CBUC: A Connectivity Based Unequal Clustering Protocol for Scalable Wireless Sensor Networks

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***Abstract*:** The clustering technique is used to increase the lifetime of the network. The existing unequal clustering uses the two techniques: the selection of the head with more residual energy and multi-hop routing. In this algorithm, the cluster members are not fixed in the cluster, when the cluster member send their data to the cluster head, a large amount of energy is spent during the data aggregation. When the cluster head sends data to the base station, the cluster head near the base station dies early due to heavy traffic which decreases the network lifetime. This paper proposed a new unequal clustering named as CBUC. In this work, the head selection is based on residual energy by fixing the degree of connectivity up to some threshold value in each cluster which reduces the intra traffic in every cluster and due to this energy consumption is low during data aggregation and low traffic burden on cluster head nearer to the base station. Results show that the average residual energy of the node is greater than the existing one and the number of dead nodes is less and as a result network lifetime will be increased.

Keywords*:* WSN, Clustering, Unequal Clustering, EEUC, CBUC

1 INTRODUCTION

Wireless Sensor Networks (WSN) [1] has taken an unbeatable place in many applications like agriculture, health, disaster management, target tracking etc. for last several years. This also has become the root component of advance technologies like Internet of Things (IoT) [2], Cyber Physical Systems (CPS) etc. Though several research has been made on multiple dimensions of WSN, still it is yet to reach at its saturation. One of the major dimensions of WSN is its scalability. Meaning, it supports the deployment of millions of sensor nodes in the application areas like forest, agriculture field, battle field etc. for monitoring or surveillance purpose. Though these tiny sensors have high sensing capabilities, but they suffer from the challenges like processing power, storage, and battery power [3]. The attempt to increase the computing power and storage may enhance the cost and size of the sensors causing difficulties in its application domains. One of the approach to meet the energy challenge is to utilize the available battery power efficiently so that the life of the nodes are increased.

There exists several research on the better energy utilization by designing algorithms and protocols in every layers of WSN architecture. One such solution is the method of clustering, where virtual clusters are formed in the network. Clustering is a proven solution to save energy of individual nodes. In this method, every cluster is headed by a cluster head who coordinates the communication between the cluster members and the sink node. Every cluster owns one cluster head and zero or more cluster members. Thus the cluster members forward their data to their cluster head who aggregates the data and eliminates the redundant data before sending to the sink node. The communication between the cluster head to sink node can be single hop communication or multi hop communication. In single hop communication, the cluster head directly sends the data to the sink node. This consumes higher energy by the farther cluster heads while connecting to the sink node with higher transmission range. In multi hop communication, one cluster head can forward the data to the sink node via one or more intermediate neighboring cluster heads. In this situation the cluster head can save its energy while forwarding the data to nearby cluster heads with lower transmission range.

In this paper, we propose a connectivity based unequal clustering (CBUC) protocol that forms different size clusters at different layers of distances from the sink node. CBUC supports multi hop communication for the cluster heads so that the distance cluster heads forward their packets to the sink node via the cluster heads closer to the sink node. This creates a gradient of packets towards the nodes in the closer proximity of the sink. The cluster heads near the sink node consume their battery power for most of their intra cluster communication along with the energy consumption associated with the inter cluster packet forwarding. Thus to reduce the energy consumption by the cluster heads near the sink node, the degree of intra cluster communication can be reduced. In other words, the energy of these cluster heads can be preserved mostly for handling the forwarding packets. This demands the formation of smaller sized clusters near the sink node and can be increased in size as the distance from the sink node is increased. Therefore, unequal clustering protocol is proposed here which is distributed and emphasizes on the degree of connectivity of every node for selecting the cluster heads.

The paper is organized such that section 2 describes the literature study in related areas of unequal clustering and multihop communication. Section 3 describes the proposed work followed by section 4 that highlights the results and analysis. Finally the conclusion section ends the paper describing the scope of future work in this direction.

2 RELATED WORK

Heinzelman et al. have proposed a clustering based routing protocol known as LEACH [4]. LEACH protocol operates in two phases: setup phase and steady phase. In the setup phase clusters are formed and cluster heads are selected randomly. In the next phase i.e. steady state phase, sensed data is transmitted between cluster member and cluster head, and between cluster head and base station. However, it is found that due to large number of transmissions, the protocol consumes lot of energy.

Younis et al. have proposed a protocol known as HEED [5] for wireless sensor networks. Here, periodic cluster head selection is done which is based on two parameters: residual energy of a node and intra-cluster communication cost. However, this protocol does not satisfy all the needs for a WSN. HEED terminates within a finite number of iterations and achieves fairly distribution of CHs over the network.

However, the equal based clustering methods mentioned above creates hotspot problem [6]. The cluster heads closer to the base station involves more packet transmissions resulting in more energy loss than the cluster heads present far away from the base station. This energy depletion results to hot spot problem.

The hot spot problem can be solved by using unequal clustering techniques.

Yu et al. [7] have proposed a protocol named Energy-Aware Distributed Unequal Clustering Protocol (EADUC) In EADUC, the process is divided into several number of rounds, where each round consists of set up phase and data transmission phase. To design the network topology, set up phase is further divided into neighbor node information collection phase, cluster head competition phase and, cluster formation phase. However, the network lifetime of the protocol can still be maximized.

Gong et al. [8] have proposed an unequal clustering algorithm named Multi-hop Routing Protocol with Unequal Clustering (MRPUC) which consist of several number of rounds in which each round is divided into three phases: cluster formation, multihop routing formation and data transmission phase.

Soro et al. [9] have proposed an algorithm called unequal clustering scheme (UCS) whose aim is to balance the energy consumption between cluster heads due to large number of inter-cluster relay traffic. In this algorithm, nodes are distributed randomly and the base station gathers information from cluster head. The base station receives the data from cluster head using multihop transmission. The cluster heads are selected dynamically to maintain uniform distribution of energy consumption among the cluster head.

Chen et al. [10] have proposed an algorithm called unequal cluster-based routing (UCR) It consists of two phases: one is for unequal cluster technique and other for routing. Initially, candidate cluster heads are randomly chosen to compete for final cluster head. Each candidate cluster head has its own competition range. Different competition ranges are responsible for creating cluster of unequal size. Finally, each competition range allows one cluster head. After selection of cluster head, each cluster head then broadcast control message across the network. Each node chooses its nearest cluster head with highest received signal strength and then sends joining cluster message to the nearest cluster head.

Li et al. [11] have proposed a head competition algorithm named Energy Efficient Unequal Clustering (EEUC) in which head selection based on the residual energy of the node. If the energy is less than threshold value it will not take part in final head selection and become an ordinary node. If value is greater than threshold value then it become a candidate cluster head node and each of these nodes compute its competition radius. Then the candidate nodes broadcast message to its neighbor. On receiving the control message from node ,the neighbour node computes its distance, if the distance is within the competition range ,that node is added to the candidate head set and then this the residual energy of node will compared to its neighbour. The node which have higher energy will be considered as a final cluster head and the node within the range of that node become its cluster member. After this inter-cluster multihop routing is performed by the nodes for data transmission. However, in this method the number of cluster heads is more and average residual energy of the nodes is less thereby decreasing the overall network lifetime.

3. The proposed algorithm

In this section we propose connectivity based distributed unequal algorithm that aims to limit the number of cluster members in a cluster head in order to save the consumed energy of the cluster heads and hence increase the network life time. The responsibility of cluster head is allotted to any node turn wise so that the energy consumption can be balanced between the nodes.

3.1 Network Model

Let us consider the wireless sensor network is represented by a graph G= {S, E}, where S is the represents the sensor nodes S= {s_1, s_2, s_3,….s_N}, such that S=N. E represents the edges between s_i and s_j and denoted as E= {(s_i,s_j)SE Ds_i,s_j <= R}, that is the Euclidean distance between the sensors si and sj is less than the transmission range R of the nodes. We start our work with the following assumptions:

- All the sensor nodes are homogeneous in nature having similar functionality and capacity and equipped with GPS enabling devices
- The sensor nodes having unique ID and same transmission range R are uniformly deployed in a square area
- The base station is deployed outside the network area
- Every cluster has maximum one cluster head CH and zero or more cluster members
- Intra-cluster communications are one-hop and inter-cluster communications are multi-hop through the cluster heads only
- As data aggregation and transmission are out of the scope of the paper, each activity is sensed by the closest sensor only and the

during transmission only one data unit (packet) is transmitted per unit time

- Every node has the capability to alter its transmission range in order to transmit its data with variable power levels. The maximum range that any node can obtain is $\mathbf{R_{max}}$.
- The network area is partitioned into k equal partitions starting from $\mathbf{p_1, p_2, \ldots, p_k}$ starting from the nearest zone of the BS.

As the inter-cluster communication adopts multi hop communication, any node in the partition p_k forwards its data via its CH to the cluster head of the partition p_{k+1}. The CH of partition forwards these packets along with its own data to the CH of partition p_{k+2} and the process continues till the data is reached to the BS. Fig. 1 clearly indicates the partitions of the network and the traffic across the network. It can be seen that the amount of data forwarded by the nearest CHs of the BS are maximum in comparison to the farther CHs. This results more energy consumption by these nearby nodes of the CH than that of the farther nodes. So the CHs closest to the BS die early to the other nodes. This imbalance in the energy consumption by the CHs motivates to find the solution for this typical problem.

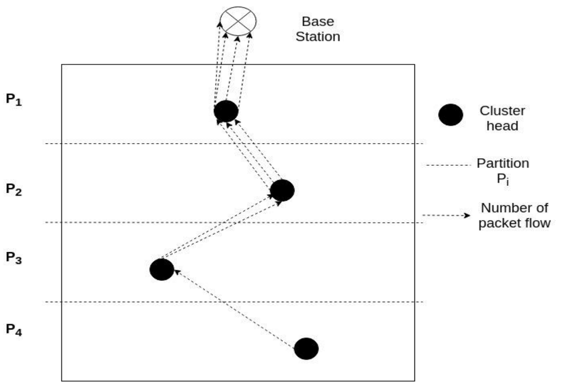

Figure 1: packet flow from cluster head to base station through different partition.

3.2 Connectivity based unequal clustering (CBUC)

Clustering is the process of partitioning the nodes in the network to virtual groups having a leader and the designation is changed from time to time among the nodes in the same partition. The change in the role of the leader or the cluster head can be periodic or basing on the occurrence of some event. In the current work, we consider the drop in the available energy level of the cluster head to a threshold value δ to be reason for any cluster head to change its status. Meaning, the existing CH changes its role from CH to the cluster member when its available energy reaches below δ and another node in the vicinity is selected as the new CH. However, the changing of the role of CH in a cluster requires reestablishment of the routing path in the network and other maintenance activities. Thus the aim of the work is to avoid overloading the CH in order to save its energy and reduce frequent change in the cluster head setup phase. We assume that the CH is responsible for forwarding two types of data to the base station. They are (i) as a router that forwards the packets coming from neighboring CHs, and (ii) as a source that aggregates and forwards the packets generated within its own cluster. While we have no control over the number of packets coming from the neighboring nodes, but the number of in house packets can be controlled if the cluster size can be decided judiciously. The CBUC algorithm can be considered to have two phases. The **cluster setup** phase and the **cluster maintenance** phase. The details of the phases are described below.

3.2.1 Cluster Setup Phase:

This phase is considered to be the initial phase of the work. It includes activities like neighbor detection of every node, computation of transmission range of every node, cluster head selection, tentative cluster member selection, and final cluster member selection for every cluster in each partition. Each of these activities are explained below:

Neighbor Detection: During this stage, each of the nodes broadcasts "Hello" packets into the network. The node that is within the transmission range of the "Hello" packet sender, receives the packet and responds back to the sender with a reply message that includes its ID and location in terms of (x,y) coordinates. Thus every node gets to know about their neighborhood and the Euclidean distance to their neighbor nodes.

Computation of Transmission Range: during this stage, the transmission range of all the nodes are calculated as below:

$$n_{i.}R_r = \left(1 - \gamma \frac{s_{max} - s(n_i, BS)}{s_{max} - s_{min}}\right) R_r^0$$

Where R_r^0 is the maximum competition radius which is predefined. S_{max} and s_{min} denotes the maximum and minimum distance between sensor nodes and base station, $s(n_i, BS)$ is the distance between $n_{i,}$ and base station, γ is the constant coefficient between 0 and 1. It can be observed that the nodes within closer partitions have lesser transmission range and it gradually increases for the nodes in farther partitions. This unequal transmission range of nodes result unequal size clusters.

Cluster Head Selection: in every partition one or more cluster heads are chosen during this stage. Every node compares its available energy with that of its neighbors detected in the earlier stage. The node having the highest available energy is selected as the cluster head. During the initiation of the network when all the nodes have equal available energy, candidates CH can be selected for the final cluster head. These Cluster head are selected on the basis of some probability valueθ. Each candidates head will take part in the competition for final cluster head.

Tentative cluster member selection: During this stage, all the neighbors those lie within the transmission range of the CH are declared as the cluster members of that CH. Thus the degree of connectivity D_{CH} is calculated.

Final Cluster member selection: this is the final step of the cluster formation phase. If the degree of connectivity D_{CH} of the cluster head is above the prescribed number of members α, then the most closest α number of members are selected as the final members of the cluster. The reason of selecting the closest members is to reduce the transmission battery power of the members during intra cluster communication. The value of α is chosen such that less numbers of cluster members are accommodated within the smaller clusters and vice versa. Figure 2 indicates the network after the cluster formation phase.

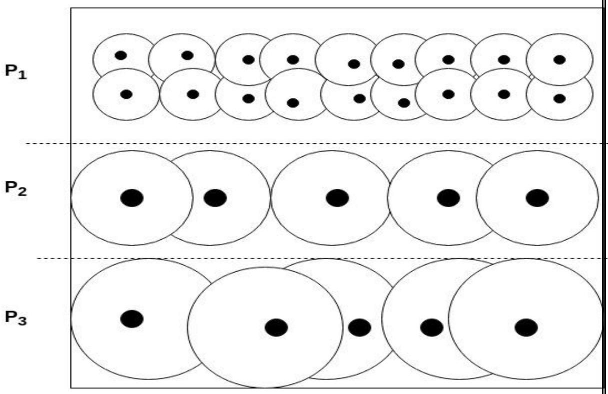

Figure 2: Unequal clustering mechanism

3.2.2 Cluster Maintenance phase:

Once the clusters are formed, the maintenance phase takes place. During this phase the following takes place in every partition:

Computation of Residual Energy:

The energy consumption $E_{CH}(m,n,s)$ for each of the cluster heads while transmitting n number of messages of each m bit size over a distance of s can be calculated as:

$$E_{CH}(m,n,s) = E_T(m,s) + E_R(m) + E_{fu}(n,m) \quad \text{--(1)}$$

Where,

$E_T(m,s)$ is the energy spent for transmitting m bits message over distance s and $E_R(m)$ is the energy spent for receiving m bits message. $E_T(m,s)$ and $E_R(m)$ can be calculated as in equation (2) and (3) respectively.

$$E_T(m,s) = \begin{cases} mE_{el} + m\,\epsilon_f\, s^2, & s < s_0 \\ mE_{el} + m\,\epsilon_p\, s^4, & s \geq s_0 \end{cases} \quad \textbf{... (2)}$$

Where E_{el} denotes the constant electronics energy with a value of $50nJ/bit$; $\epsilon_{fs}\, s^2$ and $\epsilon_{fs}\, s^4$ are the amplifier energy with value $10pJ/bit/m^2$ and $0.0013pJ/bit/m^4$ respectively and s_0 constant which can be calculated as:

$$s_0 = \sqrt{\epsilon_f/\epsilon_p} \quad \text{-------------- (2.1)}$$

$$E_R(m) = mE_{el} \quad \text{------------- (3)}$$

The energy spent for fusing n number of messages of m bits size each is denoted as $E_{fu}(n,m)$ and it can be calculated as:

$$E_{fu}(n,m) = n.m.E_{fu} \quad \text{------------- (4)}$$

The residual energy of the cluster head RE can be calculated as:

$$RE = RE - E_{CH}(m,n,s) \quad \text{------------- (5)}$$

Re-clustering:

When the residual energy of the cluster head RE reaches below δ new cluster setup phase is executed.

Proposed Algorithm (CBUC):

Cluster Setup Phase

1 $\rho \rightarrow Rand(0,1)$
2. ***If*** $\rho<\theta$ **then**
3 Candidate_Head ← TRUE and computes its R_r
4 **End if**
5. **If** Candidate_Head = TRUE
6 COMPETE_HEAD_MSG (ID,RE,$R_{r,}$,D_{CH})
7 **end if**
8 Received COMPETE_MSG from node n_i
9 **If** s(n_i,n_j)<Rr **then**
10 Add n_j into NEIG_LIST //NEIG_LIST is list of neighbour
11 **end if**
11 **while** Candidate node=TRUE **do**
12 **If** ni.RE>nj.RE,$\forall n_j \in \mathbf{D}_C$
13.Final_HEADMSG(ID)
14 n_i JOIN_CLUSTER_MSG
15 **end if**
16 **If** $D_{CH}<\alpha$ **then**
17 n_i Join _Final_Cluster_member
18 **end if**
19 **end while**

Cluster Maintenance phase

1 $E_{CH}(n_i) = E_T(ni) + E_R(n_i) + E_{Fu}(n_i)$
$RE = RE - E_{CH}(m,n,s)$
2 if $RE < \delta$,

3 repeat cluster Setup Phase
4 **end if**

4. Result and Analysis

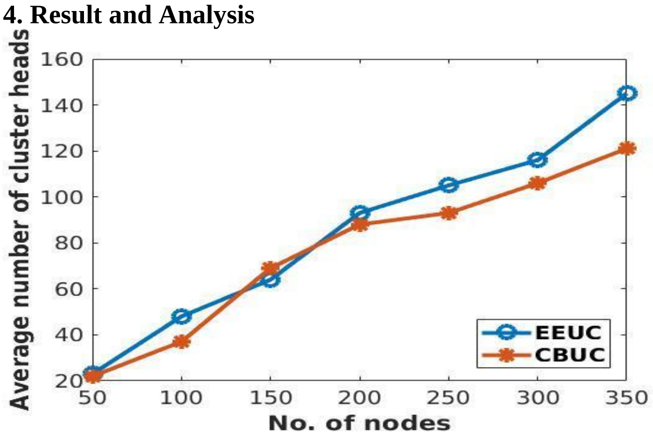

Figure 3: Average number of cluster head

Figure 3 explains the results obtained for average number of cluster heads. In the figure, the proposed algorithm CBUC shows less number of cluster heads compared to EEUC. In CBUC, the degree of connectivity is computed and compared to a fixed threshold value . If degree of connectivity of a node is less than the threshold value then it will become the cluster member of that cluster. Due to this large number of node will be participate in the cluster and less number of cluster heads will be formed.

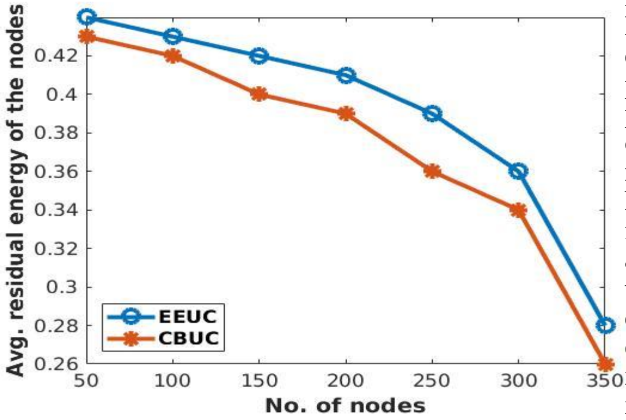

Figure 4: Average residual energy of the nodes

In Figure 2, the average energy of the nodes is compared between EEUC and CBUC. It is observed that as we increase the no. of nodes the average residual energy of nodes decreases. Here, the number of cluster heads is less which results in less data aggregation is less thereby preserving more energy of a node. The proposed algorithm CBUC consumes less energy as compared to EEUC due to less number of cluster heads formation.

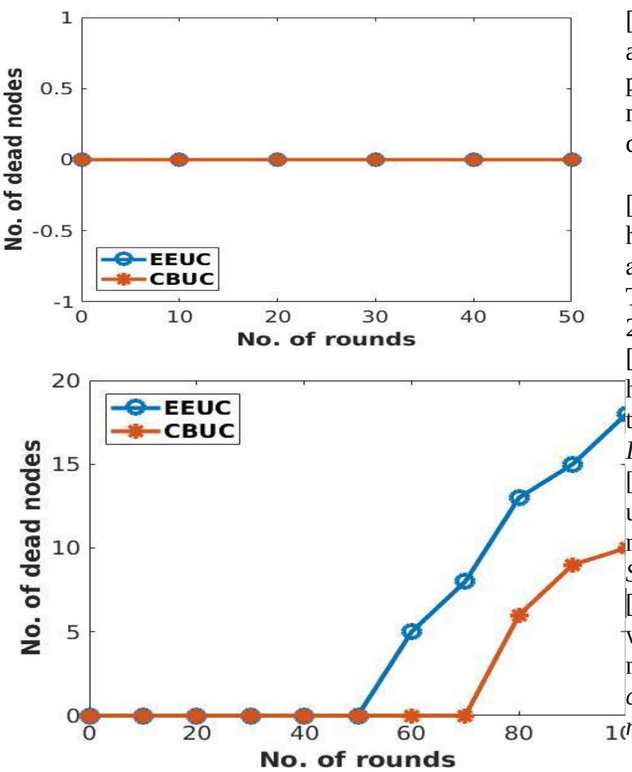

Figure `5: Number of Dead nodes over Rounds.

In the Figure 3, number of Death node is compared between EEUC and CBUC. It is observed that as we increased the number of rounds, there is no dead nodes upto 50 round in both algorithm .But after 50 round the number of dead nodes increases in case of EEUC, whereas the number of dead node increases after 70 round due to higher residual energy.

4. Conclusion

Network lifetime is one of the major issues in wireless sensor networks. The existing algorithm EEUC has been used for increasing the network lifetime But the performance of this protocol gets degraded in a large size network. To resolve this problem, the CBUC protocol is proposed. The protocol uses an unequal clustering technique which considers available energy and then choosing the node having maximum residual energy as its cluster head. The available energy is chosen as a parameter for selecting cluster head because cluster head aggregates the data from all the source nodes and takes the responsibility to transmit this data to the destination, and this requires a large amount of energy. The second parameter, degree of connectivity is chosen to fix the number of cluster member, so that intra traffic in the cluster is decreased. The simulation results show that CBUC performs better compared to the existing algorithms in a large network.

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