long as it is input as an independent variable into the free space model and the multipath fading channel model to establish an equation, the following expression can be obtained:

$$\mathrm{d0} = \sqrt{\frac{\varepsilon \mathrm{fs}}{\varepsilon \mathrm{mp}}}. \quad (3)$$

In each round of data transmission, the cluster member nodes are responsible for sensing information from the environment, then transmitting it to the CH of the corresponding cluster. Therefore, the calculation formula for the energy consumed by transmitting *e* bit information is defined as follows:

$$E_{non-CH} = e \cdot E_{elec} + e \cdot \varepsilon_{fs} d_{toCH}^2 \quad (4)$$

In (4), dtoCH represents the distance from the cluster member node to the CH. The CH receives information from the cluster member nodes in the cluster, then fuses the information with that which it senses from the environment, eventually transmits the merged information to the BS. In this paper, we assume that in each round of data transmission, the information size obtained after processing by the CH is *e* bit. The energy consumed in the process is calculated as follows:

$$E_{CH} = (\frac{n}{k} - 1) \cdot e \cdot E_{elec} + \frac{n}{k} \cdot e \cdot E_{DA} + e \cdot E_{elec} + \begin{cases} e\varepsilon_{fs} d_{toBS}^2, & d_{toBS} < d_0 \\ e\varepsilon_{mp} d_{toBS}^4, & d_{toBS} \geq d_0 \end{cases} \quad (5)$$

In (5) the energy consumed consists of three parts: receiving energy consumption, processing energy consumption, and transmitting energy consumption. In (5), n is the number of nodes surviving in the monitored area, k is the number of clusters to be divided, E_{DA} is the energy consumed by the CH to process each bit of data (including received data and sensed data), and dtoBS is the distance between the CH and the BS.

C. Optimal Number of Clusters

In general, the inter-cluster communication traffic in WSNs increases as the number of clusters increases, and the intra-cluster communication traffic increases as the number of clusters decreases. In addition, the network's energy consumption increases as communication traffic increases. The determination of the optimal cluster number of the network is of great significance to the network's communication. In this section, the researcher determines the optimal number of clusters k in combination with the network structure model and energy consumption model. The monitoring area in this paper is a circle with a diameter of M. In real life, the cluster areas of Wireless Sensor Networks must be irregular and inconsistent, and the nodes are randomly placed. To derive the optimal number of clusters more intuitively, we construct an inline square in the circular region with a side length of L. The researcher assumes that the clusters in the square are all circular in shape with a radius of R and the cluster distribution is uniformly distributed. Finally, after calculating the total circular cluster area and the spherical area to establish the relationship, we can obtain the relationship between the total number of clusters k and the number of circular clusters k1. As shown in Fig. 3, the monitoring area in this paper is a large circle with a diameter of M and the length of the embedded square is L. From this, we can derive the relationship between L and M:

$$L = \sqrt{2}M/2 \tag{6}$$

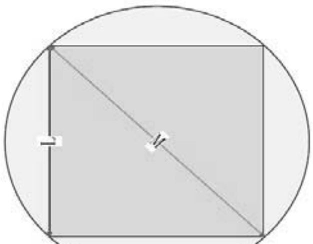

Fig. 3 Monitoring area

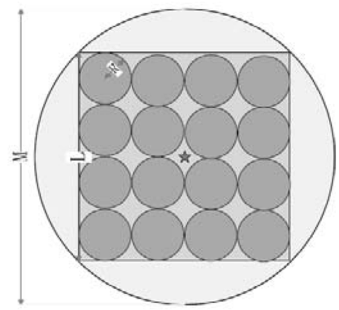

Fig. 4 Network structure model diagram (16 clusters)

After the sensor network is divided into many clusters, the CH receives the information transmitted by the cluster member nodes, and after processing, eventually transmits it to the BS for final data fusion. In the intra-cluster communication, as the distance between the cluster member node and the CH is not large, we adopt the free space model. To understand the network structure model more intuitively, Fig. 4 shows an example dividing the cluster into 16 clusters. In the Fig. 4, the positive center position of the monitoring area is the BS indicated by ✦. A blue circle indicates a cluster. Consequently, we can obtain the expression of the blue cluster number k_1 as follows:

$$k_1 = \frac{M^2}{8R^2} \tag{7}$$

The optimal number of clusters can be obtained by the following relations:

$$k = \sqrt{\frac{M^2 n\varepsilon_{fs}}{8A}} \tag{8}$$

IV. Results and Analysis

A. Simulation Parameters

The performance analysis of the proposed method is done with the help of NS-2.35. In the network, 100 nodes are organized in random fashion in 100m×100m area where BS is situated in network region. The performance assessment of proposed work is done as per the certain parameters given as: Energy consumption: total energy used by the entire nodes in their intra-cluster and inter- cluster activities; Number of alive nodes: quantity of nodes that have not so far exhausted their power; Packet delivery ratio: ratio of actual packet delivered to total packet sent; End to End delay: time utilized for message to be communicated transversely in network from source to destination. Throughput: quantity of packets per bytes received by source per unit time. The proposed algorithm is evaluated with LEACH, LEACH-C, in term of alive nodes over rounds, packet delivery ratio, energy expenditure, end-to-end delay, throughput. The total rounds used in experiment are 500. The simulation parameters are summarized in Table I.

TABLE I
Network Parameters

Parameter	Value
Nodes	100
Network size (m^2)	100 x 100
Initial energy E_0(J)	2
Base Station position	50,100
Scenario size (m^2)	200 x 200
E_{elec}(nJ/bit)	5
E_{TX}=E_{RX} (nJ/bit)	50
ε_{fs} (pJ/bits/m^2)	10
ε_{mp}(pJ/bits/m^4)	0.0013
E_{DA} (nJ/bit)	5
Packet size (bytes)	500
No. of CHs	5
No. of rounds	500

s = second, m = meter, J = joule, bit= bite, n=nano, p=pico.

Fig. 5 shows the comparative analysis of energy consumption of the proposed algorithm with LEACH along with LEACH-C and it is clear that our algorithm has better energy usage in comparison to LEACH and LEACH-C. Fig. 4 demonstrates Network structure model diagram (with 16 clusters). Figs. 5 and 6 illustrate Energy consumption over rounds and Number of nodes alive over rounds respectively. Figs. 7-9 illustrate Packet delivery ratio over rounds (PDR), the End-to-End delay over rounds and the throughput respectively demonstrating the efficiency of the network.

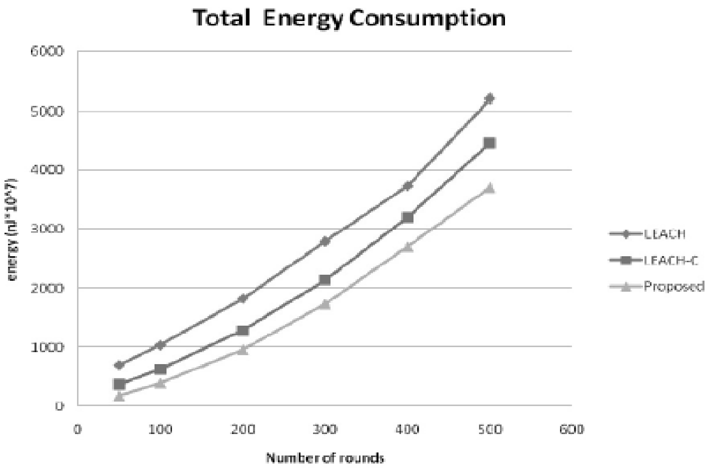

Fig. 5 Energy consumption over rounds

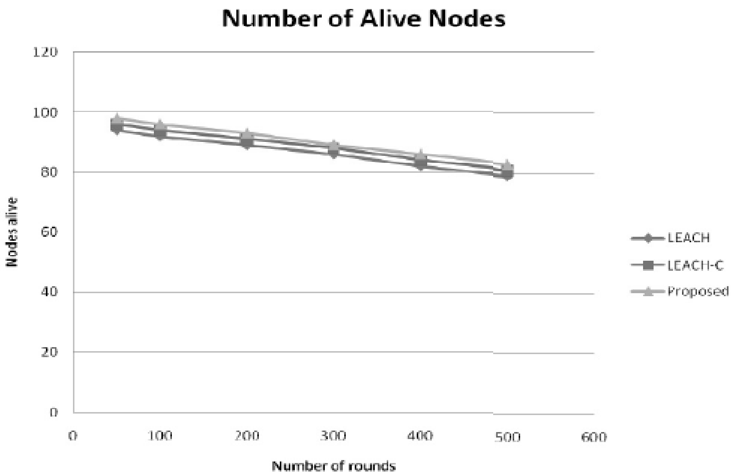

Fig. 6 Number of nodes alive over rounds

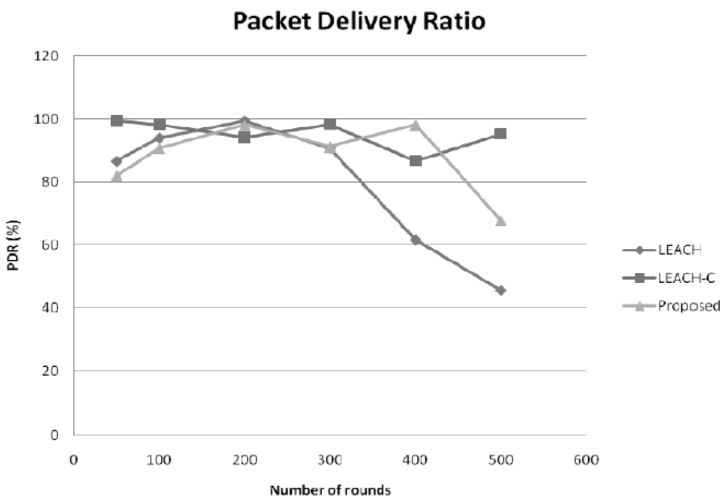

Fig. 7 Packet delivery ratio over rounds

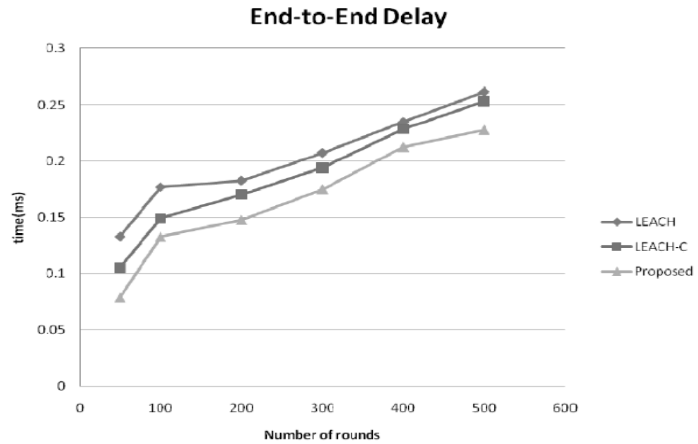

Fig. 8 End-to-End delay over rounds

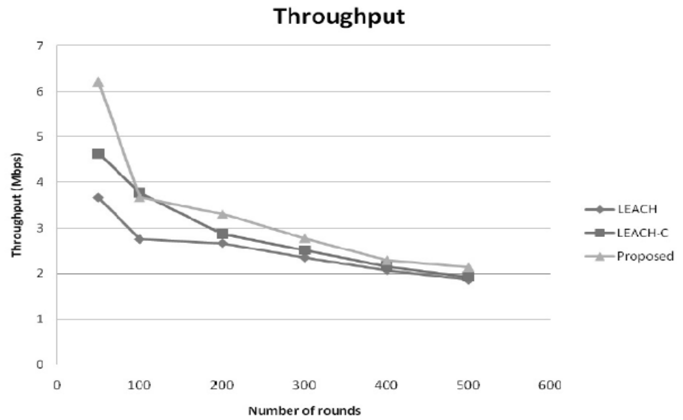

Fig. 9 Throughput over rounds

V. Conclusion

In wireless sensor networks, power consumption is an important aspect for network lifetime. Clustering is also an effective technique that can participate to entire system lifetime, scalability, and energy efficiency in WSNs. The model result shows that the remaining energy of the sensor network and the number of dead nodes after 500 rounds in 100*100 environment using NS-2.3.5 is increasing. The LEACH protocol is a very effective protocol that enhances the network lifetime. The proposed protocol increases sensor lifetime, throughput, and the delivery packet ratio and decreases both the packet delay and the sensors power consumption. Experimental results have shown that the proposed algorithm behaves better than LEACH and LEACH-C on WSNs for long system lifetime. The Cluster Head selection considers the residual energy of the node, distance of the node from the Base Station and the number of rounds in which the node has not become Cluster Head and the node-degree which results in the minimization of energy consumption in the Wireless Sensor Networks.

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