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Intra-Cluster Optimization In Zone-Based Wireless Sensor Networks Using DBSCAN

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Abstract

Effective energy utilization of nodes within the clusters is the most important issue in zone or partition based Wireless Sensor Networks. Even though the clustering mechanism achieves high scalability and efficient resource allocation, it increases energy consumption in clusters of bigger sizes. In order to achieve balanced energy consumption in all the nodes, the role of Cluster Head is rotated periodically among the nodes over the time. But this will not help us to achieve balanced energy consumption in nodes that are within the rectangular based zones of larger clusters and uneven in size. Those nodes require more energy for data transmission to the cluster head and may not follow the optimal path to the base station. In this paper, we analyze the intra-cluster communication costs in zone based network and apply DBSCAN algorithm for the cluster set up phase with the objective of minimizing the intra-cluster distance and optimizing the energy consumption of the network. Simulation results reveal that the proposed approach yields increased network lifetime, throughput and energy utilization than the existing protocol.

Key-Words: Wireless Sensor Networks, energy, rectangular zones, clusters, cluster head, intra-cluster, network lifetime, communication costs, optimal path, network lifetime, DBSCAN.

Introduction

Wireless Sensor Networks (WSNs) contain small, multifunctional, battery-powered sensor nodes with limited energy, processing power and sensing ability. They support a wide variety of applications like monitoring remote fields, surveillance of critical environments like battle field and border security where large number of sensor nodes are often unattended and work autonomously [1-4]. Limited energy resources of wireless sensor network has to be wisely used to prolong the lifetime of the sensor nodes. To achieve high energy efficiency and increase the network lifetime, sensor nodes are grouped together to form clusters. Each cluster consists of sensor nodes within the given range. Every cluster would have a cluster head (CH), and the other sensor nodes become cluster members of that cluster.

Clustering technique localizes the route setup, conserves communication bandwidth, avoids redundant messages exchange, cuts on topology maintenance overhead, implements optimized management strategies to enhance network operations, schedules activities in the cluster, prevents medium access collision by limiting redundancy in coverage, and decreases the number of relayed packets by aggregating data collected by sensors in the network [5-9]. In this technique, each group of nodes has a cluster head node that aggregates data from its respective clusters and transmits it to the base station (BS).

Several protocols have been proposed in the literature with the objective of maximizing the network lifetime by using cluster-based network architectures. Various hierarchical energy-aware routing protocols like LEACH [10], Power Efficient Gathering in Sensor Information System (PEGASIS) [11], Hybrid-Energy Efficient Distributed Clustering (HEED) [12], TEEN [13], and APTEEN [14] were introduced as solutions for load balancing and increased network lifetime.

The nodes farther from the base station have to transmit packets over long distances than the nodes nearer to the base station. As a result, they consume more energy [10]. To reduce the energy drainage of far-away nodes from the base station (BS), Zone based Stable Election Protocol-Enhanced (ZSEP-E) was proposed with heterogeneous and homogeneous zones and adopt cluster based technique to create local clusters at the zones. [15]. Advanced nodes were deterministically deployed at pre-computed locations to reduce the network partitioning and instability. However, unequal clusters were produced. This paper aims to create distinct clusters with greater similarity among the member nodes of the cluster. The main contribution of this paper is to use the Density-based spatial clustering of applications with noise (DBSCAN) to create distinct clusters at the cluster set-up phase of the ZSEP-E protocol and effectively handle outlier nodes.

The rest of the paper is organized as follows. We briefly review the related work in section 2; section 3 gives a description of the existing zone based protocol. In section 4, the proposed cluster optimization based on DBSCAN algorithm is discussed. Section 5 presents the simulation results with evaluations and analyses the proposed method. Finally, the overall conclusion and future directions are discussed in section 6 with highlights of recommended future directions.

Related Work and Motivation

Sensor nodes usually work unattended in remote geographical areas. They may be operating in a chemically or biologically contaminated field, at the bottom of oceans, in large buildings, in a battlefield beyond enemy lines. Special wireless routing protocols are essential to manage the communication between the base station and the sink. To manage high density of hundreds and thousands of sensor nodes in wireless sensor networks, clustering techniques were used. There are two broad-categories of clustered sensor networks viz. homogeneous and heterogeneous hierarchical sensor networks. In homogenous networks, all the nodes are identical in terms of energy and functionality. In heterogeneous networks, two or more different types of nodes in terms of battery energy and functionality are considered.

Low- Energy Adaptive Clustering Hierarchy (LEACH) [16] is a cluster-based protocol which distributes the energy consumption equally among the sensor nodes by electing cluster-heads under probabilistic rotation. However, energy drainage at the cluster-head is higher due to additional functionalities incurred such as data collection and processing. Cluster heads are not evenly positioned across the network. Consequently, energy is not maintained uniformly between the nodes which creates energy imbalance. LEACH-C was proposed in [10] as a further improvement of LEACH. A centralized algorithm was used by the base station to form clusters at the beginning of each round. The base station configures the network into clusters and finds a predetermined number of cluster heads during the setup phase. Results show that the overall performance of LEACH-C is better than LEACH due to improved cluster formation by the base station. Moreover, the number of cluster heads in each round of LEACH-C is equal to the desired optimal value, whereas for LEACH the number of cluster heads varies from round to round due to the lack of global coordination among nodes. The authors in [17] proposed RHEED where re-clustering takes place only when the residual energy of at least one of the cluster heads in the group falls below a certain threshold.

Distributed Energy –Efficient Clustering Algorithm (DEEC) elects cluster heads based on the knowledge of the ratio between the residual energy of the nodes with that of the average energy of the entire network [18]. Additional energy is incurred to share the knowledge between the nodes. Stochastic DEEC (SDEEC) was proposed as an extension of DEEC[19]. Two-level heterogeneity was considered and energy is conserved by making non-CH nodes sleep. The disadvantage of this protocol is that during sleep state, the non-CH members are not aware of the network operations.

In Distributed Energy Balance Clustering Protocol (DEBC), the result of two-level heterogeneity is extended to multi-level heterogeneity [20]. Cluster heads are elected based on the knowledge of the ratio between the remaining energy of the node and the average energy of the network. Stable Election Protocol (SEP) discusses the instability of LEACH in the presence of heterogeneity [21]. The weighted election probability of each node to become cluster-head is based on the energy of the node and does not require energy knowledge sharing. The higher energy nodes are not efficiently utilized.

Z-SEP is a zone-based protocol where the sensing field is divided into zones and advanced nodes were in the furthest zone of the base station [22]. Advanced nodes were elected as cluster heads and normal nodes directly communicated with the base station. But conventional protocols like Direct Transmission (DT) do not assure a balanced and uniform use of the sensor energy. SEP-E, a modified algorithm of SEP considers three-tier nodes by introducing intermediate nodes which serves as a bridge between normal nodes and advanced nodes [23]. SEP-E does not provide an ideal solution for energy dissipation, since normal nodes, intermediate nodes and advanced nodes are randomly deployed.

Clusters of equal size was formed by using an approach called Base station Controlled Dynamic Protocol (BCDCP) to avoid cluster head overload and to ensure equal power dissipation of nodes [24].

A backbone formation algorithm to construct a connected dominating set and action sets was proposed in [25]. In a dynamic environment where nodes die, it was difficult to fix the backbone. A secure energy aware routing has been proposed in [26] taking into consideration the location and position of the nodes in the network. The authors have claimed that different nodes consume different energy volumes even when adopting a same routing approach. Zone based Stable Election Protocol-Enhanced (ZSEP-E) was proposed to reduce the quick energy drainage of far-away from the base station [15]. The authors attempted to minimize the energy consumption and maximize data transmission. The proposed density based intra-cluster optimization as an extension of [15] creates evenly positioned clusters in the zones and identifies outlier nodes as low-density areas in the zones and makes them communicate directly to the base station.

Existing Zone Based Clustering Algorithm: Zsep-E Protocol

The performance and lifetime of WSNs is highly influenced by the clustering scheme. But the efficiency of the network is drastically affected by the early death of the sensor nodes which are far away from the base station. Zone-Based clustering protocol [15] was proposed to address this issue by partitioning the field and advanced nodes were deterministically deployed at pre-computed locations to reduce the network partitioning and instability.

Network Model and Specifications

Some assumptions were made about the underlying network model of area $A= X\times Y$ sq.mts. where $X=a$, $Y= b_1+b_2+b_3$, where $b_1=b_3$ and $b_1+b_2+b_3=a$ and the sensor nodes deployed.

A zone partition algorithm was used to partition the area A into three zones. Each zone was considered separately as a geographical division of the sensing field. Appropriate energy-level sensor nodes were deployed depending on the distance and orientation from the base station. m proportion of total number of nodes n were equipped with α times more energy than the *normal nodes* and referred as *advanced nodes*. b proportion of total number of nodes n were equipped with μ times more energy than the normal nodes and referred as *intermediate* nodes. The zone partition algorithm is as follows:

1. Zone1 = $a\times b_1$, lying between $0\leq Y\leq Y_1$, deployed with $n\times\frac{m}{2}$ static homogenous energy-rich advanced nodes where $Y_1 = A\times\frac{M}{2}$.
2. Zone2 = $a\times b_2$, lying between $Y_1<Y\leq Y_2$, deployed with b proportion of static intermediate nodes and $(1\text{-}m\text{-}b)\times n$ normal nodes where $Y_2 = a\times Y_1$.

3. Zone3 = $a \times b_3$, lying between $Y_2 < Y \leq Y_3$, deployed with $n \times \frac{m}{2}$ static homogenous energy-rich advanced nodes where $Y_3 = A$.

The Problem of Un-Balanced Energy Consumption

During the cluster set-up phase unevenly positioned and unequal clusters are formed in the zones as shown in Fig.1. However, we need arbitrary shaped clusters instead of irregular cluster sizes. In order to fully accomplish the introduction of advanced node in the far-away zones of the BS, we optimize the cluster set-up phase of ZSEP-E protocol. We apply DBSCAN algorithm [27] to create arbitrary clusters at the far-away zones and further reduce the instability of the network. DBSCAN clustering algorithm relies on density-based notion of clusters.

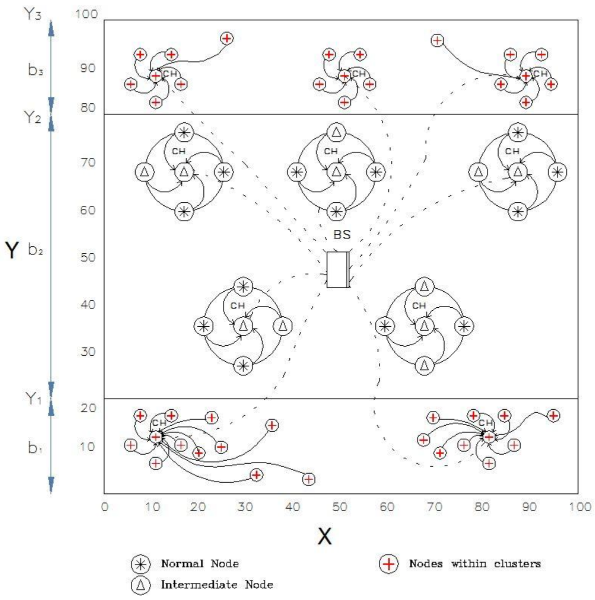


Figure 1: ZSEP-E Architecture

Proposed Intra-Cluster Optimization

Clustering is a prominent feature used in WSNs to group nodes based on different metrics. Clustering methods are categorized as distance- based [28] and density methods [29]. Distance based methods determine the similarity between two nodes in a cluster by the distance metric, e.g., Euclidean, whereas in density-based methods, the similarity may be defined by connectivity according to density. Clustering algorithms based on distance metrics like K-means, are aimed at identifying spherical clusters but are incapable of revealing clusters with random shapes and cannot detect outlier nodes. Density-based methods scan for high density nodes that are separated by areas of low density nodes. They are capable of finding arbitrary shaped clusters with different local density and extract outlier nodes. DBSCAN is a simple and effective density-based clustering algorithm and allows us to classify nodes as being in the interior of a dense region or in a sparsely occupied region.

The ZSEP-E protocol operates in rounds where each round begins with a cluster set-up phase and steady state phase. The clusters are formed in the cluster set-up phase and data transmission to the base station takes place in the steady-state phase. In order to create distinct equally positioned clusters at the cluster set-up phase, we aim to exploit the benefits of Density-based spatial clustering of applications with noise (DBSCAN).

Cluster set-up phase using DBSCAN

The proposed algorithm for the cluster set-up phase of ZSEP-E protocol at the zones is given below:

```
DBSCAN (AdvZone,DMax, MinNodesinCluster)
ClusterId = 0
for each unchecked Node N in AdvZone
mark N as checked
RelatedNodes = GetRelatedNodes(N, Dmax)
if sizeof(RelatedNodes) < MinNodesinCluster
MoveToOutlierNodeGroup(N)
else
ClusterId = ClusterId+1
GetNodesforCluster(N, RelatedNodes,
CluseterId, DMax, MinNodesinCluster)
endif
endfor
GetNodesforCluster (P, NeighborNodes, Cl, d,
MinNodes)
add P to cluster Cl
for each node P1 in NeighborNodes
if P1 is not checked already
mark P1 as checked
NeighborNodes1 = GetRelatedNodes(P1, d)
if sizeof(NeighborNodes1) >= MinNodes
NeighborNodes = (NeighborNodes
UNION
NeighborNodes1)
endif
if P1 is not yet member of any cluster
add P1 to cluster Cl
endif
endif
endfor.
GetRelatedNodes(P, threshold)
return all the nearest neighbour Nodes of P
in distance threshold including P
```

MoveToOutlierNodeGroup(P)
Add the Node P to DirectBSNodes.
Here AdvZone is the Nodes in the Zone1 or Zone3.

The effective heuristic to determine the value for DMax is the maximum radius of the circle that can be formed within the zones.Also the effective heuristic to determine the value for MinNodesinCluster is based on the proportion of nodes deployed in the zones; the larger values are usually better for data sets with noise and will yield more significant clusters. The larger the data set, the larger the value of MinNodesinCluster should be chosen.

The cluster head election is based on the randomized weighted election probabilities according to the residual energy of the node in the cluster of their respective zones.

Cluster Steady State Phase

The cluster heads create TDMA schedule for communication of the nodes in their clusters. The cluster members sense the data and transmit them to their CH. To minimize the energy dissipated by the non cluster heads, the radio components are turned off at all times except during its transmission time. Once, when all the data is available at the CH, it aggregates the data and sends them to the BS. Further to reduce energy dissipation and enhance network lifetime, CH adopts local data fusion to compress the amount of data being sent from the clusters to the base station. The data from the cluster head is sent to the base station using a fixed spreading code and CSMA (Carrier Sense Multiple Access) approach as in [16]. To efficiently use the battery of every single sensor, the cluster heads are re-established at every round.

Direct B S Nodes contains the outlier nodes which will communicate with the BS directly. The proposed intra-cluster optimization of ZSEP-E using DBSCAN is shown in Fig.2. The energy consumed in the intra-cluster processing varies proportionally to the number of nodes within the cluster.

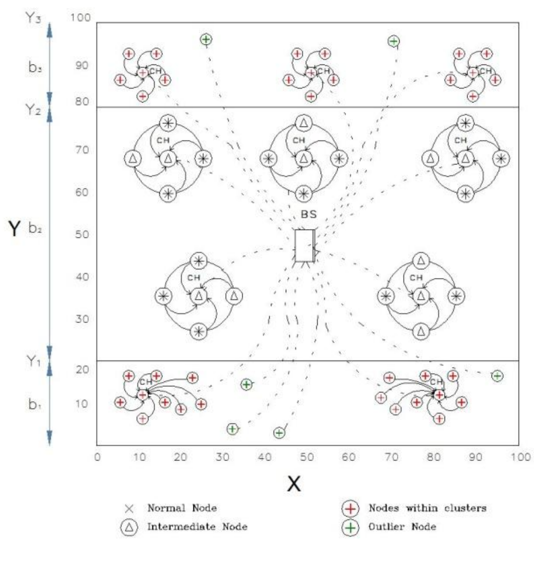


Figure 2: ZSEP-E using DBSCAN

Simulation Results

In this section, we evaluate the performance of ZSEP-E using DBSCAN via, simulations. We simulate a clustered wireless sensor network with dimensions *100m × 100m* and partition the field into three zones as per our proposed protocol in MATLAB. Table I [15] shows the various simulation parameters used in the protocol.

Table 1: Simulation Parameters

Parameters	**Values**
Initial Energy of Normal nodes E_{in}	0.5 J
Initial Energy of Intermediate nodes E_{im}	$(1+ \mu)\ E_{in}$
Initial Energy of Advanced nodes E_{ia}	$(1+ \alpha)\ E_{in}$
Data Aggregation(E_{DA})	5 nJ/bit/signal
Transmitting/Receiving Energy(E_{elec})	50nJ/bit
Short Distance Amplification Energy(E_{fs})	10 $pJ/bit/m^2$
Long Distance Amplification Energy(E_{amp})	0.013 $pJ/bit/m^4$
Min Nodes in cluster(MinNodesinCluster)	¼(n*m)
Max Distance of Neighbourhood Nodes range(DMax)	½(b1)

Case 1.1: Network Lifetime and Throughput in the presence of high energy heterogeneity with zone dimensions in *100m × 100m* network setting with the total no of Nodes n = 100.

The total population (*n*) of the sensors randomly deployed in all the zones are *100*. Advanced nodes with $\alpha = 3$ times more energy than normal nodes are deployed in *Zone1* and *Zone3* equally. In *Zone2*, intermediate nodes with $\mu = 1.5$ times more energy than the normal nodes are distributed along with normal nodes.

We compare the performance of ZSEP-E using DBSCAN with ZSEP-E and the parameters are m=0.2, b=0.3, α=3 and μ=1.5 and E_{total} = 102.5J. The results were shown in Fig. 3(a), (b). Other parameters are shown in Table 1.

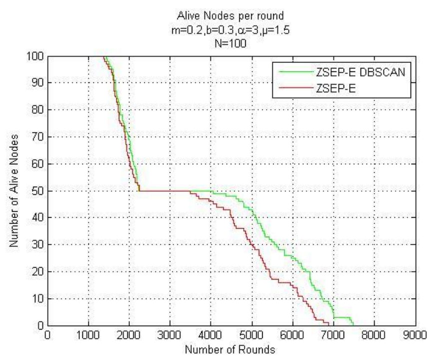


Fig. 3(a)

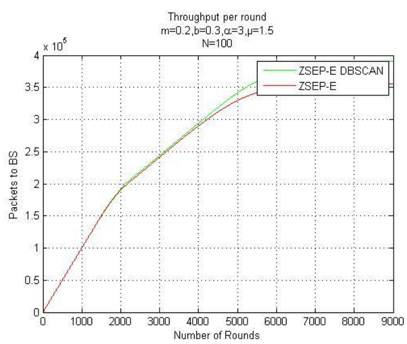


Fig. 3(b)

Figure 3: Performance of ZSEP-E using DBSCAN with m=0.2, b=0.3, α=3 and μ=1.5, ZSEP-E with m=0.2, b=0.3, α=3 and μ=1.5, E_{total} = 102.5J. Zone area Y_1=10, Y_2=90 and Y_3=100 (a) Alive nodes per round (b) Throughput

The stability of ZSEP-E using DBSCAN increased considerably than the existing ZSEP-E with the optimized cluster formation in the Zones with the Advanced Nodes. Extra energy of these Nodes were highly utilized and the instability is reduced from 7478 rounds to 6880 rounds and the stability increased from 1350 to 1437. The stability is slightly better than ZSEP-E, this is due to the influence of outlier nodes that communicates with Base Station directly.

Case 1.2: Network Lifetime and Throughput in the presence of high energy heterogeneity with zone dimensions in *100m* × *100m* network setting with the total no of Nodes n = 200.

The total population (*n*) of the sensors randomly deployed in all the zones are 2*00*. Advanced nodes with *α =3* times more energy than normal nodes are deployed in *Zone1* and *Zone3* equally. In *Zone2*, intermediate nodes with *μ = 1.5* times more energy than the normal nodes are distributed along with normal nodes.

We compare the performance of ZSEP-E using DBSCAN with ZSEP-E and the parameters are m=0.2, b=0.3, α=3 and μ=1.5 and E_{total} = 102.5J. The results were shown in Fig. 4(a), (b). Other parameters are shown in Table 1.

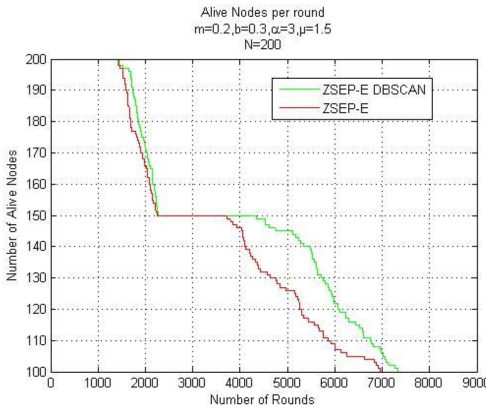


Fig. 4(a)

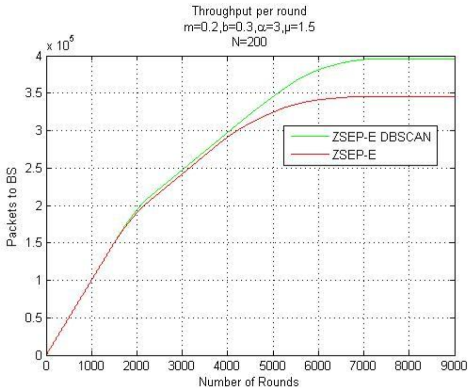


Fig. 4(b)

Figure 4: Performance of ZSEP-E using DBSCAN with m=0.2, b=0.3, α=3 and μ=1.5, ZSEP-E with m=0.2, b=0.3, α=3 and μ=1.5, E_{total} = 102.5J. Zone area Y_1=10, Y_2=90 and Y_3=100 (a) Alive nodes per round (b) Throughput

High density is directly proportional to the number of nodes. Segregated outlier nodes results in reduced instability regions . The instability reduced from 1444 to 1406. The stability region is much better than the ZSEP-E. Because of this extended stability region, throughput is relatively higher than ZSEP-E. The selection of values for D Max and Min Nodesin Cluster were analyzed and we quantify the values of those to be bounded as in Table I.

Case 2.1: Network Lifetime and Throughput in the presence of low energy heterogeneity with zone dimensions in *100m* × *100m* network setting with the total no of Nodes n = 100.

The total population (*n*) of the sensors randomly deployed in all the zones are *100*. Advanced nodes with $\alpha = 2$ times more energy than normal nodes are deployed in *Zone1* and *Zone3* equally. In *Zone2*, intermediate nodes with $\mu = 1$ times more energy than the normal nodes are distributed along with normal nodes.

We compare the performance of ZSEP-E using DBSCAN with ZSEP-E and the parameters are m=0.1, b=0.2, α=2 and μ=1 and E_{total} = 70J. The results were shown in Fig. 5(a), (b). Other parameters are shown in Table 1.

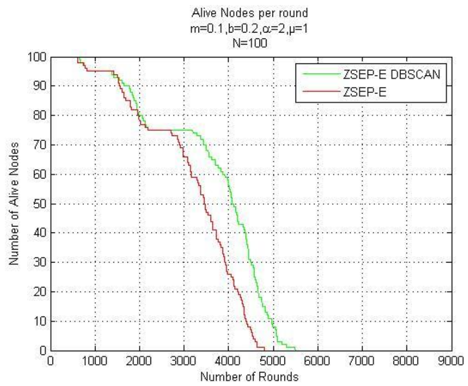


Fig. 5(a)

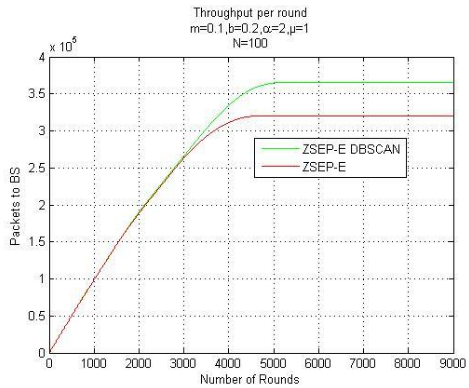


Fig. 5(b)

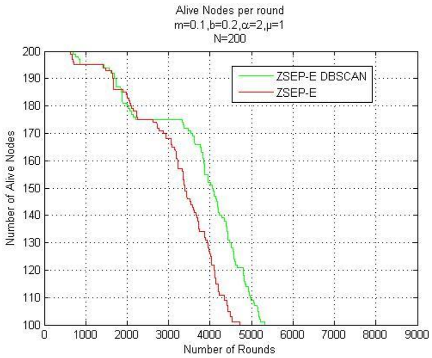
Figure 5: Performance of ZSEP-E using DBSCAN with m=0.1, b=0.2, α=2 and μ=1, ZSEP-E with m=0.2, b=0.2, α=2 and μ=1, E_{total} = 70J. Zone area Y_1=5, Y_2=95 and Y_3=100 (a) Alive nodes per round (b) Throughput

The stability of ZSEP-E using DBSCAN increased considerably even in the lower energy settings than the existing ZSEP-E. ZSEP-E performs well when there is no lower density nodes in the zones and performs very poorly in the presence of lower density nodes. ZSEP-E using DBSCAN outperforms ZSEP-E when the low density nodes are high in the zones. The stability is increased up to 11% based on the existence of lower density nodes. The instability is reduced from 5683 rounds to 5130 rounds.

Case 2.2: Network Lifetime and Throughput in the presence of low energy heterogeneity with zone dimensions in *100m* × *100m* network setting with the total no of Nodes n = 200.

The total population (*n*) of the sensors randomly deployed in all the zones are 2*00*. Advanced nodes with $\alpha = 2$ times more energy than normal nodes are deployed in *Zone1* and *Zone3* equally. In *Zone2*, intermediate nodes with $\mu = 1$ times more energy than the normal nodes are distributed along with normal nodes.

We compare the performance of ZSEP-E using DBSCAN with ZSEP-E and the parameters are m=0.1, b=0.2, α=2 and μ=1 and E_{total} = 70J. The results were shown in Fig. 6(a), (b). Other parameters are shown in Table 1.



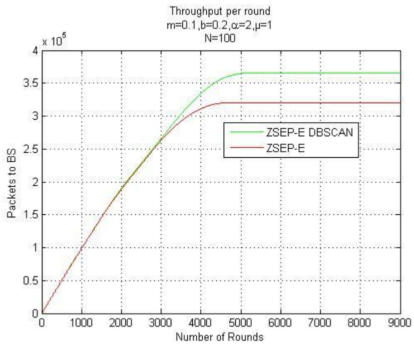


Figure 6(a): **Figure 6(b):**

Figure 6: Performance of ZSEP-E using DBSCAN with m=0.1, b=0.2, α=2 and μ=1, ZSEP-E with m=0.1, b=0.2, α=2 and μ=1, E_{total} = 70J. Zone area Y_1=5, Y_2=95 and Y_3=100 (a) Alive nodes per round (b) Throughput

Similar analysis was done as in Case 1.2 with 200 Nodes and with the total initial energy 70J. The stability region in ZSEP-E using DBSCAN is more flattened when studied over a number of trials compared with ZSEP-E is mainly due to the cluster quality by DBSCAN. Figure 6 shows the increased system life time in ZSEP-E using DBSCAN than ZSEP-E. Non Uniform Cluster size are more after a few rounds in ZSEP-E increases the communication cost.

We ran the similar experiments with increased total number of nodes with appropriate energy levels maintained as in ZSEP-E and also with relevant parameters for D Max and Min Node sin Cluster . No matter of increased nodes it outperforms ZSEP-E in all the cases.

Conclusion and Future Direction

In this paper, we present an enhanced ZSEP-E with arbitrary cluster formation in specific zones using DBSCAN. The improved cluster quality in high density regions and isolated outlier Nodes in low density regions enhances the ZSEP-E with prolonged network lifetime and reduced communication costs. Outlier Nodes directly communicates with Sink and it speed up the network routing and reduces intra-cluster communication costs considerably. The effective utilization of advanced nodes is obstructed by the uneven cluster sizes in ZSEP-E and the simulation results show that it was effectively handled in this paper. A future initiative would be to determine inter-cluster communication and also evaluate the clusters for their separation.

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