A Consistent Approach Towards Clustering in Low Energy Adaptive Clustering Hierarchy Protocol

Asma Rafiq*, **Ehsan Ullah Munir***, **M. Mustafa Rafique**†, **Samee U. Khan**Ψ
*Department Of Computer Science, COMSATS Institute of Information Technology, Wah Cantt, Pakistan
†IBM Research, Ireland
ΨNorth Dakota State University, USA
asmabasit@ciitwah.edu.pk; ehsanmunir@comsats.edu.pk; mustafa.rafique@ie.ibm.com; samee.khan@ndsu.edu

***Abstract*—Wireless Sensor Networks (WSNs) facilitate efficient and reliable monitoring of specified area for multiple applications. Variety of protocols are designed to increase the effectiveness and lifetime of WSNs. Low Energy Adaptive Clustering Hierarchy (LEACH) protocol is one of them. LEACH is a hierarchical clustering based protocol where data is transferred to the data evaluation center through an intermediary node i.e., cluster head (CH). Cluster heads (CHs) consume much more energy than normal sensor nodes which requires CH's job to be rotated among all the nodes. CHs are chosen randomly with a predefined probability of fixed update intervals (round) to preserve energy of each node and to increase the lifetime of the whole network. In this paper, we propose an enhancement to the LEACH protocol. The clustering mechanism in LEACH protocol is not efficient to endorse optimal number of CHs. The proposed clustering algorithm selects nearly equal number of CHs in each round to evenly distribute the energy dissipation and therefore delays node failures and increases the network lifetime.**

Keywords—Sensor networks; distributed algorithm; clustering protocol; energy efficient routing; LEACH

I. Introduction

Wireless sensor networks (WSNs) are extremely beneficial in numerous critical usages [1], such as monitoring of environmental changes, traffic flow, battlefield surveillance, and smart offices. WSNs help to gather real time information from physical surroundings. A typical wireless sensor network (WSN) consists of various tiny sensor devices with limited battery power that are deployed randomly in a specified area. These tiny devices have some basic components, such as power units, sensing units, processing units and communication units, i.e., transmitters and receivers. A basic structure of a sensor node is shown in Fig. 1. The sensor nodes help to collect real time information or data, such as humidity level, air pressure, heat index, or any kind of chemical saturation in the surrounding environment. This data is later interpreted and analyzed at the base station (BS) called sink.

Since, sensor nodes are highly vulnerable to the loss of energy and connectivity due to their exposure to the dynamic environment, routing protocols play a vital role in wireless sensor networks. To this end, various energy efficient and robust protocols, including centralized and distributed protocols for homogeneous and heterogeneous networks, have been proposed for WSNs. Centralized protocols are operable only with the help of complete knowledge of the whole network, while distributed protocols execute on each node and thus make WSNs more robust and resilient to network failures. Some of these routing protocols are Low Energy Adaptive Clustering Hierarchy (LEACH) [2], Power-Efficient Gathering in Sensor Information System (PEGASIS) [3], Hybrid Energy-Efficient Distributed Clustering (HEED) [4], Stable Election Protocol (SEP) [5] and Distributed Energy-Efficient Clustering (DEEC) [6]. LEACH, PEGASIS, and HEED are designed for homogeneous networks. Whereas, SEP and DEEC are designed for heterogeneous networks.

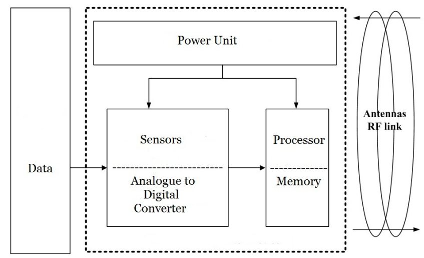


Fig. 1: Basic structure of a wireless sensor node.

Most of these protocols work on the clustering algorithm. In clustering algorithms, normal sensor nodes transfer data to the base station (BS) through a cluster-head (CH). It comparatively adds more energy consumption at the end of cluster head in the process of data aggregation and transmission to sink. It is therefore suggested to rotate the cluster-head (CH) after fixed intervals of time among all nodes to increase the network lifetime. In LEACH, certain clustering algorithm is used to select the cluster-heads (CHs) with a predefined probability to evenly divide the cluster heads (CHs). However, heterogeneous-aware algorithms, e.g., DEEC and SEP selects the CHs on the basis of their residual energy. The nodes with more residual energy will have higher chances to become the CH than the nodes with less energy. In SEP [7], [8], advanced nodes with additional energy by the factor of $(1+\propto)$ become CH more frequently than the normal nodes to enhance the lifetime of the whole network.

We propose a consistent clustering algorithm to minimize the energy consumed by all nodes while transferring data from CH to BS in energy-constraint WSNs, which prolongs the lifetime of the whole network. In this paper, we propose an enhancement to an algorithm LEACH with an objective to make it more consistent while choosing the number of CHs as specified in its algorithm. The consistent distribution of clustering responsibility among all the sensor nodes of the WSN helps in minimizing the energy dissipation of each node.

The rest of this paper is organized as follow. Section II discusses the related work. Section III describes the clustering mechanism of LEACH protocol. Section IV presents the problem statement. Section V presents the proposed solution, and its performance is evaluated in Section VI. Finally, Section VII concludes this paper.

II. Related Work

Most of the existing research on WSNs focus on the selection of CHs and its cluster nodes and clustering is one of the widely used methods in this regard. Clustering algorithms are broadly divided into two categories, i.e., centralized clustering algorithm and distributed clustering algorithm for homogeneous and heterogeneous [1], [9] networks.

An algorithm is proposed in [10] to decrease the overall energy consumption for the communication between sensors and the information processing center i.e., BS with a hierarchical design of clusters nodes. Similarly, a recent effort [11] proposes two distributed spanning tree-based data gathering algorithms namely, Link Expiration Time-based Data Gathering (LET-DG) and energy-efficient Minimum-Distance Spanning Tree based Data Gathering (MST-DG). The LET-DG trees show more endurance and exhibit considerably low delay in each round but with higher throughput per tree. In the MST-DG trees first node failure is observed after significantly longer time than that of the LET-DG trees due to the larger height of their tree and small number of leaf nodes. It consequently adds significantly longer delay in each round. Frequent tree reconfigurations in MST-DG tree and its larger depth consumes almost the same amount of energy, therefore complete node failure occurs at the same time.

LEACH [2] is one of the well-known protocols suggested for distributed clustering of homogeneous WSNs. It successfully distributes the energy among the sensors by randomly rotating the CHs. Several improvements [12], [13] to the basic LEACH protocol has been proposed. An analytical model [13] elaborates the idea of estimating the energy and data loss with a proper update interval and explains the effect of sensors mobility on the LEACH protocol. Several research efforts have investigated the process of CH selection particularly in LEACH protocol. In [14], the mechanism of the cluster formation is investigated. It proposes two algorithms, namely Centralized Energy Efficient Clustering (CEEC) and Advanced heterogeneity-aware CEEC (ACEEC) for three layered network model, which are created with three types of sensor nodes where each layer contains same type of sensor nodes. The two algorithms, (CEEC) and (ACEEC), work at the BS and select separate CHs from each layer which communicate with their respective cluster nodes, consequently increase the network lifetime. Similarly in [15], a protocol named Fuzzy Logic Cluster Formation Protocol (FLCFP) is proposed. It suggests that the use of multiple parameters reduces the energy consumption during clusters formation.

Clustering algorithm is a key technique used to reduce the energy consumption and to increase the network life-time with an objective of optimized utilization of network resources. [16] proposes to divide the network into four quadrants to acquire better clustering among the nodes that usually are deployed at far places to acquire better network coverage. Most of the energy dissipation occurs during constant and fault tolerant monitoring. Quadrature-LEACH significantly enhances network stability period, network life-time and throughput. Protocol proposed in [6] works with the same objective but selects its CH based on its initial and residual energy. Technique proposed in [5] increases stability period of the network by maintaining energy consumption with the help of determining an addition energy factor for advanced nodes. These two algorithms, i.e., DEEC and SEP are applied to heterogeneous networks.

The LEACH protocol uses the user specified probability with the threshold function to determine which node should be the CH in each round. In [17], a genetic algorithm is proposed to determine the optimal threshold probability for cluster formation in WSNs. LEACH-GA, before the setup phase, gathers complete information about nodes status in a separate preparation phase to determine the best threshold probability for clustering .

The optimum probability for selecting correct number of CH is very critical to the network performance. To this end, in this paper we propose an enhancement to the LEACH protocol. Our proposed algorithm not only selects the CHs according to the specified optimum threshold probability but applies only on the dynamically calculated number of nodes alive in each round. The conventional LEACH protocol randomly selects the CHs which makes it very difficult to obtain a correct number of CHs every time as per specified by the threshold probability. Certain checks of our algorithm have eliminated this inadequacy. Hence, our approach produces comparatively more consistent results than the conventional LEACH protocol.

III. Clustering Mechanism of Conventional LEACH Protocol

Clustering is a popular technique used by many protocols designed particularly for WSNs. LEACH also leverages a dynamic clustering technique. In this technique, equal update intervals, usually called rounds, are demarcated. Each round consists of two phases, i.e., a setup phase and a steady-state phase. Setup phase selects the CH. Clustering trails with a predefined probability. Each sensor node takes decision independently whether it will become a CH or not. Sensor nodes take this decision by comparing a randomly picked number between 0 to 1 and threshold $T(n)$ based on a user-defined probability p in each round.

$$T_n = \begin{cases} \frac{p}{1-p(r \ mod \ 1/p)}, & n \in G \\ 0, \quad otherwise \end{cases} \tag{1}$$

Here, p is the user-defined probability, r is the current round, and n is the number of nodes belongs to the set G, available for clustering. After the CHs are selected, they broadcast messages to their neighbors. After receiving these messages other sensor nodes join a nearest CH and become part of that particular cluster. Later a steady-state phase is executed. All the sensor nodes transfer their collected information to their CHs according to a pre-defined Time Division Multiple Access (TDMA) time slot. At the start of this time slot, normal cluster nodes send their sensed data to their CH. The CH aggregates, compresses, and sends the data towards the BS, usually called sink. Once the update interval finishes, the entire procedure to ensure that the job of CHs and clusters are kept on rotating.

A normal sensor node transmits the sensed data to its CH, which aggregates the received data and then transmits it to the sink. Therefore, CHs consume extra energy in this process. If E_{Ch}, the total energy disbursed by a CH for sending the data to the sink node, is equal to $E_{Rx} + E_{Ag} + E_{Tx}$, where E_{Rx} and E_{Tx} represent energy disbursed by a CH for receiving and transmitting respectively, and E_{Ag} represents the energy dissipation during data aggregation, then for a normal sensor node, its energy consumption E_S is equal to E_{Tx}. Therefore, the rotation of CHs dissipates energy more evenly across all sensors, consequently increasing the network life.

IV. Problem Statement

WSN consists of tiny energy constrained sensor nodes and the existing routing protocols for WSNs based on clustering techniques are designed to minimize energy dissipation of sensor nodes to increase the network lifetime. Considering the clustering mechanism, the value of p is critical to the network performance. A large p forms larger number of clusters and consumes more energy and a smaller p forms lesser number of clusters and decreases energy dissipation. It is proposed [13] that $p = 0.1$ is the optimal value, however it is challenging to obtain a correct number of CHs every time as per specified by the threshold probability because the conventional algorithm randomly selects CHs which increases the chances of deviation from the required outcome especially when large number of sensor nodes are dead.

Consider $N = 1, 2, 3, 4, ..., n$ is the set of sensor nodes. Similarly $A = \{a_1, a_2, ..., a_n\}$ and $D = \{d_1, d_2, ..., d_n\}$ are the sets of alive and dead nodes respectively. $p = 0.1$ is the pre-defined probability to the set of nodes N_{int} with the purpose to elect 10% of sensor nodes as CHs. This process is repeated after every round where $r = r_1, r_2, ..., r_{max}$. Assume that after the failure of half of the nodes when $r = r_S$, and $N = N_{hlf}$, the LEACH protocol will still apply threshold probability on the total number of nodes available initially, i.e.,

$$CH \approx p*(N_{int}) \tag{2}$$

Since half of the nodes are dead and $N_{int} \neq N_{hlf}$ and $N_{hlf} = N_{int} - D$, where D is the number of dead nodes. The conventional algorithm does not recognize this difference, and the number of CHs selected differs from the required percentage. Moreover, CHs are selected randomly depending on the predefined threshold probability which led to different number of CHs in every round. There is no method defined to restrict the CHs to the optimal number.

V. Enhanced Clustering Mechanism

The basic idea of setting threshold probability is to define an optimal number of CHs for even distribution of energy dissipation to minimize the chances of early node decay. Our algorithm enhances the conventional LEACH algorithm by not electing the CHs with a same specification of the network till the end. Instead, clustering begins by recognizing the current number of nodes alive in order to identify network requirements before choosing the CHs.

A. Proposed Consistent Clustering

Unlike the clustering mechanism of conventional LEACH protocol, our algorithm first count the number of alive nodes then estimates the desired number of CHs in each round i.e.,

$$CHs \approx p*(\ N_{int}\ -\ D) \tag{3}$$

Once the desired number of CHs are estimated, it selects the correct number of CHs in accordance with the current

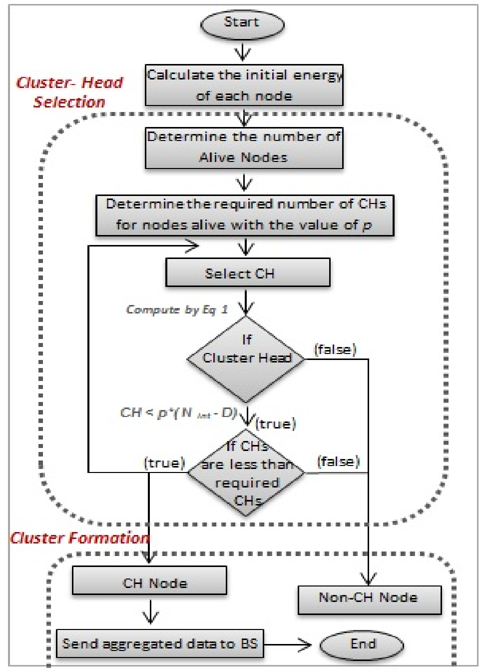


Fig. 2: Consistent clustering mechanism for CH selection.

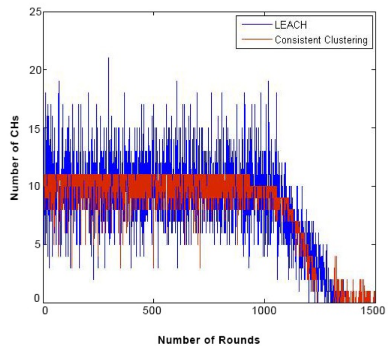
status of network in each round as shown in Fig. 2. The complete CH selection algorithm is provided in Algorithm 1.

Tracking dead nodes helps to avoid extra energy dissipation at each sensor node and improves the overall network performance. It eliminates the chances of electing more CHs than the desired number. As shown in Eq. (2) and Eq. (3), CHs consume more energy than normal nodes. Here, the energy dissipates by a CH is equal to the transmitting energy E_{Tx}, receiving energy E_{Rx}, and the energy dissipates in the process of data aggregation E_{Ag}. E_{Tx} for transmitting m bits of data over the distance d is $m[E_{Tx} + (efs \times d)]$ where efs is amplifying power, which varies with the distance between the two transmitting nodes. It is equal to efs if $d < d_s$ and emp if

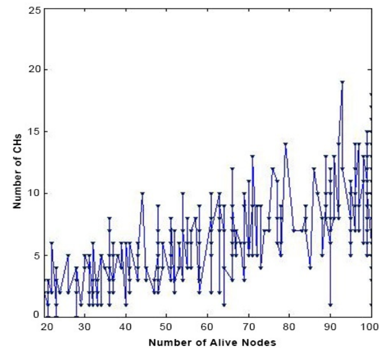
Algorithm 1: Consistent Clustering

Input: Probability p, number of Nodes N_{int}, Maximum Rounds r_{max}, Dead Nodes D, Cluster Heads Ch

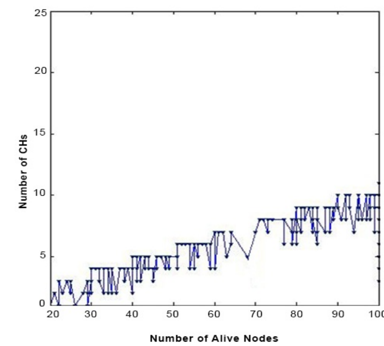
Calculate the initial energy of every node E_n
Determine the number of required CHs for network using the value of probability, $p = 0.1$
for $Ch \leq p(N_{int} - D)$ **do**
    `// Repeat twice`
    for N_{int} **do**
        `// Repeat for all nodes`
        if *($E_n > 0$ AND mod(r, round$(1/p)) \neq 0$)* **then**
            $temp = random\_number$
            $T(n) = p/(1 - p(r \ mod(1/p)))$
            if *($temp \leq T_{(n)}$)* **then**
                if *($Ch \leq p(N_{int} - D)$)* **then**
                    $Ch = Ch + 1$
                end if
                Compute E_n again
            end if
        end if
    end for
end for



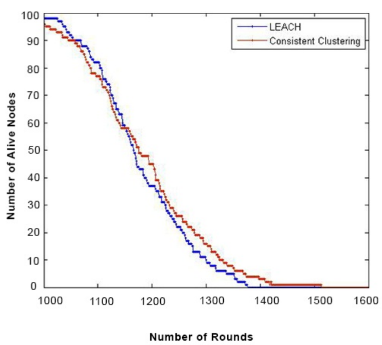
(a) Number of CHs against Rounds in LEACH and Consistent Clustering



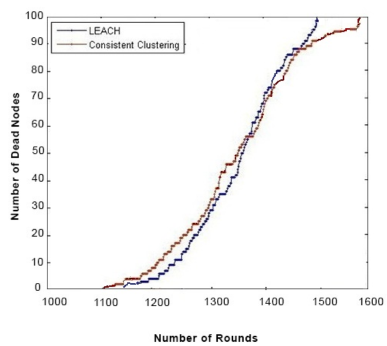
(b) Number of CHs against Alive Nodes in LEACH



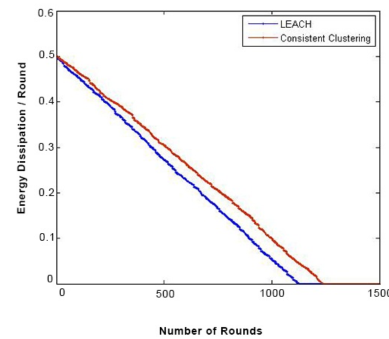
(c) Number of CHs against Alive Nodes in Consistent Clustering



(d) Number of nodes alive against increasing number of rounds



(e) Number of dead nodes against increasing number of rounds



(f) Overall energy dissipation in each round

Fig. 3: Network performance comparison between LEACH and Consistent Clustering protocols in homogeneous network.

$d > d_s$. Similarly, E_{Rx} and E_{Ag} are equal to $m[E_{Rx}(q-1)]$ and $m[E_{Ag}(q)]$ respectively. Here q is the total number of cluster nodes in a cluster formed which can be calculated as n/k, where, n is the total sensor nodes and k is the number of clusters formed. For E_{Rx}, q is $(n/k)-1$ and for E_{Ag}, q is n/k. If $d < d_s$, then:

$$E_{Ch} = m[E_{Rx}(q-1)]+m[E_{Ag}(q)]+m[E_{Tx}+(efs\times d)] \quad (4)$$

Similarly, if $d > d_s$, then:

$$E_{Ch} = m[E_{Rx}(q-1)]+m[E_{Ag}(q)]+m[E_{Tx}+(emp\times d)] \quad (5)$$

As the cluster nodes join its nearest CH, so d is assumed to be less than d_s. Considering the same factors for normal sensor nodes, E_S will be equal to:

$$E_S = m[E_{Tx} + (efs \times d)] \quad (6)$$

B. Complexity Analysis of Proposed Consistent Clustering

As shown in Algorithm 1, the set of if-else conditions within inner loop consume constant time. The outer loop runs twice and executes the inner loop O(2N) times. Therefore, the time complexity of the proposed consistent clustering algorithm is $O(N)$.

VI. Performance Evaluation

We evaluate the proposed approach in a simulation setup with the homogeneous nodes that are randomly distributed over an area of 100×100 sensor field. Total number of nodes is 100. We use similar parameter values used for LEACH protocol for evaluating our algorithm for homogeneous network as shown in Table I. The initial energy of 10% of the total sensors nodes are kept larger than normal nodes for heterogeneous networks.

A. Performance Evaluation Using Homogeneous Network

We evaluate the proposed consistent clustering algorithm against conventional LEACH using homogeneous normal sensors nodes. All nodes are positioned at a fixed point with no mobility built to work for single application. We evaluate the performance of both algorithms and show the result in Fig. 3.

The consistent clustering dynamically applies the threshold probability on the number of alive nodes in each round and makes the process of CH selection more consistent as shown in Fig. 3(a). The LEACH algorithm selects larger number of CHs even with less number of nodes alive as shown in Fig. 3(b) but the consistent clustering iteratively calculates the dead nodes and applies the predefined threshold probability only to the

TABLE I: General Values used for Different Parameter in Leach Protocol

Parameter	Value
Probability	0.1
Initial Energy(Each Node)	0.5J
Receiving Energy (E_{Rx} /bit)	0.5nJ/bit
Transmittinging Energy (E_{Tx} /bit)	0.5nJ/bit
Amplifier (efs)	10 pJ /bit /m_2
Amplifier (emp)	0.0013 pJ /bit /m_4

TABLE II: Cluster Head Fluctuation for Consistent Clustering and LEACH in Homogeneous Network

Number of Nodes Alive	CHs (LEACH)	CHs (Consistent Clustering)
100	1 - 21	9 - 11
90	1 - 20	9 - 10
80	3 - 15	7 - 9
70	2 - 14	6 - 8
60	1 - 13	5 - 7
50	1 - 11	4 - 6
40	1 - 12	3 - 5
30	1 - 6	2 - 4
20	1 - 6	1 - 3
10	1 - 5	1 - 2

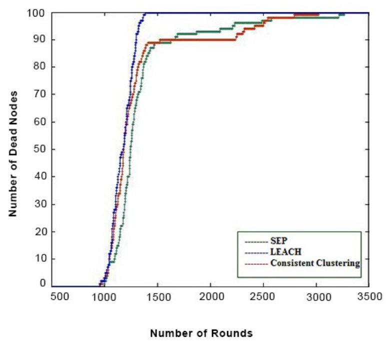


Fig. 4: Network lifetime comparison between LEACH, SEP and Consistent Clustering in heterogeneous network.

alive nodes. Thus, selects CHs in accordance with the current requirement as illustrated in Fig. 3(c). It is more evident from the comprehension comparison of CHs fluctuation for LEACH and the consistent clustering with decreasing number of alive nodes as shown in Table II.

It is obvious that consistent clustering distributes the energy evenly among all the nodes. Fig. 3(d) shows the number of nodes alive per round. Though the first node dies a bit earlier but the frequency of nodes dying decreases with the increasing number of rounds with the proposed consistent clustering algorithm as compared to the LEACH. Similarly, Fig. 3(e) shows the number of dead nodes per round. The consistent approach towards clustering also facilitates less energy consumption as shown in Fig. 3(f).

B. Performance Evaluation Using Heterogeneous Network

LEACH protocol is not designed for heterogeneous networks where network nodes vary in communication range, initial energy or the application of the sensor nodes. The heterogeneous-aware SEP protocol [9] prolongs the stability of network with increased energy of the system by $(1+\propto)*m$ times where m is the percentage of advanced nodes and $\propto$ is the additional energy of advance nodes. SEP maintains the energy consumption among normal and advance nodes thus increases the network lifetime. We compare our proposed algorithm with SEP and LEACH protocols in a heterogeneous environment using $m = 0.1$ and $\propto = 1$ and show the result in Fig. 4. LEACH does not perform well in heterogeneous environment as compared to SEP. The performance of the consistent clustering is better than both of these algorithms. The consistent clustering produces results near to SEP but shows better network lifetime than SEP.

VII. Conclusion

In this paper we have proposed a consistent cluster protocol that is an extension of LEACH protocol. LEACH algorithm uses a fixed user defined threshold during network lifetime without considering the actual alive nodes. It ignores the current status of the network in the process of cluster heads (CHs) selection which may result in suboptimal outcome. The consistent clustering begins by recognizing the current number of alive nodes before choosing CHs then estimates the desired number of CHs in each round. Our evaluation shows that the proposed clustering approach elects the optimal number of CHs and prolongs the network lifetime by significantly decreasing the energy dissipation in each round.

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