

Self-Organized Energy Conscious Clustering Protocol for Wireless Sensor Networks

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Abstract – Wireless Sensor Networks have been evolved and applied to industrial, commercial, defense and civil applications. Energy is the main constraint in sensor networks. Energy management techniques increases the life cycle of sensor network and enhances the performance of throughput. Multi-hop communication and clustering approaches are used to save the node energy in sensor networks. Energy aware protocols minimize the participation of sensor nodes with less threshold energy and selects optimal energy path. In sensor networks, Cluster Heads (CHs) collect data from the sensor nodes and forward it to the neighboring CHs and finally to the Base Station (BS). CHs contribute to save the node energy. Cluster management techniques aim to minimize the number of clusters, density of clusters and energy consumption per cluster. In this article, we propose Self-organized Energy Conscious Clustering protocol (SECC) for WSNs to group the sensor network into clusters based on node energy and node distance. If the node energy is below the threshold value, SECC forms self-organized clusters and re-organizes the sensor network. Nodes with energy attributes less than the threshold value are eliminated from the clusters to maintain energy efficient sensor network. Energy aware cluster management in SECC is based on node parameters (like node distance, node energy, node density) and cluster parameters (like cluster density, sensor nodes per cluster). Performance analysis and simulation results are given with variations in number of clusters, energy levels and node distance.

Keywords - Energy-efficient techniques, clustering techniques, sensor networks, dynamic energy management

I. INTRODUCTION

Wireless Sensor Network is a group of homogeneous or heterogeneous sensor nodes, which are independent and work in a collaborative manner. Sensor nodes compute, transmit, receive and forward the data to adjacent sensor nodes, CH and further to the base station. Sensor networks are limited in computations, node energy, buffer size and signal strength. Multi-hop data forwarding and clustering methods are used to save the energy in sensor networks. Energy conservation [1] techniques helps to increase the life cycle of sensor networks. Clustering is defined as the process to form groups (clusters) from a set of nodes such that nodes in same group have

similar properties as compared to other groups. Each group is disjoint and works in cohesion. Clustering methodologies are applied in data bases, search engines, soft computing applications, networks, image processing, bioinformatics, etc. Clustering is used to group the sensor nodes with fixed or varying number of node attributes like node energy, node distance, node signal strength, buffer size and degree of adjacent node connectivity. Fixed number of sensor node attribute is used to establish and maintain a guaranteed connection between the nodes with limitations in energy distribution. Varying number of sensor node attribute is used to establish and maintain a guaranteed energy distribution with connection less service. Energy efficient clustering techniques decrease the number of control signals between sensor nodes based on attributes values of routing tables. Low energy adaptive clustering hierarchy (LEACH) [2], a standard protocol used in energy management changes the role of CH and saves the node energy. [3] Explains energy efficient distributed and multi-level clustering techniques for sensor networks. Energy efficient heuristic algorithms generate minimum size clusters [4] such that, each sensor node is p hop (maximum) distance from CH. Energy efficient and energy aware protocols in sensor networks are based on the following characteristics:

<i>Data aggregation</i>	collects data samples from a set of sensor nodes
<i>Data acquisition</i>	collects data samples periodically or event based
<i>Duty cycle</i>	Enables the radio-receiver of a sensor node in sleep or idle state to increase the node life cycle
<i>Cluster</i>	set of nodes with similar attributes like node distance and signal strength which are grouped together
<i>Mobility</i>	static sensor nodes save more energy as compared to dynamic sensor nodes. Mobile sensor nodes are used if the energy levels of nodes are uneven and enhance the data delivery rate

Energy efficient clustering is based on attributes like node density, cluster density, cluster coverage, distributed clustering and multi-level clustering.

II. RELATED WORK

Low-energy adaptive clustering hierarchy (LEACH) [2], a self-organized adaptive clustering protocol for wireless sensor networks is mainly used as the basis for energy aware clustering protocols in sensor networks. Efficient clustering in sensor network [5] increases the network coverage and enhance the features of network scalability. Energy Efficient Voting-based Clustering Algorithm (EBVCA) [6] uses features like network balancing, topology and energy attributes of sensor nodes to select the CH. This technique increases the life cycle of quasi-stationary sensor networks. Round Robin Cluster Head (RRCH) [7] selects a CH to balance the energy consumption and prevent repetitive selection of the same CH. RRCH calculates the CH node energy consumption E_{CH} and the non-CH node energy consumption E_{Non-CH} per session. Distributive Energy Efficient Adaptive Clustering (DEEAC) [8] protocol uses adaptive clustering with respect to data rates and sensor node energy. An Adaptive Energy Efficient Clustering (AEEC) [9] for heterogeneous sensor network selects CH based on node energy with varying sensor node attributes. In Energy-Efficient Balanced Clustering (EEBC) [10] nodes are clustered based on node energy and optimization to balance the number of clusters. Low Energy Intelligent Clustering Protocol (LEICP) [11], an enhancement of LEACH protocol aims to balance the node energy within each cluster and increase the network life cycle. Based on the node residual energy [12] and the node positions, node energy is balanced more accurately. Distributed energy efficient clustering selects minimum number of CHs and updates the CHs based on node energy and node coverage. Energy-efficient clustering algorithms [12] [13] are based on distributed clustering and coverage clustering techniques.

III. ENERGY MANAGEMENT TECHNIQUES IN WSNS

A. Data Gathering

- Collect data from a set of sensor nodes with minimum distance to reduce the energy consumption of sensor nodes.
- Balance the energy load within a cluster.
- Mobile collectors use the static sink nodes and collect data from sensor nodes, forward it to CH and finally to the base station.
- Buffer space of data gathering nodes is more as compared to sensor nodes to store aggregated data.
- Data gathering combined with clustering save the node energy within a cluster.

[6] [12] Explains the distributed energy clustering methods with improved coverage for sensor networks.

B. Clustering

- Clustering aims to minimize the topology control overhead and save node energy, channel bandwidth.
- Nodes with maximum energy are selected as the CH and periodically change with energy metrics.
- Hierarchical clustering is used to save the energy in tree structured sensor network.
- Intra-cluster group management is used to manage the complexity of clusters in sensor nodes.

C. Routing

- Nodes with maximum energy levels are used in the routing paths.
- Energy aware intra-cluster routing reduces the size of routing tables.
- Energy efficient adaptive multipath routing is used between the source node and target node with adaptable routes and minimum energy.
- Real-time routing protocols are used in applications with varying signal strength and network traffic to reduce the energy levels of the sensor nodes.

D. Coverage

- Coverage is based on sensor area, degree of node connectivity, signal strength and set of target nodes.
- Energy coverage techniques schedule active nodes and passive nodes, minimize the number of redundant active nodes and enable a few passive nodes (to establish an alternate route).
- Energy-efficient coverage techniques for the target nodes: (i) minimize the set of working nodes close to target area (ii) save the node energies and (iii) increase life cycle of the sensor network.
- WiFi and WiMax technologies are used to support coverage in sensor network.

IV. ENERGY AND CLUSTER METRICS IN THE PROPOSED SECC PROTOCOL

A. Energy Metrics

Energy consumption for the initial setup of sensor network based on active sensor nodes (SNs) is the sum of CH energy ratio and sensor node energy ratio. Energy setup is given as follows:

$$EnergySetup_i = \frac{EnergyCH_i}{ActiveSN_i} + \sum_{j=1}^n \frac{EnergySN_j}{ActiveSN_i} \dots\dots\dots (1)$$

[9] Explains mathematical analysis of energy equations for transmitter node, receiver node, CH node and non-CH node which are used in sensor networks.

Energy consumed by node i with voltage v to send the packet pkt at time t is given as follows:

$$E(pkt)_i = EnergyCurrNode_i * voltage_i * tpkt_i \quad \dots\dots\dots (2)$$

Energy consumed to transfer data between the node i and adjacent node Adj_i is a function of node distance, node energy and signal strength. Energy data transfer per session is given as follows:

$$E_{DataTransfer} = \sum_{i=1}^k DataTransfer \left(\begin{matrix} Distance(SN_i, Adj_i), Energy(SN_i, Adj_i), \\ RSSI(SN_i, Adj_i) \end{matrix} \right) \quad \dots\dots\dots (3)$$

Energy consumed by a sensor node is the sum of transmitted energy, received energy and control signal energy. Total energy consumption by a sensor node is given as follows:

$$Energy(SN_i) = E_{Tx}(SN_i) + E_{Rx}(SN_i) + E_{Control} \quad \dots\dots\dots (4)$$

B. Cluster Metrics

The size and magnitude of cluster is proportional to sensor node density, node distance and coverage area. For a sparse network, more number of clusters are formed and for a dense network, less number of clusters are formed. Energy maintained by CH per cluster is the sum of Sensor Nodes (SNs) per cluster and adjacent CHs. Energy per CH is given as follows:

$$E_{CH} = \sum_{i=1}^n E_{SN_i} + E_{AdjCH} \quad \dots\dots\dots (5)$$

Data transfer energy rate per cluster with average aggregate message and distance from Base Station (BS) is given as follows:

$$E_{DataTransferCH} = \left(\sum_{i=1}^k E_{SN_i} * \frac{AverageAgg.Message}{TotalMessage} \right) + \epsilon * Dist(CH, BS * DTransferRate) \quad \dots\dots\dots (6)$$

Where ϵ is the permittivity of free space in pJ/msq.

Power efficient and adaptive clustering [14] hierarchy protocol is used in tree structured protocols for sensor networks.

V. SELF-ORGANIZED ENERGY CONSCIOUS CLUSTERING

Dynamic clustering techniques [15] resolves node energy distribution across the network, form new clusters and re-elects new CH. This method leads to more energy consumption. In this article, we propose Self-organized Energy Conscious Clustering (SECC) to group nodes into clusters based on node energy and node distance. The proposed model considers the self-organizing nature of clustering when energy levels of sensor nodes are below the energy threshold E_{Th} .

The algorithm for the proposed SECC is given below.

Algorithm : Self-Organized Energy Conscious Clustering (SECC) Protocol for WSNs

```
// Number of sensor nodes : n; Energy Range (er) : ER1 to ER2; Distance Range (dr) : DR1 to DR2

Self-orgEnergyConciousClusterWSN(SN, EnergyRange, DistanceRange, Clusters)

Begin
  For i ← 1 to n; do
    // Find the energy of sensor nodes based on energy ranges
    FindEnergySN(SN[i], EnergyRange);
    // Find the neighbor sensor node based on distance range
    FindNeighborSensorNodes(SN[i], AdjSN[i], Distance(SN([i], AdjSN[j])));
  End For

  // Sensor Node Ratio Factor is a function of node density and the node distance. Cluster Ratio Factor is the number of SNs per SN ratio factor

  ClustRatioFactor = Number of SNs / SN RatioFactor;

  For (j ← 1 to ClustRatioFactor, k ← DR1 to DR2)
    Cluster[j] = FindMeanDistance(SN, Dist[k], EnergyRangeEi);
    FormEnergyAwareClusters(Cluster[j], er, dr);
  End For
End Function
```

A. Analysis of the Proposed SECC

In the proposed algorithm, the first phase calculates energy of sensor nodes and the distance between adjacent sensor nodes. Sensor node ratio factor is a function of node density and average mean distance between a set of nodes. Sensor node ratio factor in a cluster is given as follows:

$$SN_{Ratio\ Factor} = f(SN_{Density}, SN_{Set\ Same\ Mean\ Distance}) \quad \dots\dots\dots (7)$$

Cluster density is defined as the number of clusters per sensor network. Cluster ratio factor is the ratio of sensor nodes and sensor node ratio factor. Cluster ratio factor is given as follows:

$$Cluster_{Ratio\ Factor} = \frac{Number\ of\ SNs}{SN_{Ratio\ Factor}} \quad \dots\dots\dots (8)$$

Sensor nodes within nearly same average distance range and neighborhood are placed in same cluster. [16] [17] Explains efficient clustering protocols for sensor networks. In the next phase, energy aware clusters are calculated based on energy threshold and energy attributes of sensor nodes. Energy aware clusters formed are given as follows:

$$Energy\ Aware\ Clusters = \sum_{j=1}^c \sum_{i=1}^n \left(Clusters_j(SN_{i,j}, Dist(SN_{i,j}, AdjSN_{i,j})), \right. \\ \left. Energy(SN_{i,j}, AdjSN_{i,j}) \right) \quad \dots\dots\dots (9)$$

After a series of data transmissions between the sender node and the receiver node, energy consumption of the sensor node increases. In the proposed model, the sensor nodes with energy value less than the threshold energy value, E_{Th} are disabled and do not participate in sensor network operations. The mean distance between sensor nodes are re-calculated and new clusters are formed. Energy efficient relay [18] with minimum distance clustering is used in self-organized clustering. Self-organized energy aware clusters are formed with new threshold values and are given as follows:

$$Self - Org_{Energy\ Aware\ Clusters} = \sum_{j=1}^c \sum_{i=1}^n FindMeanDist(SN_{i,j}, E_{Th}, Dist(SN_{i,j}, AdjSN_{i,j}, E_{Th}) + \\ \sum_{j=1}^c \sum_{i=1}^n \left(Clusters_j(SN_{i,j}, Dist(SN_{i,j}, AdjSN_{i,j})), \right. \\ \left. Energy(SN_{i,j}, AdjSN_{i,j}, E_{Th}) \right) \quad \dots\dots\dots (10)$$

[19] [20] Explains energy efficient clustering algorithms and efficient clustering methods for self-organized sensor networks.

V. SIMULATIONS

Simulations are done using MatLab. Simulation parameters are given as: Coverage area: 600m x 600m; Number of Sensor Nodes: 200, Maximum number of sensor nodes per cluster: 20; Energy of sensor node, $E(SN_{i,j})$:0.5J, Threshold Energy: 0.55J; Node distance range: 50m-65m; Energy range: 0.5J to 0.63J

The simulation process is organized into four steps and given as follows: (i) form sensor nodes based on node distance and node energy (ii) form clusters based on sensor node ratio factor (self-organize) (iii) after a series of data transmissions, find the sensor nodes with energy below the threshold value (E_{Th}) and (iv) re-organize the sensor nodes and form new clusters.

Figure 1 gives the simulation for 200 sensor nodes based on node energy and average mean node distance. The energy levels for sensor node are in the range 0.5J to 0.64J. Figure 1 indicates that sensor node are scattered across 600 x 600 square meter and distributed uniformly.

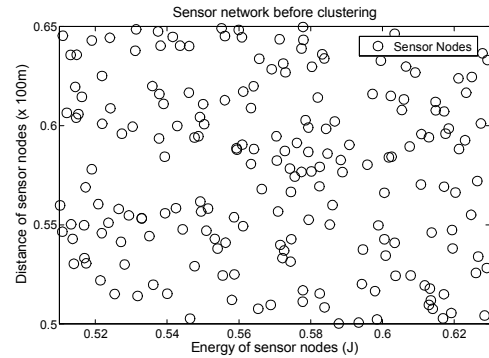


Figure 1. Sensor nodes based on node energy and node distance

Figure 2 gives the simulation for 200 nodes and form clusters. The cluster ratio factor is set to 10, which indicate that 10 clusters are formed for 200 sensor nodes. Simulations indicate an average of 12 sensor nodes per cluster. Less number of clusters indicates increase in sensor node density per existing clusters.

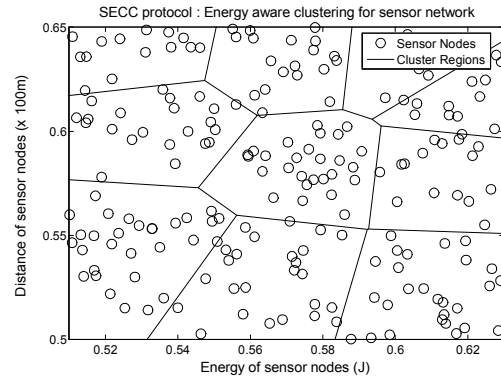


Figure 2. Form 10 clusters for 200 sensor nodes based on node distance and node energy

Figure 3 gives the simulation for sensor nodes with less threshold energy ($E_{Th} = 0.55J$) which is shown as $\oplus$ in the figure along with existing sensor nodes with adequate energy levels above the threshold energy E_{Th} . Energies on left hand side of figure 3 indicate sensor nodes with less threshold

energy values which are needed to be removed from the clusters.

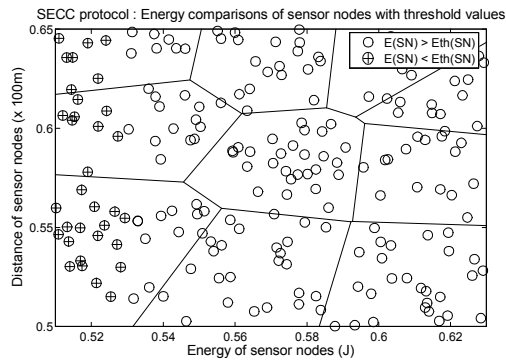


Figure 3. Left hand side indicate sensor nodes with energy levels below the threshold value $E_{Th} = 0.55J$

Figure 4 gives the simulation for sensor nodes with energy attributes more than the threshold value $E_{Th} = 0.55J$ and eliminates sensor nodes with energy less than E_{Th} . Clusters are re-formed to balance the node density per cluster. The left side of figure 4 indicates the region of sensor nodes with energy values less than the threshold value E_{Th} which are eliminated by the proposed self-organized energy conscious clustering protocol.

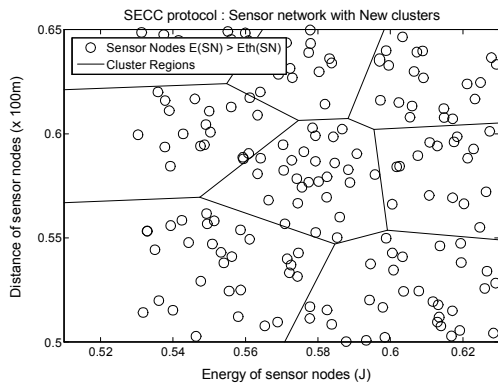


Figure 4. Self-organized energy conscious clustering eliminates the sensor nodes with less threshold values and form new clusters

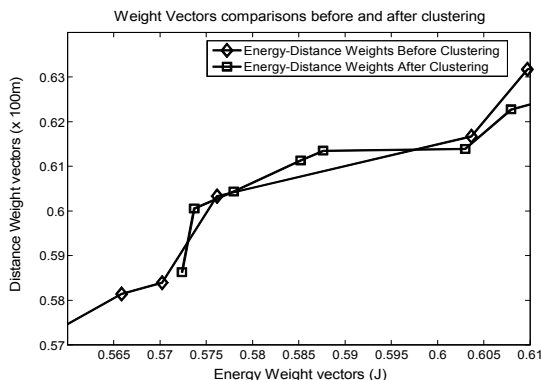


Figure 5. Weight vector comparisons for sensor nodes before clustering and after clustering in the proposed SECC protocol

Figure 5 gives the simulation for sensor node weights before clustering and after clustering in the proposed SECC protocol. The node weights are associated with energy and node distance. Simulations indicate that node weights show an improvement in the weight matrix for the proposed SECC protocol.

VI. CONCLUSIONS

Energy aware clustering protocols in sensor network save node energy and increase the network life cycle. Cluster management techniques aim to minimize the number of clusters, density of clusters and energy consumption per cluster. In this article, we propose Self-organized Energy Conscious Clustering protocol (SECC) for WSNs to save node energy and re-organize the clusters. In SECC, the clusters are re-organized based on attributes like node distance, node energy, node density and signal strength. Simulations indicate an improvement in energy aware clustering for sensor networks. An extension of this work could be node scalability and mobile agent to enhance the performance of energy conscious clustering in sensor networks.

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