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Constrained Clustering Approach in Wireless Sensor Networks to Minimize the Energy Consumption

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***Abstract*— The applications of Wireless Sensor Networks (WSNs) are massive in the range that starts from the defense, civil, military to our day to day routine life. Energy conservation in WSNs is a crucial issue to make the network operational for a long time. It is entirely worth noting that most of the energy consumption occurs during the data transmission. Routing protocol plays a significant role in carrying and forwarding the data to the destination. Clustering is one such branch of routing technique that increases the Network Lifetime unexpectedly through minimal energy consumption. In this regard, this research paper aims to formulate an exciting clustering problem in WSNs where the coordinates of patterns are random variables. The clustering problem is solved using the CENTROID approach, such as Cluster Head (CH) selection is done with an optimization interpretation. The proposed protocol is verified through the ns-2 simulator, and the results obtained from the simulations show that the proposed constrained clustering LEACH (CC-LEACH) offers its superiority over the existing protocols such as LEACH and LEACH-C in terms of various performance parameters.**

***Index Terms*—WSN, Mobility, Clustering, Hessian Matrix**

I. INTRODUCTION

In the research area of pattern recognition, data mining, and many other human endeavor fields, pattern vectors are grouped into classes based on the proximity of metrics. Various clustering algorithms, such as the fuzzy clustering algorithm, grid-based algorithm, k-means algorithm, and many more, have been proposed in the current literature. These algorithms are found to be of practical utility in clustering under the unsupervised learning algorithm (commonly employed for classification problems). There has been extensive research effort on developing the communication protocols in WSNs in the last few years. As WSNs operate in hazardous environments, the replacement/recharging of battery in the sensor field is not possible in many practical applications. Thus, the strategy of the protocols/algorithms in such networks must be energy-aware. Clustering is the most popular technique in a hierarchical system consisting of hundreds or thousands of sensor nodes. Instead of each node sending the data to the base station, only cluster head (CH) can transmit and receive the data to the base station, which reduces energy utilization and increases the network lifetime. LEACH and other energy-efficient protocols select the CH by exchanging the hello messages among each other within a cluster ensuring that cluster head is placed at the centroid (that happens by minimizing the squared distances from centroid/CH to sensor nodes in a cluster). The research work discussed in [1] uses inter clustering to transmit the data from one CH to another CH until it reaches the base station. The research in [2] [3] discusses Cluster Based Topology (CBT), where clustering is widely used in a static and mobile environment to perform various tasks in different applications. The author in [4] discusses the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol as one of the oldest hierarchical routing protocols in which the sensor nodes communicate within its cluster. The work in [5] proposes a modified LEACH protocol called Low Energy Adaptive Clustering Hierarchy Centralized (LEACH-C), where the BS executes the clustering process in a centralized manner to minimize energy consumption. Hybrid Energy-Efficient Distributed Clustering (HEED) protocol [6] presents a CH selection procedure by considering node degree, residual energy, and relative distance. The elected CH is found to be more realistic and more energy-aware. The research works in [7-20] discuss many potential clustering techniques to make the sensor networks energy efficient.

Despite intensive research efforts on clustered-based routing in WSNs, a question remained unanswered is the interpretation of CENTROID computation. In this research paper, we address and solve the problem of the optimization interpretation of CENTROID. We also address and solve an interesting, constrained clustering problem. Further, we consider the case where the components of pattern vectors contain random variables. With such random pattern vectors, we formulate and solve the clustering problem of potential practical interest. This research paper focuses on the quadratic optimization problem to select the CH by considering the distance between the sensors and many other factors. The cluster head is determined to be CENTROID of sensor position coordinates. As far as our knowledge is concerned, the derivation of CENTROID patterns is an exciting optimization problem and is not addressed in the literature.

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The remaining part of the paper is arranged as follows. In Section II, we derive an interpretation of optimization CENTROID technique using Euclidean distances from patter vectors and consider random pattern vectors that solve an interesting clustering problem (i.e., we endow the CENTROID with an optimization interpretation). In section III, we have explored the implications of results. Section IV concludes the paper.

II. PROPOSED HEURISTIC (THEORETICAL PROOF)

In this section, we have discussed the placement of sensor nodes and the position of cluster heads theoretically. The initial deployment of sensors in a sensor field, cluster heads are placed at the centroid, i.e., we give the importance of cluster reconfiguration. Two types of deployment scenarios are possible.

A) Random deployment

B) Planned deployment

In both Random and Planned deployment, the position of CH at centroid can be derived by articulating and cracking an optimization problem.

A) Constrained Clustering: Random Sensor Deployment

Assumption: Let the sensor nodes are deployed in a sensor network randomly {i.e. the spatial position coordinates of X (X_1, X_2, and X_3) are random variables}. To simplify the derivation, let N data points in M-dimensional pattern space such that we can derive M-dimensional random vectors. (i.e., elements of these vectors are random variables).

$$X_1, X_2 \ldots X_N \text{ with } X_j=[x_{j1}, x_{j2}, \ldots, x_{jm}] \text{ for } 1 \le j \le N \quad (1)$$

Consider X_0 be the preferred centroid i.e., $X_0 = [x_{01}, x_{02} \ldots x_{0m}]$ and $EX_0 = [\tilde{x}_{01}, \tilde{x}_{02}, \ldots, \tilde{x}_{om}]$. The problem occurs to compute the mean values $\{\tilde{x}_{0i}$ *one* $\le i \le m\}$ (i.e., compute EX_0 mean centroid vector in such a way that the mean value of the square of Euclidean distances from it to pattern vectors are decreased).

Hence, the objective function can derived as

$$J(X_0) = J[\tilde{x}_{01}, \tilde{x}_{02}, \ldots, \tilde{x}_{om}] = E[\textstyle\sum_{j=1}^{N} \sum_{i=1}^{m} [x_{ji} - \tilde{x}_{0i}]^2] \quad (2)$$

We aim to solve this unconstrained optimization problem by swapping differentiation summation.

$$\frac{\delta J(X_o)}{\delta x_{0i}} = \sum_{j=1}^{N} (-2) E[x_{ji} - \tilde{x}_{0i}] \quad (3)$$

Setting it to zero, it can be expressed as

$$\sum_{i=1}^{N} Ex_{ji} = (N)(\tilde{x}_{0i}) \text{ for } 1 \le i \le M \quad (4)$$

Hence, we can find

$$\tilde{x}_{0i} = \frac{1}{(N)} \sum_{j=1}^{N} (Ex_{ji}) \text{ for } 1 \le i \le M \quad (5)$$

That is

$$\tilde{x}_{0i} = \frac{1}{(N)} \sum_{j=1}^{N} (Ex_{ji}) \quad (6)$$

and so on.

Now, it can be proved that such a centroid $X_0 = [Ex_{01}, Ex_{02}, Ex_{0m},]$ is indeed a global minimum point (i.e. second partial derivatives are determined and the reason justifies that Hessian Matrix is positive definite. i.e., Eigenvalues are all positive and a diagonal Hessian Matrix can be found out).

$$\frac{\delta^2 J(x_o)}{\delta \tilde{x}_{0k}^{\;2}} = 2N \qquad \text{for } k = i \quad (7)$$

$$\frac{\delta^2 J(x_o)}{\delta \tilde{x}_{0k} \delta \widetilde{x_{01}}} = 0 \qquad \text{for } k \ne i \quad (8)$$

As N > 0, it can be proved that the Hessian matrix is a positive definite diagonal matrix.

B) Constrained Clustering: Planned Sensor Deployment

Now, constrained clustering problem can be formulated and solved by considering planned sensor deployment. Specifically, the case where patterns are deterministic and not random vectors are considered.

Problem Statement: The optimization problem is to reduce squared Euclidean distance from pattern vectors to the centroid vector.

$$J(X_0) = \left[\textstyle\sum_{j=1}^{N-1} \sum_{i=1}^{m} [x_{ji} - x_{0i}]^2\right] + \lambda \left[\textstyle\sum_{k=1}^{m} (x_{Nk} - x_{0k})^2 - S\right] \quad (9)$$

Subject to the following constraint:

Constraint: The squared Euclidean distance from pattern vector X_N to the centroid is equal to the value of "S," i.e., X_N is the extreme pattern.

Set L = (N-1)

$$\frac{\delta J(X_0)}{\delta x_{0i}} = \sum_{j=1}^{L} (-2)[x_{ji} - x_{0i}] + \lambda(-2)(x_{Ni} - x_{0i}) \text{ for } 1 \le i \le M \quad (10)$$

Setting it to zero, it can be derived as

$$\sum_{j=1}^{L} x_{ji} - L(x_{0i}) - \lambda(x_{0i}) + \lambda(x_{Ni}) = 0 \quad \text{for } 1 \le i \le M \quad (11)$$

$$\sum_{j=1}^{L} x_{ji} - x_{0i}(L+\lambda) + \lambda(x_{Ni}) = 0 \qquad \text{for } 1 \le i \le M \quad (12)$$

$$x_{0i} = \frac{\sum_{j=1}^{L} x_{ji} + \lambda(x_{Ni})}{L+\lambda} \qquad \text{for } 1 \le i \le M \quad (13)$$

Equality constraint

$$\sum_{k=1}^{m} (x_{Nk} - x_{ok})^2 = S \quad (14)$$

$$\sum_{k=1}^{m} \left(x_{NK} - \frac{\left(\sum_{j=1}^{L} x_{jk} + (\lambda)x_{NK}\right)}{L+\lambda} \right)^2 = S \quad (15)$$

$$\sum_{k=1}^{m} \left(\frac{\left((L+\lambda)x_{NK} - (\lambda)x_{NK-\sum_{j=1}^{L} x_{jk}} \right)}{L+\lambda} \right)^2 = S \quad (16)$$

$$\sum_{k=1}^{m} \left[\frac{(L)x_{Nk} - \sum_{j=1}^{N-1} x_{jk}}{L+\lambda} \right]^2 = S \quad (17)$$

Note: Equation 17 can easily be applied for random sensor pattern deployment (discussed in subsection A of Section II). Exact duplication of derivation is avoided for conciseness, and the above derivation is useful for solving constrained clustering problems practically.

III. IMPROVED LEACH PROTOCOL THROUGH CONSTRAINED CLUSTERING (PRACTICAL APPROACH)

In LEACH, when the residual energy in a cluster head goes down, such as below a threshold value, cluster head rotation is performed because of the optimization interpretation of CENTROID. However, the following dynamic clustering algorithm is proposed in Wireless Sensor Networks. When CH is depleted of energy (below a threshold value), the residual power of remaining cluster members in a cluster is almost equal. So, the cluster head is chosen as the CENTROID of remaining sensor nodes to minimize energy consumption in transmission. Thus, the cluster head rotation is performed, and the new cluster head is selected as close as possible to other cluster members having more or the same residual energy to all other cluster members as they sense the phenomena in a close geographical area. This approach also minimizes the energy consumption and reduces the intra-cluster communication cost. It reduces not only intracluster communication costs (within the clusters) but also inter-cluster communication costs (energy spend in communication between the cluster heads) at a given power level.

Further, it minimizes the Euclidean distance between nearby cluster heads. The cluster head is reachable from all the cluster members via one hop or multi-hop communication. We prove our intuitive perception with simulation results, as discussed in section IV.

A) Network Assumptions

Assume N quantity of sensor nodes are deployed in a sensor field. All the sensor nodes are homogeneous by nature. The sensor field is created in a planned or random manner by ensuring the cluster head position at CENTROID. The location of CENTROID is calculated through Euclidean distance. If the cluster head is not positioned at CENTROID, the sensor node is closed to CENTROID with relatively large residual energy is chosen as the cluster head. In the case of mobile WSNs, the mobile sensor node is considered as the CH is relocated to the CENTROID. If the placement of sensor nodes is planned by the user and controlled by the user (mobile or static), then CENTROID position is kept fixed for the cluster head. Constrained clustering uses the Hessian matrix to find CENTROID mathematically as discussed in Section II and provides a near-optimal solution.

B) Proposed Model

The cluster head is placed precisely in the center position of all the sensor nodes as discussed in previous section and probable model is illustrated in Fig. 1. All the CHs gather the data from corresponding clusters and the gathered data is sent to the BS. In each round, the rotation of CHs takes place among the cluster members by ensuring the position of CENTROID.

C) Experimental Set-Up

In our experiment, ns-2 Simulator is used as the evaluating tool to validate the performance of the proposed protocol. There are 101 sensor nodes deployed randomly over a rectangular grid area of 100 x100 m^2, and BS is placed in the coordinates of (x=50, y=175). These sensor nodes are divided into five clusters initially. The channel capacity is set to 1 Mbps. The payload part carries 500 bytes of data. A header length of 25 bytes is added along with the data packet. The same energy model is followed as used in LEACH. The duration of each round is 50second. After running the simulations for a long time, the experimental results are plotted in Fig 2 to Fig. 5.

D) Simulation Results

The efficiency of the proposed protocol is measured through a few performance metrics, which are discussed below. LEACH and LEACH-C protocol are taken as the reference protocol to compare the proposed protocol's performance. These two protocols are still in demand even after 17 years of development and provide a base to explore many new protocols. We address our proposed protocol as a constrained clustering LEACH (CC-LEACH protocol).

- **Transmitted packets from the source node**: In our experiment, first, we checked the number of packets transmitted from the source sensor node. It is depicted from Fig. 2 that around 160,000 data packets are transmitted to the BS that includes both data packets and control packets. As time increases, even more, no. of data packets are sent in proposed CC-LEACH compared to LEACH and LEACH-C.
- **Delivered packets to the BS**: This is one of the primary metrics that justifies the superiority of a protocol. It is shown from Fig. 3 that when time increases a significant number of data packets are

dropped in LEACH and LEACH-C as compared to CC-LEACH. So the packet delivery ratio (PDR) is better in CC-LEACH compared to other two protocols.

- **Average Energy Consumption**: Fig 4 shows that the average energy consumption is more in CC-LEACH compared to LEACH and LEACH-C. It's around 900 joules in CC-LEACH, whereas LEACH-C consumes 650 joules and LEACH consumes only 320 joules. It justifies that as more no. of packets is transmitted in CC-LEACH. So, it consumes more energy.
- **Network Lifetime:** The sensor network lifetime depends on the battery life of individual sensor node. Our simulation results show that initially all these three protocols perform equally. As time increases, slowly sensor nodes die in LEACH, followed by LEACH-C, and then CC-LEACH. The graph shown in Fig 5 concludes that at 600 rounds, almost all the sensor nodes die in LEACH, at 650 rounds, all the sensor nodes die in LEACH-C, and up to 700 rounds, around 20 sensor nodes remain still alive in CC-LEACH. This makes the sensor network to survive for a long duration.

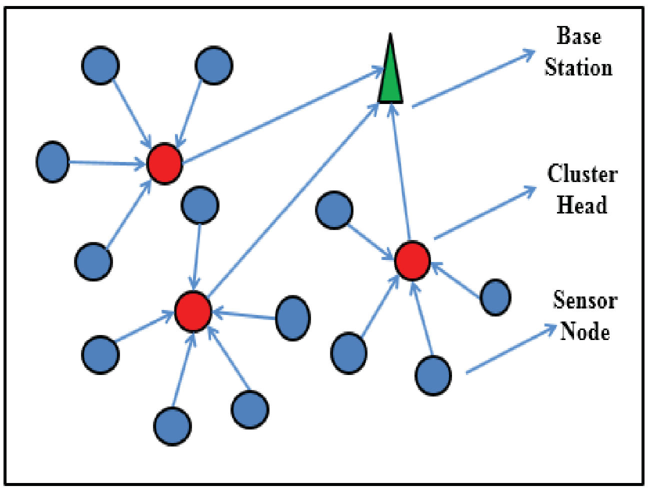

Fig. 1. Example of Proposed Model

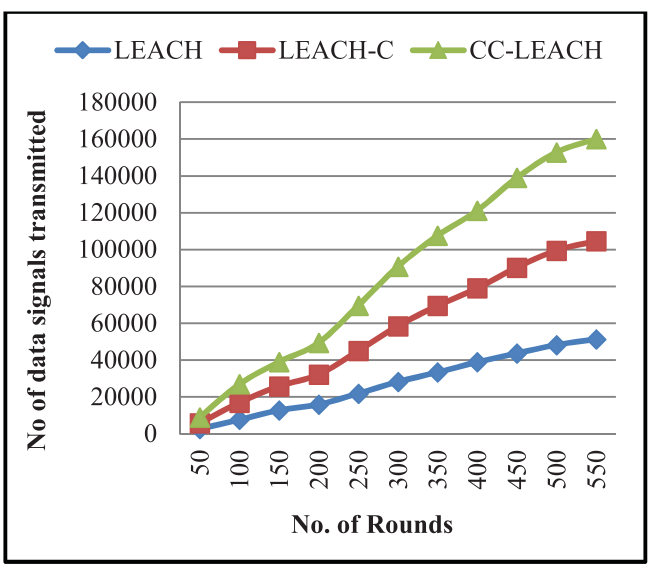

Fig. 2. No. of data packets transmitted Vs. No. of Rounds

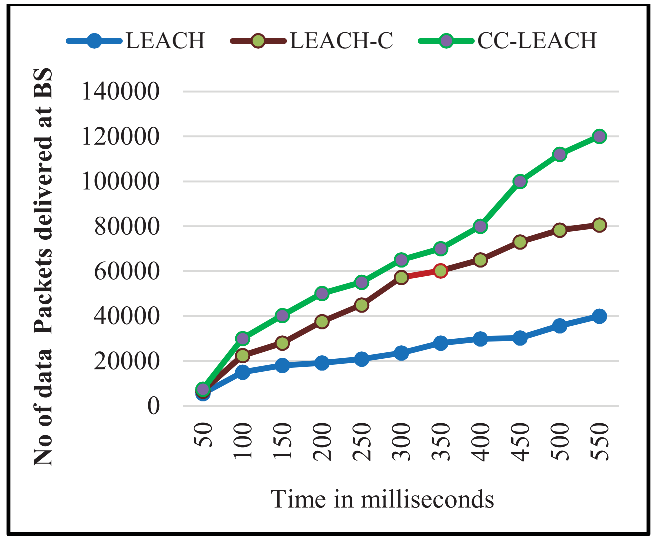

Fig. 3. No. of packets delivered to BS

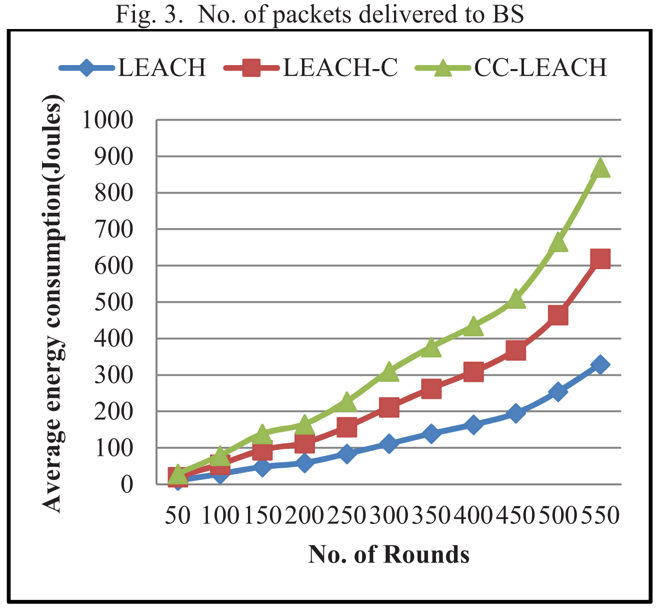

Fig. 4: Average energy consumption Vs. No. of rounds

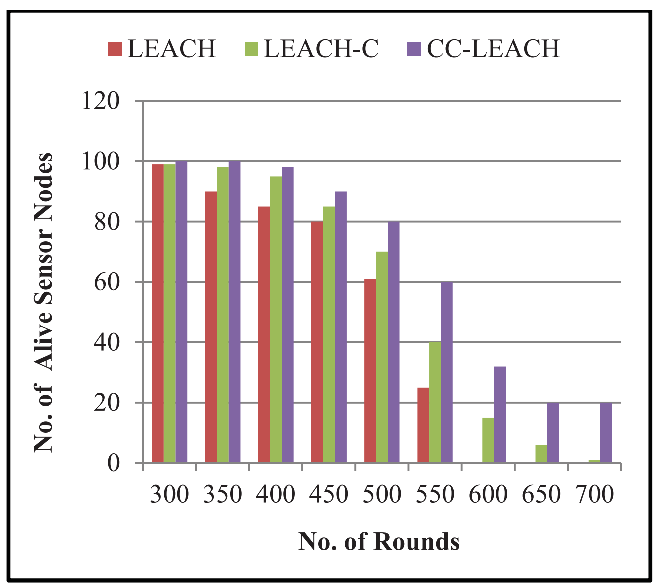

Fig. 5: Network Lifetime w.r.t No. of alive nodes

IV. CONCLUSION

Clustering is one of the most energy-efficient techniques but exhausts more energy if it is not addressed correctly in Wireless Sensor Networks. This research paper presents an energy-efficient hierarchical routing protocol based on the principle of LEACH and LEACH-C, where the cluster head position is considered as the CENTROID of all the sensor nodes positions. Both the random deployment, as well as the planned deployment of sensor nodes is considered. Each round ensures the placement of cluster head at CENTROID of all sensor nodes in a rotation basis in order to balance the load among the sensor nodes and reduce energy consumption. We formulate and solve the associated optimization problems using Hessian Matrix. Thus, we propose an OPTIMAL clustering of sensor nodes (concerning centroid position) for a particular paradigm of stationary Wireless Sensor Networks. We expect that the results will be useful for dynamic clustering in arbitrary mobile Wireless Sensor Networks.

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