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An Efficient Energy Saving Scheme Through Sorting Technique for Wireless Sensor Network

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ABSTRACT

The role of a sensor is to sense and gather the information from both remote and domestic zones. Wireless sensor network (WSN) is still emerging to exploit its uses in new extents, though, a lot of works have been done such as habitat monitoring, health care, agriculture, seismic effects, etc. This work focuses on prolonging the lifetime of the WSN through optimizing its energy consumption. The miniature size of the sensor leads to the restrictions with power, lifetime, and memory. In traditional approaches, energy management has been done at the sensor node level whereas, in this work, we focus on cluster-level for energy management. The proposed algorithm named as Residual Energy Adaptive Cluster Head Selection Algorithm (REACH) is a simplified cluster formation process. REACH focuses on uniform energy-based cluster formation for the efficient energy management. The simulation results shows the outperformance of REACH over heterogeneous Stable Election Protocol (SEP) and homogeneous Low Energy Adaptive Clustering Hierarchy (LEACH) in terms of life time and dead node ratio.

Key words: Wireless Sensor Network, Heterogeneous, Homogeneous, Residual Energy, Energy Management.

1. INTRODUCTION

Wireless Sensor Network is playing a very significant role in collecting information from the environment where human interaction is quite impossible. Many applications have so far developed to maintain the role of sensor nodes, such applications are disaster relief, health care, military defense, etc. The deployment may be centralized or distributed based on network requirements. The implementation of this wireless network was developed by the military to monitor the movement of enemies. Later on, it has immerged to a large extend in various fields as mentioned above. Nowadays nature-inspired meta-heuristic approaches have to make a tremendous change in optimizing SN performance by considering the constraints such as lifetime, energy consumption, memory, etc. Apart from all its limitations, energy optimization is a major concern to prolong the networks lifetime. Initially, every sensor node used to collect the data from the environment and then propagate it to the base station (BS) where a lot of energy is consumed. Later on, the clustering concept brought a breakthrough to reduce the activities of the sensor node to a large extend that consumes less energy as compared to earlier communication strategies. Now, most of the researchers are using clustering techniques as a sub-process to optimize the energy as well as to increase the lifetime of the network. Our work is also motivated by one of the natures inspired approach called the chameleon attack principle [2]. Normally in chameleons attack, the predator approaches towards prey by measuring the gap which must be in the range of its tongue. The sensor nodes in the network are very much limited to its resources and computing capacity, due to its tiny nature [3]. Hence, to increase the lifetime of the sensor network, energy management needs to be focused. Sensor nodes are deployed in various environments where human intervention may be possible or not based on the condition. This is the actual reason why a lot of researches are carried out in the energy management domain of WSN [4]. In this work, we have focused on the above-said constraint.

The implementation of WSN has been extended from domestic to hostile environments like defense, medical, habitat monitoring, natural calamity monitoring etc. The WSN is an indeed technique explicitly for those operations where life risk is there like volcanic or seismic effects. In these situations, battery depletion rate monitoring is one of the primary criteria for accurate monitoring. In this line of thought, the clustering is one of the efficient methods which prolongs the sensor network lifetime [2] [3] [4]. The direct communication between the sensor and base station can be avoided by forming small groups or clusters of sensor nodes.

During this process, several factors can be considered and the inter-neighbor-node (INN) gap and residual energy falls under that [5] [6] [7].

This paper focuses on the improvement of an energy-efficient clustering algorithm by extending the existing algorithms LEACH and SEP. For our work, we have considered homogeneous energy level among sensor nodes and the nature of sensor nodes are static [8]. Our proposed algorithm is a mimic of the chameleon attack which executes in two phases. The first phase implemented the calculation of residual energy of SNs and sorting them in descending order. From the sorted value, the top 10% of High residual energy-based nodes clubbed in a set called CH-set. And the second part of execution is responsible for cluster formation by measuring the INN gap which is based on nature-inspired phenomena. Our proposed procedure advocates against the adopted sub-operations by our existing traditional algorithms LEACH and SEP. The simulation and evaluation of REACH are compared against the above said traditional algorithms individually. In our clustering process, we also paid the same level of attention to the energy-saving scheme [9] .

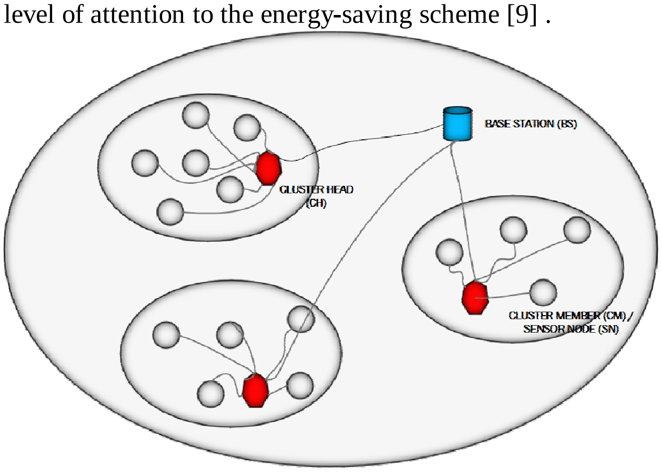

Figure 1: WSN architecture

In a cluster-based design, the SNs are partitioned into a few gatherings known as clusters. Each cluster has an administrative node named as CH. All the SNs sense neighborhood information and pass it to their respective CH [10]. The CHs at that point total the nearby information lastly send it to the BS straightforwardly or utilizing different CHs. Figure. 1 displays the architecture of a cluster-based WSN. Following are the advantages of a cluster-based WSN:

- The concept of data aggregation is enabled at CH for eliminating uncorrelated and redundant data. To transmit 1 bit of data, the energy dissipated can also be used in a high amount of data aggregation. Hence the reduction in consumption of energy is done by propagating aggregated data apart from sending a large amount of redundant data [11].
- Since SNs communicate with their CHs, it conserves communication bandwidth and avoids the exchange of redundant pieces of information among themselves [12].

The motivation of this proposed work is to develop an energy-efficient protocol for wireless sensor network which can outperform both in the homogeneous and heterogeneous environment.

The rest of the paper is organized as follows: Section 2 covers literature survey. Section 3 discusses the environment of simulation. Section 4 focuses on proposed REACH algorithm. The result and discussion has been covered under section 5. Section 6 presents the conclusion with future probability.

2. LITERATURE REVIEW

The extensive literature survey concludes the variations in the energy management process. Several factors influence the clustering process such as static, dynamic, centralized, or distributed, etc. Out of all such approaches, LEACH (Low Energy Adaptive Clustering Hierarchy) is the hierarchical algorithm that works towards the lifetime of WSN. The random rotation of the cluster head selection method enables the LEACH to maintain the energy balance among the sensor nodes [13]. The LEACH primarily works in a homogeneous environment. The proposed stable election protocol (SEP) is an improvised version of LEACH which works in a heterogeneous environment [14]. This heterogeneous environment is the combination of two types of nodes such as normal node and high energy based node. Called advanced nodes As the advance nodes are used here, the network becomes heterogeneous in terms of the node energy. As the election of CH is done randomly in LEACH, but here in SEP probability is done by considering the initial energy of each node with the other nodes. It helps in extending the lifetime of the network as the first node dies lately, which is important for some applications [15,16].

In [17] a bio-inspired meta-heuristic cuckoo search was proposed to form clusters in an optimized way. Here the research scholar proposed a nesting concept with high accurate falsie node injection into others nest. In cuckoo search, the fitness function of sensor nodes is calculated by adding weight plus a degree of the node. This approach focuses to extend the life span of the sensor network by reducing the intra-cluster gap. In [18] the integration of harmony and the cuckoo were suggested to enhance the clustering technique and simultaneously an optimized routing protocol. In the initial part of the simulation, a cuckoo search was implemented to detect optimal CHs for clustering, and in the subsequent part; the harmony algorithm helps to choose an optimized route for transferring the information to the BS [19]. The integration of the genetic algorithm and fuzzy approach proposes a soft-computing based methodology for WSN. This method is the combination of three parameters like density, energy, and centrality [20]. This unique combination of parameters helps to find the most suitable CH with its position of allocation [21]. Though these algorithms are working fine but it has a major drawback related to cluster formations and cluster membership which leads to a short lifetime for WSN [22].

3. SYSTEM MODEL

3.1 Network Model

For our simulation, we have considered a bio-inspired meta-heuristic approach. We assume the following constraints such as all SNs are static, the network is the heterogeneous type and SNs are participating in data exchange. To reduce the amount of energy consumption during data transmission, we used the chameleon attack approach [9]

3.2 Radio Energy Model

The proposed algorithm actualizes the comparable technique for the radio model [10-11]. To achieve sensible Signal-to-Noise Ratio (SNR) in exchanging single bit information over a distance ***d***, the following equation will be used by us:

$$E_{Tx}(l, d) = l \times E_{elec} + l \times \varepsilon_{fs} \times d^2, \quad \text{if } d < d_0 \quad (1)$$
$$E_{Tx}(l, d) = l \times E_{elec} + l \times \varepsilon_{mp} \times d^4, \quad \text{if } d \geq d_0 \quad (2)$$

Here, $\mathbf{E_{elec}}$ denotes the amount of energy consumed for 1 bit of data transmission, that is used to enable transceiver. The amplification coefficient factors are denoted by $\boldsymbol{\varepsilon_{fs}}$ and $\boldsymbol{\varepsilon_{mp}}$. It represents the transmission amplifier in free space and multi-path respectively. $\mathbf{d_0}$ symbolizes the threshold value of the transmission distance. And for receiving a single bit of data, the amount of energy dissipated is calculated as follows:

$$E_{Rx}(l) = l \times E_{elec} \quad (3)$$

4. PROPOSED ALGORITHM

To prolong the network life time, we propose a residual energy-based clustering algorithm, called Residual Energy Adaptive Cluster Head selection algorithm (REACH) (*Ref.Figure 2*). The REACH basically considers equal load distribution among the sensor nodes. For that, REACH adopts a sorting mechanism to fom equal energy based clisters. To setup an environment for REACH, few constraints have been assumed or considerd. The constraints are:

1. The WSN is static inature.
2. In WSN all nodes including CH and BS knows the location of each other..
3. The dominated node CH is responsible for data accumulation.
4. The considered WSN is homogeneous in nature.
5. Energy investment solely depends upon the data size and distance.

The communication mode within WSN can be segregated into two types such as intra-cluster or inter-cluster communication mode [23]. The clustering process is dependent upon inter-cluster communication mode. The data transmission between sensor ndoes and CHs can made either through single-hop or multi-hop communication mode [24]. The CH is responsible to integrate the collcted data from indivudial sensors by removing unnecessary data. Further, the CH forwards that integrated data to the BS.

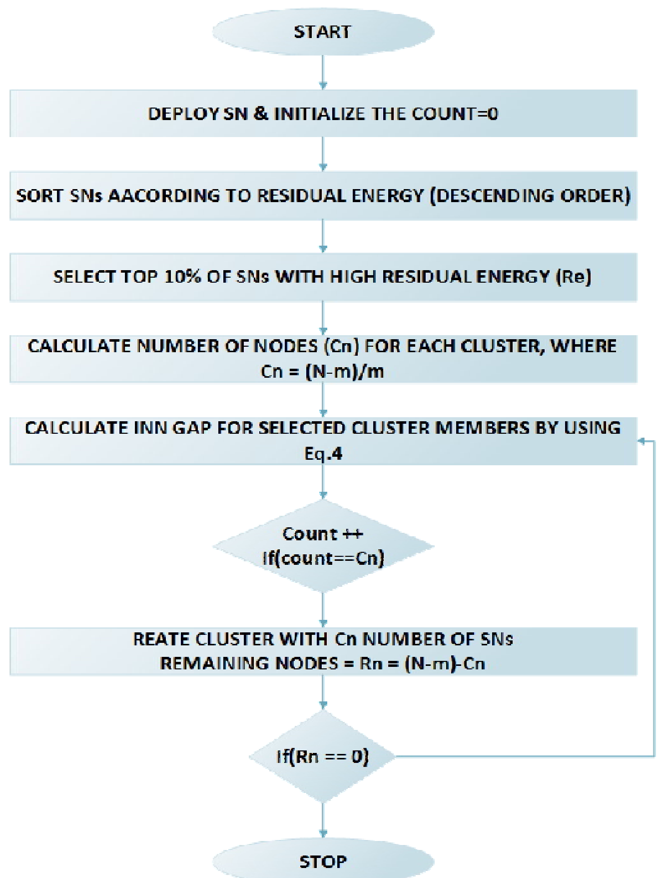

Figure 2: Flowchart of Proposed Scheme (**REACH**)

This indirect communication puts less pressure on the sensor nodes which leads to a long lifetime for the SNs and the network. By selecting a specific node as CH for each round leads to rapid energy depletion and that leads to new CH selection rounds. The cluster head selection round itself consumes a substantial amount of energy. So, by reducing such CH selection round the network life span can be enhanced. The proposed REACH algorithm works with the above theme where it creates equal energy-based clusters and reduces frequent CH selection processes. The residual energy (**R_e**) is the criteria for selecting the new CH.

Algorithm: REACH Algorithm (Proposed)

Assumption: Sensor nodes (SNs) are homogeneous by considering identical residual energy (R_e). *Where, R_e = Residual Energy, N =Number of Sensor Nodes, m = Number of Cluster Heads, C_n = Number of SNs in each Cluster, CH = Cluster Head).*

Input: Set of SNs S= {S_1, $S_{2...}$ S_N} and N is the total number of SNs. R_e of individual nodes is provided.

Output: Optimized cluster formation and optimized lifetime of the cluster.

Step 1: **Initialization**
For i=1 to N
Evaluate the R_e of each SN.
End
Sort, SNs according to R_e in descending order.

Step 2: Calculate the number of SNs in a particular cluster using Eq. 4
$C_n = (N-m)/m$ … (4)
Form CH-set with top 'm' SNs from the above-sorted list.

Step 3: Evaluate the INN gap of CH-set from the SNs using Eq. 5
For each node n_i, i = 1, 2, …, (N-m)
Calculate distance d (n_i, CH_e) between CHs and node n_i,
$d(n_i, CHe) = \min_{\forall e=1,2,\ldots,m}\{ d(n_i, CHe) \}$ … **(5)**

Step 4: Restrict cluster population
Initialize count=0
If (count==C_n)
Then (Form cluster)
Do {
(Remaining Node) $R_{mn} = (N-m)-C_n$ … **(6)**
} while (C_n==0)
Repeat Step 4 for each m while condition is true

Step 5: Repeat Steps (1-4) for new CH selection.

Step 6: Stop

A clustering-based protocol consists of four stages such as; (i) CH selection stage, (ii) Cluster formation stage,(iii) data aggregation stage, and (iv) data communication stage [25].

This whole process executes through two phases that are, setup phase and steady-state phase [26,27]. During the set-up phase, the sensor nodes are intimating about their remaining energy level with location information to the BS. Based on this data the BS calculated the average energy consumption by the sensor network. As CH is responsible for many other works like data aggregation, forwarding data to the BS hence, the sensor nodes which has the highest **R_e** is elected as CH. The proposed REACH algorithm makes ensure that the node with the highest **R_e** is only elected as CH[28,29].

The execution of the REACH algorithm has been processed through the following phases: In the initialization phase, SNs are randomly deployed in a target area. Next, the SNs are sorted according to **R_e** in descending order. Let the sorted list is represented as S. In the CH selection phase, to select the best CH, top 10% SNs have been chosen from the list S and a CH-set is formed. Now, these selected nodes will behave as a CH. In the third phase, the INN (Inter Neighbor Node) gap is evaluated, which is nothing but selecting cluster members for the CHs. The selection of cluster member processes for CH is inspired by nature i.e. the way chameleon attacks its prey. If the prey is coming under the range of chameleon's tongue length then it attacks that prey. In the same way, CH selects its member by evaluating the INN gap. Cluster formation phase: This is the final step of the setup phase.

REACH has adopted a different mechanism of cluster formation. Initially, one cluster member is assigned to each CH by using the INN gap. Suppose CH1 founds its first cluster member then CH2 will find its cluster member and this will continue till the last CHn. Again, the same procedure will continue for the next cluster member from CH1 to CHn. This will help in the uniform distribution of SNs in respective clusters. After cluster formation, data aggregation and data communication phases take place. The proposed REACH is unique in terms of several factors such as:

- It avoids the frequent involvement of SNs in the cluster formation process.
- It prolongs the network lifetime by voiding non-uniform cluster formation by considering the energy level.
- It maintains a synchronous energy depletion policy so that the entire cluster will uniformly deplete energy.
- The proposed algorithm has been compared against both homogeneous and heterogeneous clustering protocols.

The limitation of the proposed clustering scheme is, when the density of SNs increases it leads to form more numbers of clusters and CHs. This enhances the complexity of the algorithm. Secondly, the distribution of SNs must be scattered rather than clubbed. During clubbed environment, it may all the CHs or maximum of CHs could be deployed in a specific portion of the target zone. It happens as per the algorithm if the INN gap will be more between SNs and CH and that leads to more energy investment processes.

5. SIMULATION AND RESULTS

Table 1: Network Parameters

Parameters	**Value**
Number of nodes	100
BS Location	(50, 50)
Network Size	100 × 100
E_{elec}	50nJ/bit
E_{mp}	0.0013pJ/bit/m^4
E_{fs}	100pJ/bit/m^2
$E_{aggregate}$	5 n J/bit/signal
Percentage of CHs	10% of the total nodes
Initial Energy	0.5 J/node
Packet size	4000bits

The supercomputer (PARAM SHAVAK) with MATLAB-R2016A is used for the execution of the REACH algorithm [27]. An area of (100m × 100m) with 100 nodes is used as the setup environment. The initial energy for all the sensor nodes SNs is equal i.e. 0.5 Joule for each node. To maintain an approximately equal distance between the CHs and the BS the CH has been deployed at the location (50, 50) that represents the center point of the network. The other considered parameters are mentioned in Table 1. The second step of REACH includes sorting of SNs according to the Re whereas, it is not true for the first iteration due to the homogeneous nature of the network. From the 2nd round till the end of the process, the homogeneous network converted to heterogeneous type by varying Re. Hence, we have compared our bio-inspired meta-heuristic algorithm with both homogeneous and heterogeneous existing protocols such as LEACH and SEP respectively. The simulation of REACH is carried out in two scenarios.

5.1. Scenario 1: Homogeneous Environment

Initially, all the SNs will have 0.5 Joule as startup energy. Around 10% of the total nodes will be elected as CHs. The CHs will form clusters by applying "(4)".

$$d(n_i, CHe) = min_{ve=1,2,\ldots,m}\{ d(n_i, CHe) \} \quad (4)$$

Where, ***n*** denotes the number of nodes, CH as cluster head. The 2nd part of the equation calculates the minimum distance between ***n*** and 'CH' by varying i=1, 2, 3…n. Like other traditional homogeneous network protocols. We have done the comparison with the existing LEACH [22] protocol which is homogeneous. Figures. 3(a) and 3(c), presents the ratio between the number of dead nodes with the number of rounds for both REACH and LEACH respectively. Figures.3(b) and 3(d) presents the comparison between REACH and LEACH in terms of total average energy consumption respectively. The numerical computation of results represented in Table 2. In Figures.3 (a,b,c,d), we have presented the ratio between the number of dead nodes against numbers of rounds for both REACH and LEACH respectively.

Table.2: Comparison between REACH and LEACH

PROTOCOLS	LEACH	REACH (Proposed)
FND	509	**1320**
HNA	792	**1557**
AND	1174	**1674**

Table 2 illustrates the performance of REACH over LEACH. The performance has been recorded at different levels of (three different instances) such as First Node Dead (FND), Half Node Alive (HNA), and All Node Dead (AND). From this simulation REACH performs in an optimized way in comparison with LEACH by 41%, 39%, and 25% during FND, HNA, and AND respectively.

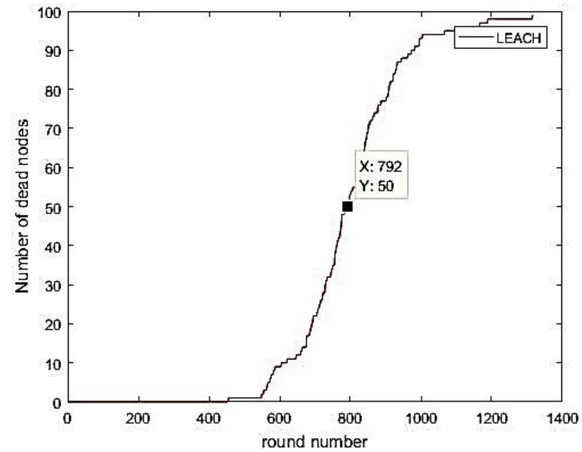

Figure 3: (a) 50% of nodes are alive in LEACH.

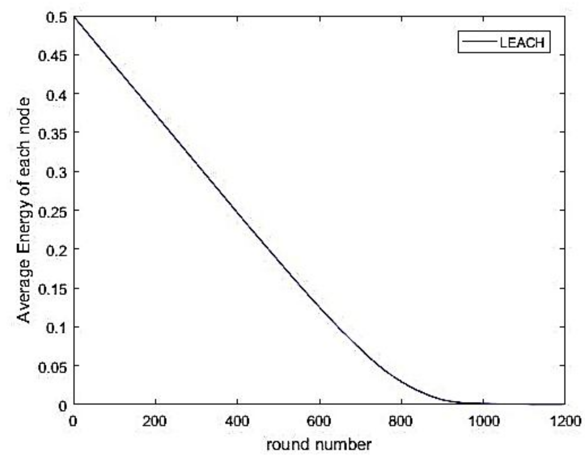

Figure 3: (b) Energy consumed by LEACH protocol.

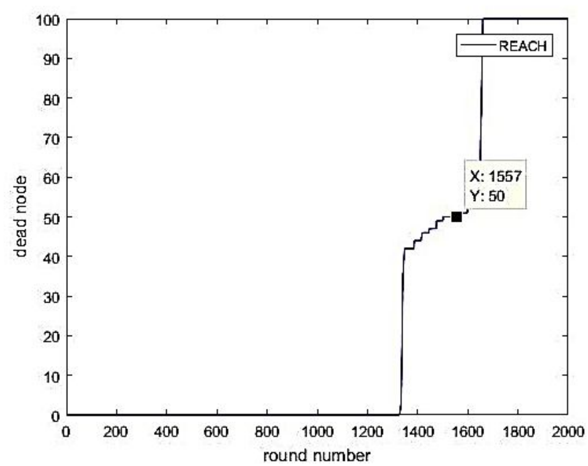

Figure 3: (c) 50% of nodes are alive in REACH.

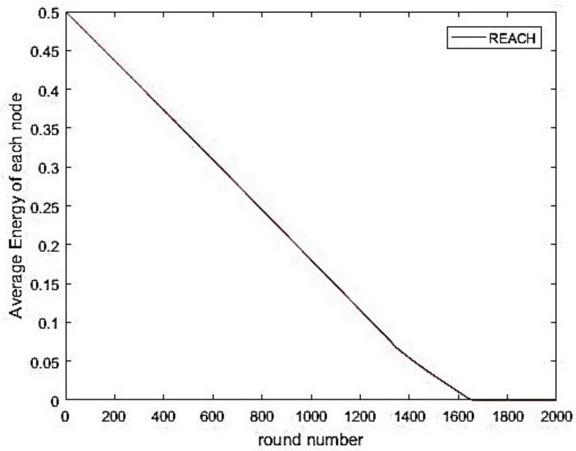

Figure 3: (d) Energy consumed by REACH protocol.

5.2. Scenario 2: Heterogeneous Environment

After the first iteration, the considered homogeneous network converts into a heterogeneous sensor network. After the first electoral round, there is a variation in the Re level of the SNs. According to the REACH algorithm, we have sorted the SNs according to their Re level in descending order. The top 10% of the sorted SNs have elected as CH for that round. In the second step of REACH, the remaining SNs excluding CHs need to be clubbed with CH to form clusters. In the proposed REACH model, we have used the INN gap distance to allocate SNs as a cluster member for a particular CH during each round. Initially, the CH1 will choose the nearby SN as its cluster member. Likewise, the rest of the CHs will choose their cluster member.

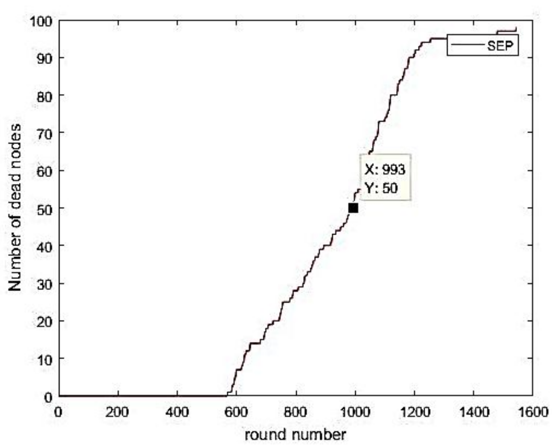

Figure 4: (a) 50% of nodes are alive in SEP.

This cluster-member assigning process will continue until the last node of the sensor network. After cluster formation like other traditional WSN protocols, the data aggregation, and segregation process will continue. After completion of data transmission of aggregated data from CHs to BS is over. Again, all the SNs including CHs will be sorted and the above said process will iterate. We have done the comparison with the existing SEP protocol which is heterogeneous. Figures. (a,b,c,d) represents the comparison between REACH and SEP in terms of total average energy consumption respectively. The numerical computation of results represented in Table 3.

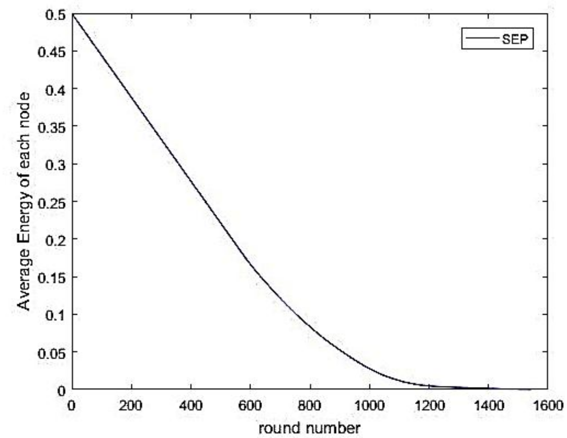

Figure 4: (b) Energy consumed by SEP protocol.

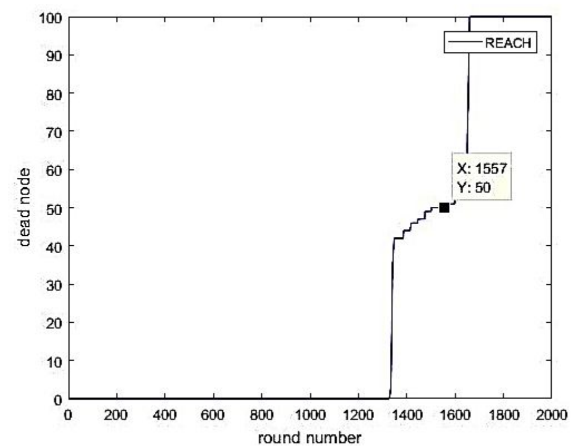

Figure 4: (c) 50% of nodes are alive in REACH.

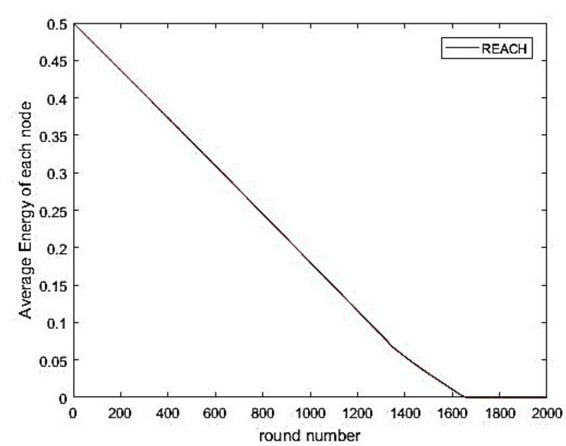

Figure 4: (d) Energy consumed by REACH protocol.

Table 3 presents the performance comparison between REACH and SEP. The performances has been recorded at 3 distinct positions such as first node dead (FND), half node alive (HNA), and all node dead (AND). From this simulation REACH performs in an optimized way in comparison with SEP by 39%, 31%, and 11% during FND, HNA, and AND respectively. The performance comparison of proposed REACH against LEACH and SEP proves the outperformance both in a homogeneous and heterogeneous environment. The cumulative comparison graph claims the better performance of REACH.

Table 3: Comparison between SEP and LEACH.

PROTOCOL S	SEP	REACH (Proposed)
FND	539	**1320**
HNA	993	**1557**
AND	1456	**1674**

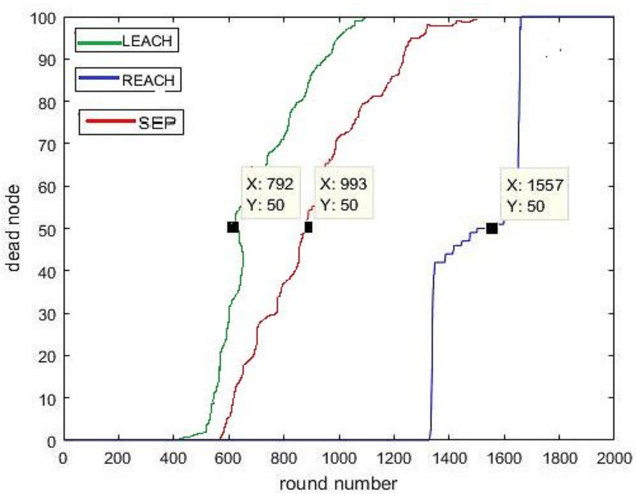

Figure 5: Comparison of Network Lifetime after 50% of nodes are alive in REACH, SEP, and LEACH.

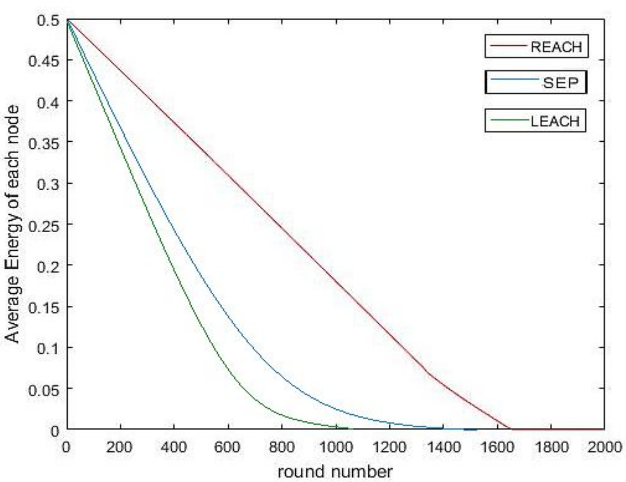

Figure 6: Comparison of Average Energy consumed by REACH, SEP, and LEACH protocol.

The character comparison among LEACH, SEP, and REACH is illustrated in Table. 4 (*Ref. Figures 5 and 6*). For this comparison, we have considered a few explicit properties of these said protocols. The properties are: heterogeneity level, clustering method, location information, cluster information, sensitivity, intra-cluster communication, CH and BS communication mode, probability, neighborhood information, and presence of faults. These are basic character for any sensor network and considering those properties of the REACH protocol has been explored by exploiting LEACH and SEP protocols.

5.3. Complexity Analysis

This sub-section discusses the complexity analysis of these stated algorithms. During LEACH, the CH selection process is purely based on the threshold value of the SNs. Every SN of the cluster maintenance a different level of threshold which concludes that the complexity of LEACH is: O (n). In the case of SEP, it uses two types of nodes like normal SN and advanced SN. The probability of getting CH is based on the threshold values of two types of nodes hence; the complexity of SEP is O (2n). The proposed REACH protocol is dividing the whole SNs set based on the sorted residual energy level. If there is an m number of clusters that need to form from n numbers of SNs, in that case, the complexity will be O (n/m). The present complexity analysis proves the efficiency of the proposed REACH algorithm (*Ref: Table 4*).

Table 4: Comparitative anlysis

REACH	SEP	LEACH	Protocols
Yes/2	Yes/2	No/-	Heterogeneity and Level
D	D	D	Clustering Method(Centralize(C)/Decentralized(D) Mixed(M)
N	N	N	Location Information (Y/N)
F/V/V	F/V/V	V/V/V	Cluster (Count/Size/Density) Variable (V) / Fixed (F)
Y	Y	Y	Existence of Sensitivity (Y/N)
Multi-Hop	1-Hop	1-Hop	Intra-cluster Communication
D/I	I	D	CH and BS Communication Direct (D) / Indirect (I)
W	W	W	Probability (Pure(P)/Weighted(W))
Y/Y	Y/Y	Y/Y	Neighborhood Distance/Location)(Y/N)
C	C	C	Fault- Clustering(C)/Routing:(R))

6. CONCLUSION

In this paper, an advanced hierarchical clustering algorithm named REACH has been discussed with proper validation against exiting clustering algorithms LEACH and SEP. The uniqueness of the validation is the proposed REACH has been evaluated against both homogeneous and heterogeneous algorithms. From the simulation it has been observed that the reach outperforms by 37% and 27% over LEACH and SEP. Enegy management is a trending domain of research. The state-of-the-art can be enhanced by considering dynamic sensor deployment scenario. In real-time, the REACH is more suitable for unattainable SNs deployment structures like aquatic monitoring, volcanic monitoring, etc. This work gives an insight towards the equal distribution and reducing the frequent CH selection process. To motivate the readers, few relevant research under uncertainty [30-38] have been suggested.

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