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Cluster Head Rotation in Wireless Sensor Network: A Simplified Approach

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Abstract

Wireless sensor network (WSN) is a collection of sensor nodes deployed in the sensing space that coordinate wirelessly to communicate information to base station. In network layer, to ease communication overhead and to determine route from sensor node to base station, sensors can be organized into collection or groups known as clusters. Each cluster is headed by a cluster head. The cluster head is responsible for entire communication that takes place between the cluster and the base station. In a cluster, energy consumption of a cluster head is relatively greater than that of cluster members as they receive data from members as well as sense data, process the data and communicate the result of processing to the base station. This implies for uniform depletion of nodes energy level, design of an efficient cluster head rotation schema is necessary.

This works aims at devising an energy efficient cluster head selection and rotation mechanism with an objective to avoid repeated clustering during each round and emphasize on transferring role of being cluster head to the next nearest node from the initial cluster head based on Received Signal Strength Indicator reading.

Keywords: *Wireless Sensor Network (WSN), Cluster Head, Received Signal Strength Indicator (RSSI)*

1. Introduction

Wireless sensor network is a collection of multiple sensors deployed randomly or deterministically cooperating to monitor physical environment and acquire information, which is then wirelessly communicated to the base station after processing. Sensors are type of devices that converts physical parameters into digital form which can be processed further to derive bases for quality decision. A sensor node also contains processing unit, communicating unit and storage unit. With the advancement in technologies, miniaturization of computing and sensing components and wireless communication resulted into widespread use of wireless sensor networks.

WSN although being efficient suffers from several inherent challenges and constraints,

- the nodes are provided with limited power supply (*e.g,*: battery), their energy must be used in optimal and effectively to complete mission time efficiently.
- once sensor nodes are deployed, they must first startup, configure and organize them self in the network.
- further, due to wireless communication, sensor networks suffer from various constraints, eg: attenuation, interference, security *etc*.

Therefore protocols and algorithm of WSN must operate efficiently in resource constraint devices.

The main objective of the sensor nodes is to sense the data and send it to the base station. The direct transmission of the data to the base station is not appropriate because of inherent distance between peers and increased communication overhead. So, an appropriate clustering technique is to be used in order to efficiently cluster sensors into

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group related by factor such as distance around a randomly or deterministically selected cluster head. The cluster head receives information from the sensors, aggregates and then communicates to the base station as shown in Figure 1.

Clustering is a hierarchical based routing technique in which deployed nodes are grouped into clusters. One of the nodes from cluster is selected as the cluster head which is responsible for communicating information to base station. All other nodes known as cluster members communicates directly to cluster head which implies all communication to base station passes through cluster head. Other than routing, clustering also facilitates in-network data aggregation, duty cycling and reduce collision in wireless channel.

In abstraction it can be concluded that formation of clusters, cluster head selection and rotation in case of wireless sensor networks is a challenging filed of research that calls for development of techniques that efficiently handles the task listed above as well as saves energy to increase the network life time.

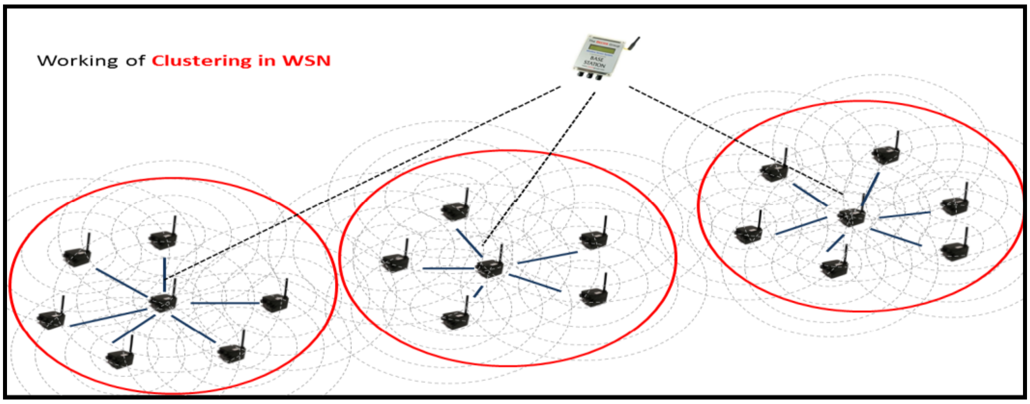

Figure 1. Clustering in WSN

Need for cluster head (CH) rotation can be explained using law of conservation of energy [7]:

Energy utilization of cluster member (E_{CM}) can be expressed as sum of energy required for sensing and transmitting information to the cluster head.

$$E_{CM}=E_{sense} + cE_{TX} \ldots\ldots \text{equation 1}$$

Energy utilization of cluster head (E_{CH}) can be expressed as sum of energy required for sensing, collecting information from its members, processing information so as to reduce communication overhead and transmitting the same to base station.

$$E_{CH}=E_{sense} + n(E_{RX})+E_{process} + CE_{TX} \ldots\ldots \text{equation 2}$$

where

CM=cluster member
$E_{process}$=In-network processing energy
c,C=Constant, C>>c
E_{sense}=Energy required for sensing
n=number of cluster members

From equation 1 and 2, it can be concluded that energy utilization of cluster head is very high as compared to the energy utilization of cluster member

$$E_{CH}>>E_{CM} \ldots\ldots \text{equation 3}$$

Therefore, in order to prevent rapid depletion of energy of a node nominated as cluster head, this role should be rotated amongst members in the cluster.

Energy Model under Consideration for Low Energy Radios [9]:

- Energy dissipated for radio transmission $E_{Tx}(k,d)$ of a message of '*k*' bits over distance *'d'*

$$E_{Tx}(k,d)=E_{Tx\text{-}elec}(k)+E_{Tx\text{-}amp}(k,d)=E_{elec}*k+E_{amp}*k*d^2 \quad \text{……..equation 4}$$

- Energy dissipated for reception $E_{Rx}(k)$ of a message of 'k' bits

$$E_{Rx}(k)=E_{Rx\text{-}elec}(k)=E_{elec}*k \quad \text{……….equation 5}$$

where $E_{Tx\text{-}elec}(k)$: transmitter circuitry
$E_{Tx\text{-}amp}(k,d)$: transmitter amplifier
E_{elec}: transmitter or receiver circuitry dissipation per bit
E_{amp}: transmit amplifier dissipation per bit

2. Literature Survey

In this work [6] various clustering strategies have been discussed in detail. These are classified into deterministic, adaptive and hybrid approaches. In deterministic approach [1], predefined sequence is pursued to exchange the role of cluster head amongst the nodes. In adaptive mechanism, depending upon the situation of current network configuration, clustering of nodes is performed. It can be base station assisted or self assisted. Hybrid approach combines both deterministic and adaptive techniques based on the temporal requirement of network.

Least Rotation Near- Optimal cluster head rotation strategy has been proposed by Wu *et. al.*, [7] in which dynamic programming method has been used for energy efficient cluster head rotation for increasing network life time. Here, the upper and the lower bound of the cluster life time are determined taking into account law of energy conservation. The devised mechanism has concluded that the life time is more biased towards upper bound. In comparison to LEACH, this technique relies on rotation of cluster head rather than re-election in each round. This work can be advanced by taking into account certain heuristics based relationships to determine optimal threshold for duration till which a cluster head performs its role.

In this work [2] proposed by Suresh *et. al.*, initially the base station determines the location information and residual energy of all the nodes in the deployment area and then uses K-means technique for formation of clusters. The clustering is performed by including the nodes in the cluster that is at shortest distance to the mean of the cluster. This technique heavily relies on the location information of the nodes which may make the mechanism cost ineffective. This technique incurs greater energy if the base station in located at a farther distance from the sensor nodes. Hence, this technique lacks self-organization of nodes into cluster and relies on the ability of the base station.

Gamwarige *et. al.*, proposed [8] an energy driven cluster head rotation mechanism is devised where in a predefined threshold on the residual energy governs the cluster head rotation. In this scheme a designated cluster head acts as a cluster head till the residual energy does not fall below the threshold. The efficiency of the technique may be enhanced by devising a mechanism that aids in determination of optimum threshold value.

In this work [9] performed by Heinzelman *et. al.*, cluster head is determined based on a randomly generated number and a self-status maintained by the nodes that keeps track of itself acting as cluster head in the previous rounds. In addition to this a threshold value is associated to the control the selection of cluster heads. This process may lead to creation of variable sized clusters that would result in nonuniform dissipation of residual energy. It calls for re-clustering every time a new round is initiated which incurs greater computational and communication overhead.

In this technique proposed by Kumar *et. al.*, [4] the base station creates logical radial bands in the network. The logical bands are created in a manner that the grid nodes are in between radial bands. These grids nodes are orthogonally oriented with respect to the base station. The association of sensor nodes to the grid nodes is assisted by base station. These grids nodes act as cluster heads. This approach is most suitable for situations where in base station is located at a shorter distance from the sensor deployment area.

In this work [3] proposed by Singh *et. al.*, the cluster head collects location information of all the sensors deployed in the sensing area. The sensing area is then portioned in to zones; subsequently from each zone a cluster head is randomly selected. The cluster head rotation is performed by determining the nearest friend that has maximum residual energy. The method is refined by creating homogeneous cluster for reducing frequent clustering and to conserve energy.

In this work [5] performed by Zytoune *et. al.*, the sensing area is composed of heterogeneous nodes *i.e.*, nodes with different configurations namely normal nodes and advanced nodes. The base station is placed at the center of the deployment area for efficient communication. Here, the nodes compete to nominate self as cluster heads with advanced nodes having high chances for the same. The cluster performs the role many rounds to minimize the communication overhead.

3. Proposed Solution Strategy

Once the sensor nodes are activated on deployment, sensor node goes into idle mode for period of time generated through randomization. Node self elects oneself as cluster head and sends advertisement message to all other node within its range. Upon receiving response from the collaborating nodes, it decides to continue as cluster head or to join any of the other existing clusters.

Upon formation of clusters, successive cluster head in each individual clusters are selected by radial diverging from initial cluster head. That is, in each round, current cluster head nominates successor cluster head based on the information collected by initial cluster head. This information contains identification of all members sorted as per Received Signal Strength Indicator (RSSI) reading with respect to initial cluster head and is stored in a packet called NODE packet. RSSI is a measurement of power present in a received radio signal. In each round, successor cluster head is the node whose ID is in next location in NODE packet. Current cluster head communicates this packet to their successor cluster head. The nominated cluster head thus, is the next nearest node from initial cluster head. This technique can be classified as hybrid method as it combines the feature of both adaptive and deterministic methods.

Communication overhead is minimized by only rotating the responsibility of cluster head rather than re-clustering in each round. This technique further reduces energy consumption by using only one control packet (NODE packet) for performing cluster head rotation.

The devised technique can be explained with the help of following steps,

Step 1: The initial cluster head creates node packets which includes identification of all the nodes in the cluster sorted as per their RSSI reading, and also includes its own identification with RSSI as 0

Step 2: The current cluster head sends the node packet to the node that is nearest to it based on the initial information in the node packet

Step 3: Nominated node on receiving the node packet, create TDMA schedule and broadcast to all

Step 4: Cluster member on receiving TDMA starts communication in their allotted slot with the cluster head
Step 5: After each round, present cluster head nominates next cluster head, goto step 3 until simulation time ends

The efficiency of the implemented process was assessed in terms of energy efficiency, reduction in number of packet communication and the network lifetime (in terms of First Node Dead and Half Node Dead) against the ability of the cluster based technique (reference LEACH protocol). The implementation was done using Castalia framework of Omnet++ networking tool kit.

Simulation parameters:
Number of nodes : **100**
Area : **(70 x 70) m^2**
Simulation time (s) : **{50,100,150,200,250,300}**
Data packet size (B) : **2000**
Deployment : **Randomly uniformly distributed**
Mobility : **Static**
Radio module : **CC2420.txt**
E_{elect} : **50 nJ/bit**
E_{amp} : **0.00134 pJ/bit/m4**
E_{aggr} : **5 nJ/bit/signal**

Example: If the nodes with node ID 32, 17, 87 and 62 are cluster heads in round 1 with 11, 21, 19 and 27 members respectively. Cluster head with ID 32 creates NODE packet containing ID of all nodes sorted as per RSSI reading as 32, 95, 64, 21, 61, 70, 23, 89, 18, 68, 79 and 67. For subsequent rotation of cluster head, node 32 sends this packet to node 95. Node 95 on receiving NODE packet declares itself as cluster head is continues the responsibility. Next cluster head for round 2 is 95 followed by 64, 21 and so on.
Likewise similar configuration is maintained by other cluster head's as well.

3.1. Simulation Results

Simulation inferences for performance assessment of the proposed technique in comparison with CBA:

The first and the most significant parameter assessed was consumed energy at the end of each simulation. The simulation results taking into consideration 50, 100, 150, 200, 250, 300,350,400,450 and 500 seconds is shown in Table 1.

Table 1. Consumed Energy (measured in Joule)

SIM-TIME(s)	PROPOSED TECHNIQUE(PT)	CBA
50	1.268	1.733
100	2.66	3.295
150	3.975	4.746
200	5.746	6.064
250	7.449	8.456
300	9.299	9.886
350	11.245	11.974
400	13.289	14.254
450	15.408	15.877
500	17.206	17.976

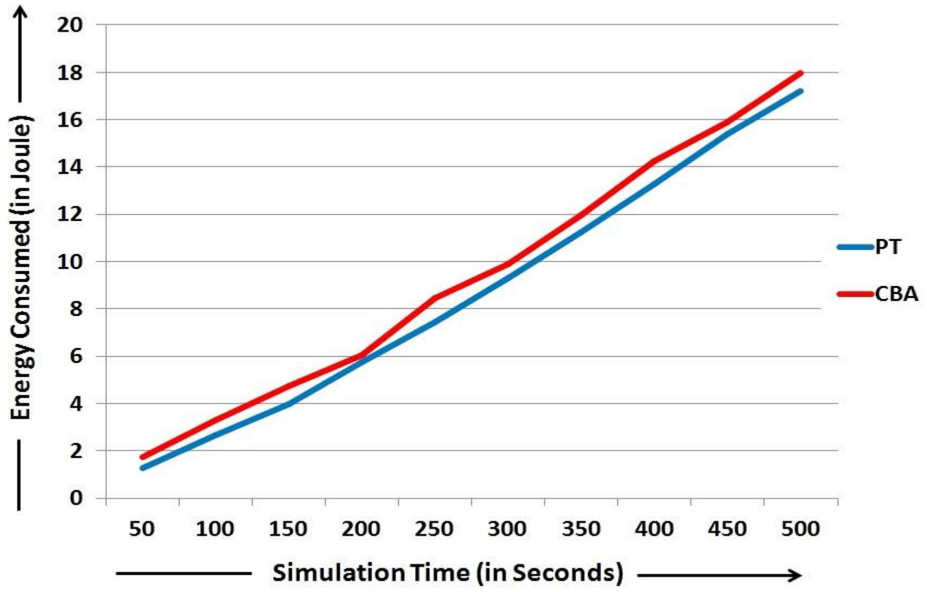

Figure 2. Energy Consumption

It was observed that there is a reduction of 7% in energy consumption in comparison to CBA as represented in Table 1 and Figure 2.

Number of packet transmission at the end of simulation was the second parameter that was assessed.

Table 2. Number of Packet Transmission

SIM-TIME(s)	PROPOSED TECHNIQUE(PT)	CBA
50	130	170
100	100	208
150	220	290
200	280	416
250	350	520
300	490	624
350	550	690
400	580	730
450	640	810
500	730	890

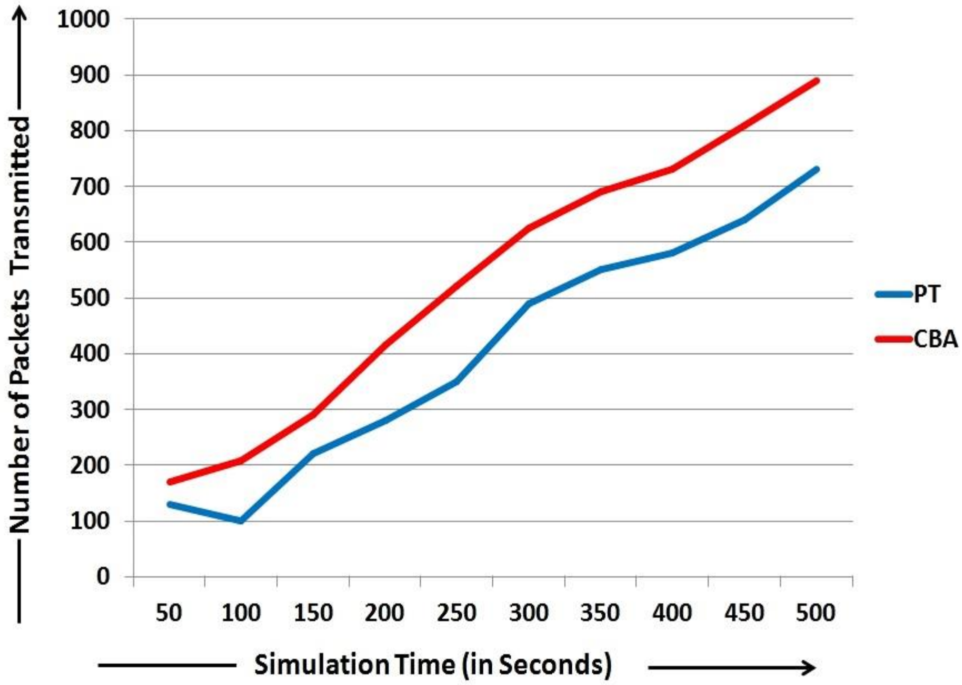

Figure 3. Number of Packet Transmission

It was observed that there is a reduction of 31 % in packets transmission in comparison to CBA as represented in Table 2 and Figure 3.

Simulation inferences for analysis of network life time of proposed technique in comparison with CBA:

The number of nodes which became dead after simulation is initiated was compared for both the protocols. A node is declared dead when its energy becomes zero and it cannot contribute to the network anymore. Network lifetime is calculated by determining First Node Dead (HND) and Half Node Dead (FND). We can conclude that proposed technique extends the network lifetime compared to CBA, as the nodes dead during simulation was faster in CBA than in proposed technique. This can be explained by the following simulation results,

Simulation parameters:

Number of nodes	: **100**
Area	: **(70 x 70) m^2**
Simulation time (s)	: **250**
Data packet size (B)	: **2000**
Deployment	: **Randomly uniformly distributed**
Mobility	: **Static**
Initial energy	: **8 Joule**
Radio module	: **CC2420.txt**
E_{elect}	: **50 nJ/bit**
E_{amp}	: **0.00134 pJ/bit/m4**
E_{aggr}	: **5 nJ/bit/signal**

Table 3. Network Life Time

	Half Node Dead		First Node Dead	
Number of nodes	PROPOSED TECHNIQUE(PT)	CBA	PROPOSED TECHNIQUE(PT)	CBA
100	150.01	159.71	117.72	117.85
200	118.46	157.87	117.70	117.74
300	118.87	158.67	117.66	117.91
400	106.36	119.00	117.70	117.71

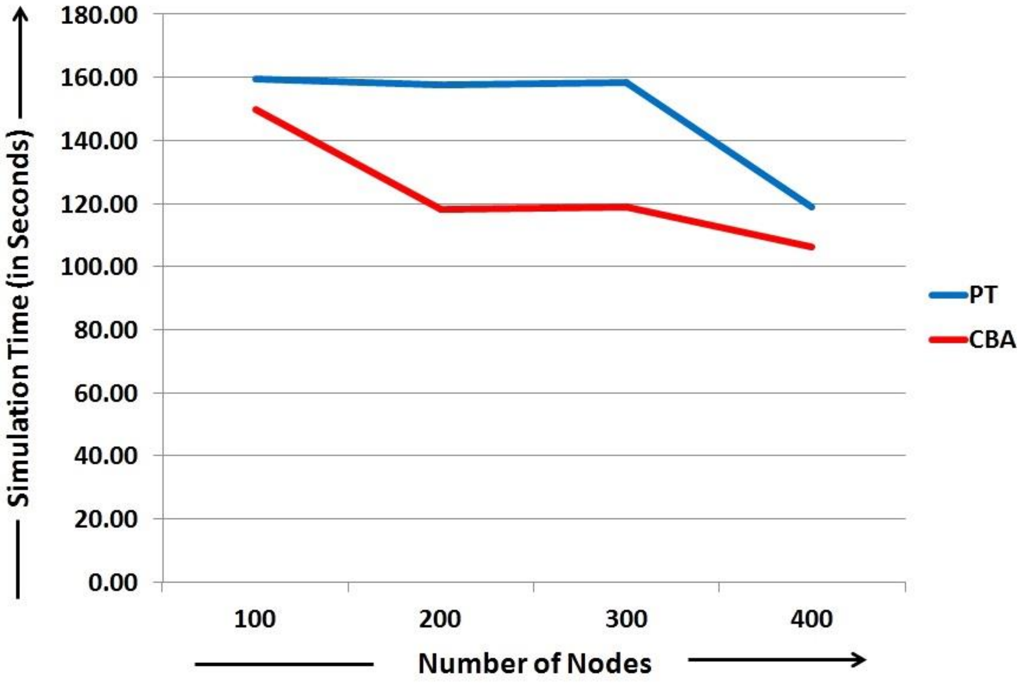

Figure 4. Half Node Dead (HND)

It was observed that the 50% nodes (Half nodes) in CBA died 20% times faster than compared to that of the proposed technique, making the proposed technique more efficient than that of CBA as represented in Table 3 and Figure 4.

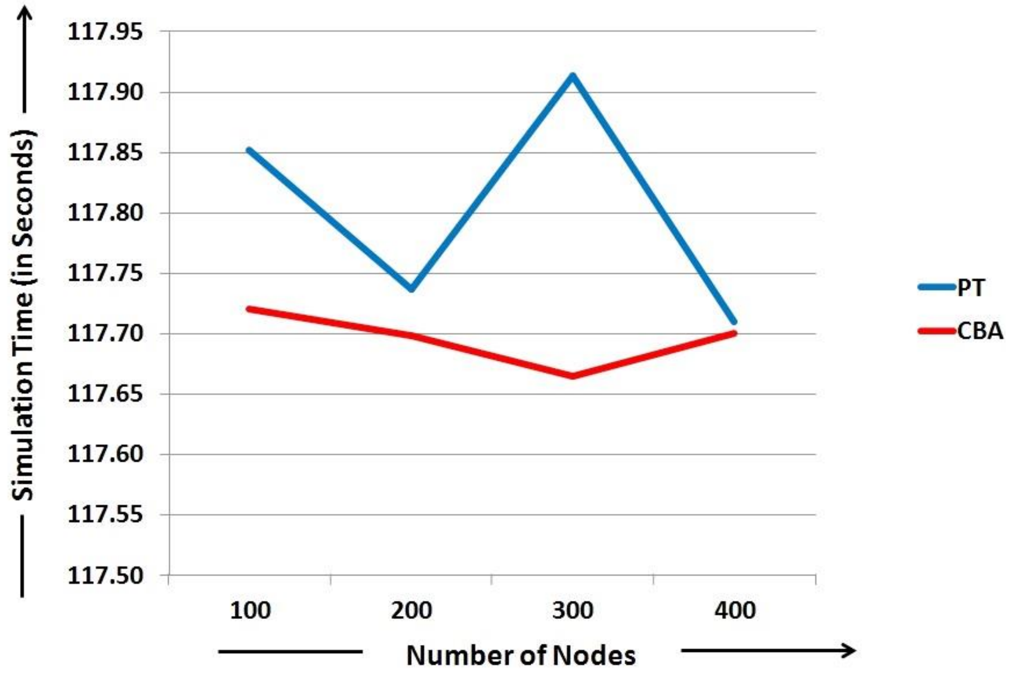

Figure 5. First Node Dead (FND)

It was observed that the first node in CBA died 0.09% times faster than compared to that of the proposed technique, making the proposed technique more efficient than that of CBA as represented in Table 3 and Figure 5.

4. Summary and Conclusion

In wireless sensor network, replenishment of energy for sensor node is a big challenge as these nodes once deployed may not be physically accessible; in addition transmission of large data packet increases communication overhead leading to increased consumption of energy. The efficiency of wireless sensor network greatly relies on the ability of sensors to manage their residual energy. In this work an attempt has been made to devise mechanism for generating equi-sized clusters, efficient cluster head rotation and efficient aggregation in a wireless sensor network for optimizing energy usage for increasing the life time of the network.

Such mechanisms can be used for wireless sensor networks deployed in situations where the sensor nodes are expected to sense the environment for prolonged period of time. It is highly suitable for sensor network deployed for monitoring forest fires, soil and ecological monitoring for agricultural projects, for determining parameters for concluding with vulnerable susceptibility of structural health of infrastructures as a consequence of natural or anthropological changes, temperature monitoring of glaciers for predicting GLOF (Glacier Lake Outburst Flooding) and many more.

It was observed that in comparison to the CBA the proposed technique has,

- reduction of 7% in energy consumption in comparison to CBA while selecting subsequent cluster heads
- reduction of 31 % in packets delivered in comparison to CBA during interaction
- it was observed that the HND in CBA is 20% times faster than compared to that of the proposed technique
- it was also observed that the FND in CBA is 0.09% times faster than compared to that of the proposed technique

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