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An Application Oriented Integrated Unequal Clustering Algorithm for Wireless Sensor Network

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ABSTRACT: Wireless Sensor Network consists of group of interconnected devices which are used to sense and exchange the gathered data from the sensing field to understand the perceptual information of the real world. For the importance of monitoring the real world environment, this paper introduces Application Based Integrated Framework for Unequal Clustering Algorithm in WSN. In this chapter the proposed algorithms are integrated together to comprise the data aggregation, cluster formation, Cluster Head election and re-clustering for prolonging the network lifetime in both small scale and large scale application of WSN. The proposed algorithms are chosen based on the required parameters for specified applications. The result shows that the proposed algorithm selects the preeminent suited clustering algorithm for particular applications significantly.

Keywords: Unequal Clustering, Network Lifetime, Energy Consumption

I Introduction

WSN includes numerous practical applications inside the medical service for example estimating biometric parameters of patients. Clustering could provide an energy efficient framework for wireless sensor networks [1]. Intuitively, the size of clusters varies according to different applications [3]. It is essential to provide a general clustering framework which could provide tailored clusters to diverse applications. In order to achieve less energy consumption while communication between nodes, this paper introduce an Application based integrated unequal clustering algorithms for sensor nodes for extending the lifetime of the network.

The main contributions of this chapter are the following:

1. To increase the network lifetime, it constructs an unequal clustering and increases the number of clusters nearer to the BS to mitigate the "hot spot" issue.

2. The frequent re-election of Cluster Head is avoided by assigning predefined threshold energy level for each sensor node
3. The hot spot problem appears when employing the multi-hop communication in clustering algorithms.

4. The proposed framework argues both inter-cluster communication and intra-cluster communication among the nodes.

5. It also considers the re-election of Cluster Heads and residual energy are not adequate to balance the energy consumption between the entire network. To address the problem, unequal clustering algorithms are introduced to balance the energy consumption among the entire network.

6. Using this framework, suitable algorithm for a specific sensing field can be elected manually.

II Related Work

Energy Efficient Level based and Time based clustering (LTCA) [4] algorithm construct clusters with unequal size associated to the boundaries between upper and lower energy level. It partitions the network into clusters according to the energy level of each node. The energy level is calculated by taking the difference between energy utilization of each Cluster Head in both single-hop and multi-hop communication models. Based on the saved energy, few clusters enlarge their sizes to occupy the remaining nodes for an efficient communication.

In Energy Efficient Heterogeneous Clustered Scheme for heterogeneous WSNs (EEHC) [5], weighted probability of each node is determined to elect the Cluster Heads (CH) in EEHC. The CMs can directly communicate with selected CH. CHs aggregate the data from its Cluster

Members (CM) and transfer it to the Base Station (BS). Three different types of nodes with different threshold are used for each type. It also guarantees that all the three type of node become CH depending upon their probability of weight. Due to the variable cluster count, EEHC show the way to unequal sized cluster.

A Probability Driven Unequal Clustering Mechanism for WSNs (PRODUCE) [6] composes the network in the form of clusters with unequal in size. The various types of probability is assigned to elect the Cluster Head. In PRODUCE, the clusters nearer to the Base Station are smaller in size and it increases the size of clusters farther away from Base Station. The PRODUCE prompts unequal sized cluster because of variable cluster count but it spends more energy in re-clustering phase.

From the survey, it is transparent that the proposed energy efficient clustering algorithms depletes more energy when re-electing the Cluster Head periodically and collecting a data from its CMs. few algorithms provides the resolution for mitigating the hotspot problem and few are focused to maximize the effectiveness of network lifetime but both the problems are not mentioned together.

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III A Framework of Unequal Clustering Algorithm for Wireless Sensor Networks (FUCA)

The WSN is homogeneous, the network have same residual energy and communication range of sensor nodes [9]. Each node is stationary, after deployment in sensing field. Unique ID is assigned to all the nodes. Each link is symmetric. No local information and synchronization is required on each node. No synchronization service is required. The assumptions guarantee that a network structure can be represented by a graph which helps to analyze the proposed work. The process of a network begins with set up the cluster and data transmission. In set up the clusters, the sensor nodes are grouped into clusters and the sensed information is transferred in data transmission phase.

The framework of Unequal Clustering algorithm uses different user parameters to achieve the goal of prolonging lifetime of the network by extending the lifetime of each sensor node in Wireless Sensor Network. This framework is applicable for both indoor applications such as home automation and outdoor applications such as military applications, weather report generation, etc. The framework shown in Figure 1 consists of two components: Node Elector and Energy Trust Value which are used to elect and re-elect the CH.

The node elector elects the CH according to the energy level of each sensors and the number of neighbors. Once the CH is initialized, it calculates the competition radius for constructing unequal clusters to mitigate the hotspot issue. The energy trust value is responsible for re-electing the Cluster Head which is applied to the threshold energy function. Threshold energy function invokes the re-clustering algorithm if it satisfies the specified constraint. The appropriate proposed algorithms and parameters are chosen according to the applications of WSN.The components of the framework are decribed in detail below.

The framework includes the proposed algorithms namely BUCA [10], UCAPN [11], FPUCA [12], MinD-CDS [13] and OUCA [14] for large scale WSN. FUCA selects the best algorithm based on sensing field and the observed parameters such as energy depletion, network lifespan and communication overhead. The existing frameworks considers a specific protocol for transferring data over multi-hop communication and do not integrate with any other protocols. In existing framework, large number of communicating nodes participates for transferring data which results a communication overhead and unbalanced energy consumption among sensor nodes. Therefore, the intent of this framework is to integrate the proposed algorithm together to select the suitable algorithm for gathering the data in specified sensing are. The proposed framework is a generic framework in which the proposed algorithms are combined together to provide an energy effectual unequal clustering technique for various applications in WSN.

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Neighbor Node

In neighbor Node, every node sends a beacon signal to the node neighbor to observe the number of neighbors and its residual energy. The notation of neighbor node observer is assumed as follows:

Notation 1: For a node ‘i’, a neighbor node of ‘i’ is a node that is reachable from i with one-hop wireless communication.

To monitor the energy level of each node, the following assumption should be made to satisfy the energy prediction model in WSN. The sensor nodes are distributed randomly. After deployment, the nodes are stationary. The unique address ID is allotted to every node. The data from sensing environment are collected periodically and forwarded to the BS. The sensor nodes are monitored at discrete intervals of time. Every node calculates the space between the nodes according to the strength of received signal. The BS is placed at the middle of the sensing area and it is controlled by the wireless transmission control. The proposed algorithm uses the radio dissipation of energy method to transmit the amount of data along a distance d and is defined as follows:

$$ET_x\,(k,d) = \begin{cases} k * E_{elec} + k * E_{fs} * \mathrm{d}^2 \;, \mathrm{d} < \mathrm{d}_0 \\ k * E_{elec} + k * E_{fs} * \mathrm{d}^4 \;, \mathrm{d} \geq \mathrm{d}_0 \end{cases} \quad \ldots (1)$$

Where, E_{elec} represents the electronic energy, E_{fs} represents amplifier energy d is the difference between receiver and transmitter and d_0 is threshold distance. If d is less than the threshold d_0 then d^2 is single-hop communication otherwise d^4 is multi-hop communication. The energy spent for receiving k bits data from its neighbor is calculated using the following formula:

$$ER_x\,(k) = k \times E_{elec} \quad \ldots (2)$$

Where ER_x is the amount of energy depletes it energy to receive k bits of data.

Energy Level

The Energy Level continuously monitors the energy level of every node by transfer a beacon signal to its nearest neighbor. The average energy level of each node is computed using equation (3).

$$E_a = \frac{1}{d} \sum_{i=1}^{d} s_i . E_r \quad \ldots (3)$$

where d is the number of neighborhood and E_r is residual energy of specified node s_i. The waiting time is calculated for sending a message to its neighbor is calculated as follows.

$$t = \left[(1-\propto) * \frac{N_i}{N_{max}}\right] + [\propto * V_{random}] \quad \ldots (4)$$

Where N_i is the number of neighborhood, N_{max} is the total amount of nodes, α is a constant coefficient among 0 and 1, V_{random} is a random number between 0 and 1. For the duration of round 0, every node has equal energy level to further nodes. The neighbor node information collected from each node is shown in Table 1.

Table 1 Nearest Neighbor Node Information

Node ID	**Residual Energy (E) in Joule**	**Node Status**	**Number of Neighbors Nodes**
N1	2.0	Unknown	5
N2	2.8	Unknown	8
.	.	.	.
.	.	.	.

The Node ID represents the unique ID for each node i.e., N1, N2, N3,…………………,Nn where n is number of nodes present in the network. Residual energy (E) represents the energy level of each node that will be measured in joule. The status of node is mentioned in the column of Node Status and the number of neighbors for every node is specified in the column of Number of Neighbors Nodes.

The energy level manager helps to elect the Cluster Head. The maximum residual energy among its neighbor node is elected as a CH.

Competition Radius

To avoid hot spot problem, the proposed algorithms should form more amount of clusters closer to the BS. To construct clusters with unequal in size and every node is responsible to calculate its individual competition radius R_c using equation (5).

$$R_C = 1 - c\,\frac{d_{max} - d(s_i, BS)}{d_{max} - d_{min}}\,R_o c \qquad \text{... (5)}$$

The distance between maximum nodes and minimum nodes and Base Station is represented as d_{max}, d_{min}. The weighted factor specified as c and maximum competition radius represented as R_oc. Every node elects the nearby CH and conveys the Join_Msg with its ID and residual energy. Every CH prepares the node schedule list for each node based on expected Join_Msgs and transmits the list to its CMs.

The algorithm for selecting a CH is given in Algorithm 1:

Algorithm 1: Unequal cluster formation

```
Begin
status=unknown
t=waiting time to broadcast CH message
r=radio signal
while (status==unknown) do
broadcast ADV_msg within
compute R_c competition radius
broadcast HELLO_Msg from node i to neighbor node j
collect neighbor node information
 update it in neighbor node table
 calculate average residual energy
  if (E_i>E_j) then
  broadcast HEAD_Msg(ID=i, d, E,NN)
  exit
  if (current time>t) then
  if (HEAD_Msg receives from node i from node j) then
  status=unknown
  else
 continue
 end if
else
 status=header
 broadcast HEAD_Msg to its neighbor
 send JOIN_Msg from node j to node k
end if
 if status==header then
 receive JOIN_Msg from its neighbor node
 set status=member
end if
```

The aforementioned algorithm selects the Cluster Head according to number of neighbor nodes and its residual energy. It builds clusters with unequal in size by increasing the amount of clusters nearer to the BS to avoid the hot spot issue and to increase the network lifetime.

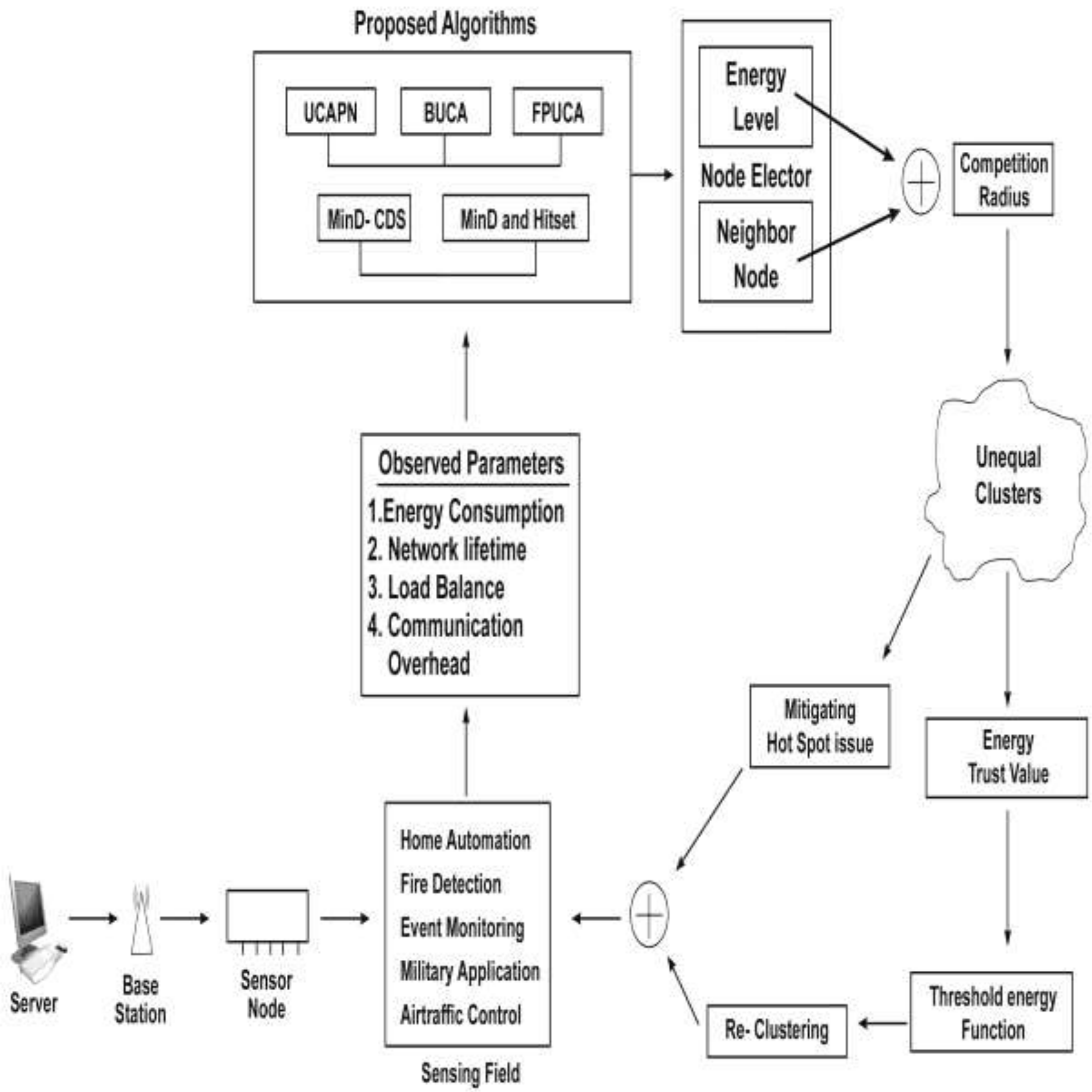

Figure 1 Framework for Unequal Clustering Algorithm

Trust Value

The Trust Value decides to which node will become a CH. Once the CH is elected, forward the message to its neighbor. The neighbor node directs a join message to nearby Cluster Head. The neighbor node observer and energy level monitor maintains a table with number of neighbors and its energy level.

Threshold Energy Function

The Threshold Energy Function avoids the frequent re-election of Cluster Head. Once the clusters are constructed, the threshold energy value is assigned to each Cluster Head. The Cluster Head is rotated when its residual energy is lower than the threshold energy value.

IV Overview of FUCA

FUCA integrates the proposed algorithms together in order to mitigate the hot spot issues and to extend the lifetime of the network in various applications of WSN. In FUCA, the proposed algorithms are chosen based on the observed parameters and nodes distributed in the sensing area. Once the nodes are deployed, the required parameters are selected for analyzing the performance of the specified application in sensing field. The FUCA needs to decide three main things before electing the proposed algorithm. They are, 1) sensing field is large scale or small scale, 2) energy driven or time driven method for rotating CH and 3) Node degree is maximum or minimum. The algorithm is chosen based on the following combination.

- The proposed algorithm UCAPN is elected when the nodes are deployed in small scale and uses time driven method for rotating Cluster Head.
- BUCA is elected when nodes are deployed in small scale and energy driven technique for rotating Cluster Head.
- FPUCA is elected when the nodes are deployed in large scale sensing area and forecasting the energy level of each node in advance at discrete time interval.
- For a large scale WSN, the MinD-CDS algorithm is chosen with minimum node degree and rotating the Cluster Head with energy driven technique.
- The OUCA is chosen when the nodes are in large scale WSN with maximum node degree and energy driven technique.

After electing the proposed algorithm, the node elects the Cluster Head according to the energy level of each node and number of neighbors using node elector. To construct the clusters of unequal size, the competition radius is calculated for each sensor node. The proposed algorithms BUCA, MinD-CDS and OUCA use the energy trust value and threshold energy function for minimizing the recurrent re-election of CH which preserves some more energy for prolonging network lifetime. Finally, the processed data are gathered by the CH and onward to the server through the BS.

V Application of FUCA in Structural Health Monitoring

In recent year, using Wireless Sensor Networks for Structural Health Monitoring (SHM) has established increased consideration from diverse fields such as civil, mechanical, structural and aeronautical engineering due to low cost, low maintenance, flexibility, fast and easy connection through wired sensor networks [15]. The target of SHM is to monitor complex events such as impairment, crash and erosion in physical system [16]. In proposed framework, the sensor nodes are distributed on different places of structure to gather the structure response. Therefore, the sensing area of SHM is small scale and the nodes should response only if it finds a problem in the structure. In this situation, the proposed algorithm BUCA is suitable for detecting the location of damaged structure. This data is then transmitted through Base Station to the destination. In BUCA, the group of sensor detect damage event fully changes over time.

VI Application of FUCA in Habitat Monitoring

In WSN, the Habitat Monitoring necessitate each node should detect the environmental condition periodically and forward the detected data to the BS [17]. In temperature monitoring application, there is only one report from each sensing area. Hence, one temperature record from each CH is adequate if the communication range of each sensor node located roughly 10 meters to 15 meters with multi-hop communication [18]. The habitat monitoring is a large scale WSN and difficult to recharge in sensing field. In habitat monitoring, each node send the collected data to the BS if any unexpected even occur in sensing field. Therefore, it is necessary to elect the optimized CH for monitoring the node to a longer life. The optimized cluster head algorithm is chosen for detecting the event in unattended environment. In OUCA, the clusters are constructed evenly over the sensing area. It also reduces the amount of clusters to attain the energy efficiently and increases the rate of data transmission for each cluster member.

VII Application of FUCA in Home Control

In WSN, the application of Home control is a good illustration to provide control as well as protection at home [19]. The UCAPN algorithm is suitable for the application of home control which provides the detail data about electric, gas and water usage by distributing the sensor network in the specified area at home. The proposed algorithm also provides the automatic announcement upon discovery of some unused activities in the home.

VIII SIMULATION AND RESULTS

The performance of proposed framework is evaluated by conducting a series of simulation. In the experiment, a network of 50-250 sensors is consistently distributed in square field with the radius 200m *200m. After the formation, nodes become static, no longer moving. Assuming the Base Station is placed at the center of the sensing area; experiment is carried out on the factor of energy depletion, network lifetime and average delay time.

1 Scenario-1 - Performance evaluation of FUCA in Habitat Monitoring

The proposed framework is analyzed itself to select the best proposed algorithm for specified applications. In this scenario, the nodes are distributed in the sensing field of monitoring the habitat of weather based on the temperature and humidity. The result of the proposed framework is analyzed according to the performance metrics of energy consumption, network lifetime, cluster formation and amount of clusters formed closer to the Base Station. In this scenario, there are 1000 nodes are distributed in the sensing arena with the initial energy of 5J.

1.1 Experiment 1- Performance evaluation of FUCA based on Energy Consumption

The energy consumption of the proposed algorithms are analyzed over time. The Figure 2 show that the OUCA consumes less energy related than the other proposed algorithms MinD-CDS, FPUCA, BUCA and UCAPN. The proposed algorithm UCAPN consumes 19% of more energy than the proposed algorithm OUCA and BUCA consumes more than 12% energy than OUCA.

In UCAPN, the CHs are re-selected periodically which will consume extra energy. The FPUCA spent some more energy for forecasting the energy level of each sensor node at discrete interval of time. In MinD-CDS, more number of communicating nodes are participated to transfer a data by constructing clusters with smaller in size using CDS. But in OUCA, the Hitting Set is applied over the dominating set to elect the optimized CH and to reduce the amount of communicating nodes for data transfer. Therefore, the proposed algorithm OUCA consumes less than 6% of energy than MinD-CDS.

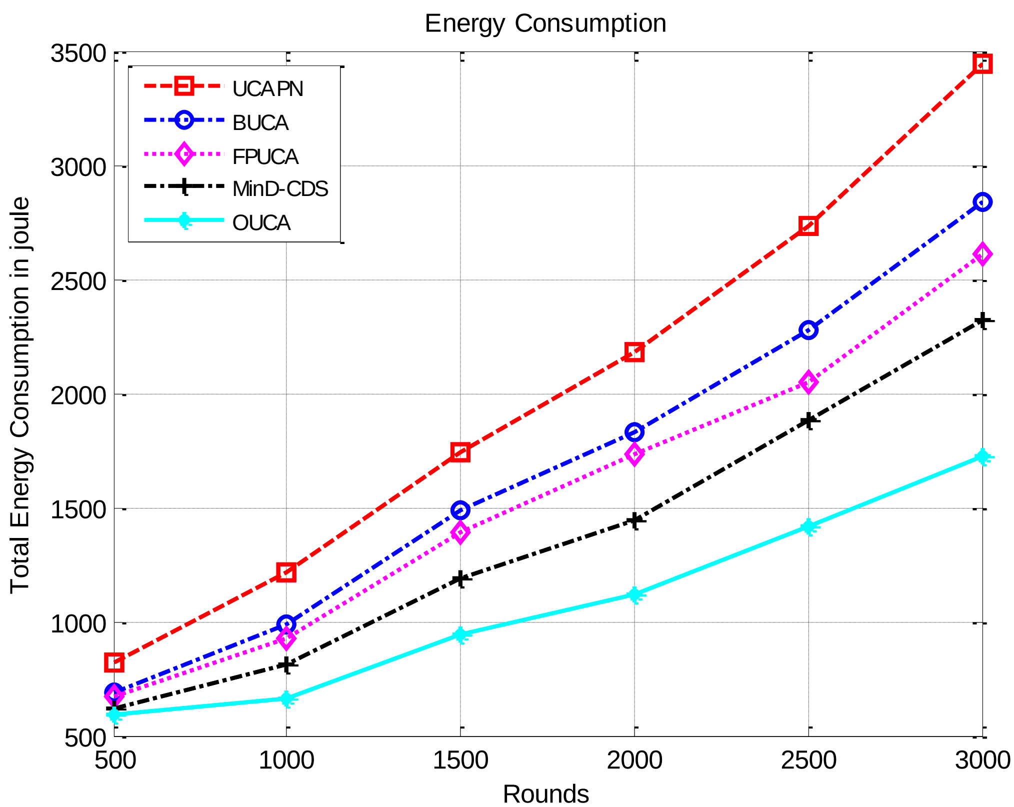

Figure 2. Energy consumption in the sensing area of Habitat monitoring

Table 2. Energy consumption in the sensing area of Habitat Monitoring, Number of Rounds vs. Total Energy Consumption in Joule

Rounds in Sec.	UCAPN	BUCA	FPUCA	MinD-CDS	OUCA
500	822	692	671	616	593
1000	1211	983	923	813	662
1500	1745	1483	1391	1187	947
2000	2184	1826	1736	1446	1120
2500	2733	2273	2048	1882	1414
3000	3440	2841	2612	2321	1726

1.2 Experiment 2 - Performance evaluation of FUCA based on Network Lifetime

The network lifetime is analyzed by varying the distance from Base Station along with the time. The Figure 3 shows that the OUCA extends the lifetime of the network by 23% over UCAPN, 14% over BUCA, 12% over FPUCA and more than 7% to MinD-CDS. In OUCA, the energy consumption among the sensor nodes are minimized by electing an optimized Cluster Head. Therefore, OUCA extends the lifetime of the network efficiently than other proposed algorithms.

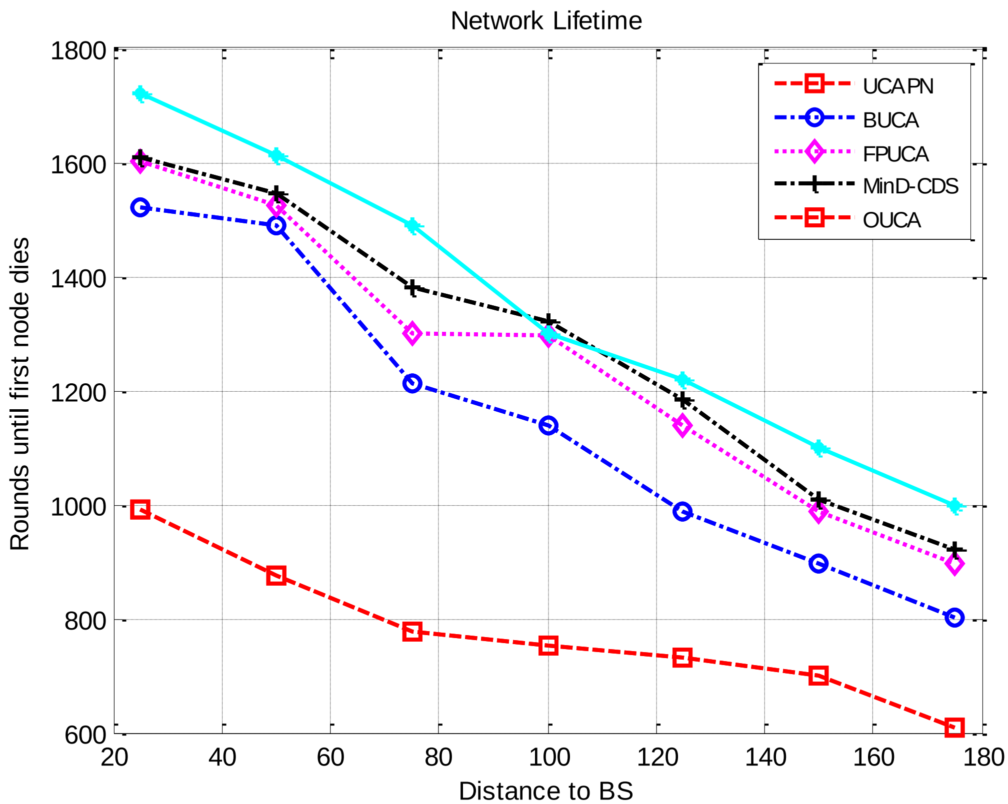

Figure 3. Network Lifetime for Habitat Monitoring

Table 3. Network Lifetime: Distance to the Base Station Vs. Time for first node dies

Distance to BS	**UCAPN**	**BUCA**	**FPUCA**	**MinD-CDS**	**OUCA**
25	**990**	**1520**	**1600**	**1608**	**1720**
50	**876**	**1488**	**1526**	**1545**	**1612**
75	**778**	**1211**	**1301**	**1380**	**1489**
100	**753**	**1140**	**1298**	**1320**	**1301**
125	**732**	**989**	**1140**	**1183**	**1221**
150	**701**	**896**	**989**	**1010**	**1101**
175	**609**	**802**	**898**	**921**	**998**

1.3 Experiment 3 – Performance evaluation of FUCA based on Cluster Formation

In experiment 3, the performances of the proposed algorithms are analyzed according to the amount of clusters formed by varying the number nodes from 200-1000. In MinD-CDS, the CHs are selected according to the parameters of high remaining energy and minimum node degree. The number of nodes in the cluster is reduced and the numbers of clusters are increased. The proposed algorithms UCAPN, BUCA, FPUCA and OUCA elect the CH according to the maximum remaining energy, distance from BS and number of neighbors. Figure 4 depicts, the proposed algorithm MinD-CDS constructs more number of clusters compared than other proposed algorithms. MinD-CDS construct the virtual backbone to provide an efficient data transfer among the sensor nodes.

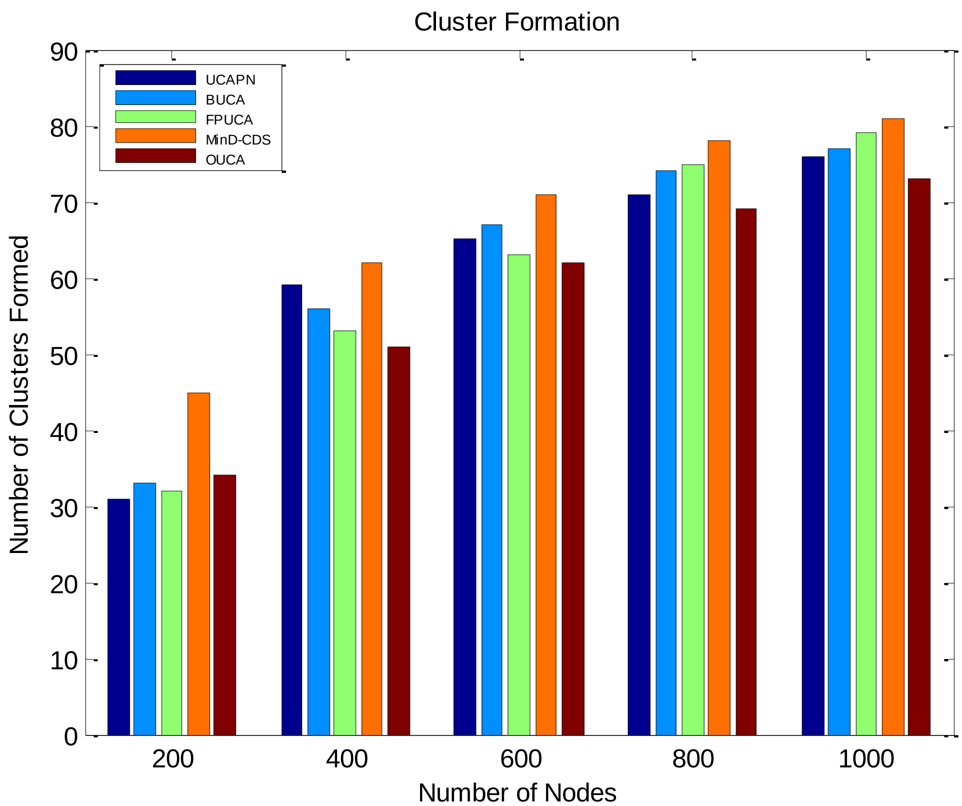

Figure 4 Cluster formation in Habitat Monitoring

1.4 Experiment 4 – Performance evaluation of FUCA based Amount of clusters closer to the BS

In order to protect from hot spot issue, the proposed algorithms use a competition radius for partitioning the sensing field into layered architecture which helps to constructs the unequal size clusters. The layer nearer to the BS has more amounts of clusters than farther away from BS. In this framework, the MinD-CDS constructs more amounts of clusters closer to the Base Station compared to other proposed algorithms. MinD-CDS uses the Connected Dominating Set with minimum node degree to select the CH. Hence, it reduces the number of nodes in every cluster and maximizes the amount of clusters especially nearer to the BS. In OUCA, the communicating nodes are reduced by applying the Hitting Set over a dominating set which will results the number of clusters is reduced compared than MinD-CDS. The MinD-CDS construct 6.2% of clusters more than OUCA. The proposed algorithms UCAPN, BUCA and FPUCA constructs approximately equal number of clusters closer to the BS and construct 13% of clusters less than MinD-CDS.

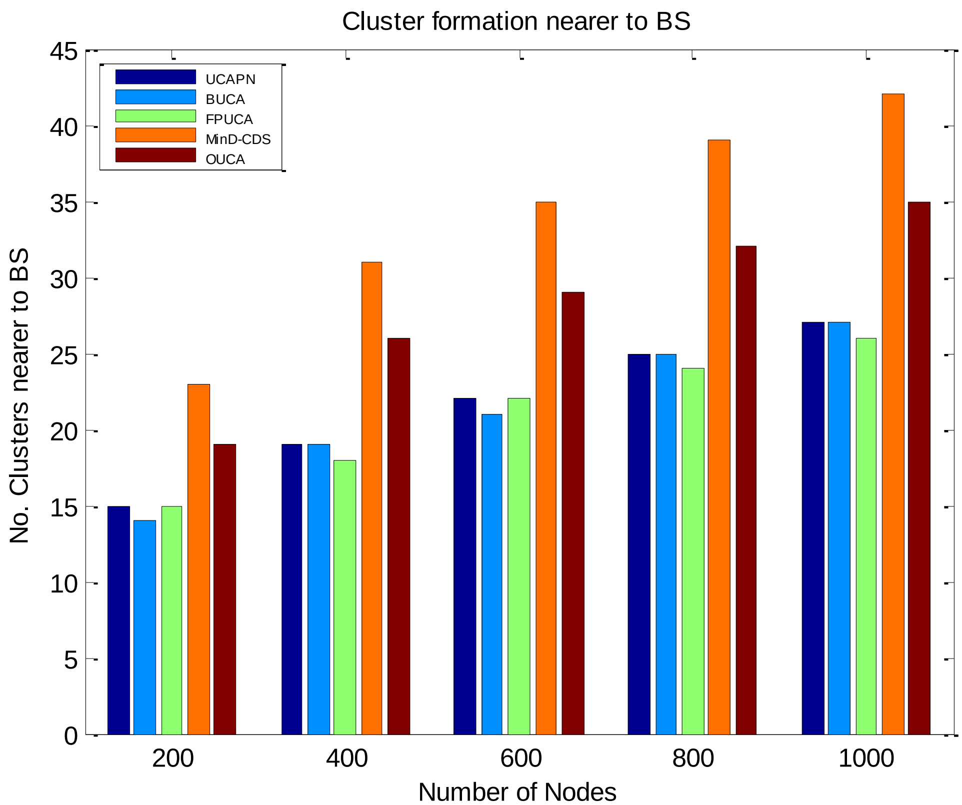

Figure 5 Clusters Nearer to the BS in Habitat Monitoring

Conclusion

From the scenario 1, the proposed algorithm OUCA consumes less energy and maximizes the network lifetime by reducing the communicating node by electing an optimized Cluster Head. But in cluster formation and in amount of clusters closer to the BS, the algorithm MinD-CDS constructs 6% of clusters more than OUCA. In clustering, the communicating nodes are responsible for collecting and conveying data to the Base Station. Therefore, communicating nodes consume more energy than other nodes. The proposed algorithm OUCA decreases the number of communicating nodes and energy consumption is balanced among the sensor nodes. The network lifetime is increased by minimizing the energy depletion of the sensor nodes. Hence it is found that OUCA is suitable for Habitat monitoring application in WSN.

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