Performance Analysis of K-Means Clustered Wireless Sensor Network with Differential Data Dissemination

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Abstract - *Dynamic clustering has been proved in literature to be more effective than static clustering. However, a lot of overheads cost wastage of the very limited on board resources. Static clustering poses challenges of death of nodes which are far away from the cluster heads if the nodes transmit directly to the cluster heads. So, if it were possible to reduce the amount of data being transmitted from nodes by significant amount, the lifetime of static clustering would improve. Differential data dissemination has been approached for improving the performance of static clustered wireless sensor networks. In this article, we extend the application of K-means clustering for identification of best possible cluster head (CH) locations for advanced nodes in heterogeneous environment (algorithm 2). Algorithm 3 is proposed which is an iterative version of algorithm 2, iterations triggered with death of any node in the network. Finally, algorithm 1 is proposed for homogeneous wireless sensor networks which includes identification of CH locations & it's mapping to nearest possible node. Through simulations it was observed that the lifetime of algorithm 3, which is based on heterogeneity in the network, is highest. Algorithm 1 despite being a homogeneous network based algorithm provides significant stability region.*

Key Words: WSN, LEACH, SEP, Routing, Clustering, Heterogeneous Networks.

1. INTRODUCTION

WSN is characterised by a huge count of nodes that sense environmental events and send this information to a predefined destination. Usually the environments in which these wireless sensor nodes are deployed is very harsh [1]. Thus, the sensor nodes are prone to frequent failures. The reliability of network is ensured by large number of nodes. These nodes are equipped with very limited power to support communication & processing within the module. Highest amount of power is consumed in communication & therefore it is required to minimize this consumption so that the lifetime of the network is large. One of the most important technology in the realm of WSN is routing. Compared to an ad-hoc network, routing in WSN is quite challenging because of the limited on-board resources and unavailability of global addressing [2]. In addition to these, the topology is prone to frequent changes especially when the network has mobile nodes e.g. in case of wildlife monitoring. In some conditions it is required to ensure time bound delivery of data from wireless sensor network which is highly redundant because of random & dense distribution of sensor nodes. But above any QoS parameter, lifetime is emphasized because nodes have only limited resources. WSN are classified broadly into Flat & Hierarchical networks. As the name suggests, a Flat WSN would possess all nodes with same capabilities, functionalities & resources. Directed Diffusion [3], SPIN [4] are two most popular routing protocols in flat sensor networks. Such routing protocols are beneficial for networks that operate over small scale i.e. small area, low count of nodes. For large scale networks, such routing techniques are not suitable because it would require huge amount of data processing to avoid data redundancy, a very large bandwidth and shall suffer huge latencies. Therefore, for large scale wireless sensor networks, hierarchical topology is used. In such topology, nodes are categorized into clusters and every cluster is led by a cluster head. In some cases, multiple hierarchies are also used within the same network. The cluster heads are required to process and communicate information received from the cluster members, to the sink of the network. Also, the network may contain homogeneous or heterogeneous nodes and accordingly referred to as a homogeneous or heterogeneous network. A homogeneous WSN is one in which all sensor nodes have exactly the same capabilities & features. A heterogeneous network may comprise of some nodes which have some improved capabilities. Obviously the cost of a heterogeneous wireless sensor network is much higher than a homogeneous network but it only delivers improved lifetime. Improvement in lifetime is a challenge for both homogeneous and heterogeneous wireless sensor network. Clustering offers scalability in network as managing a set of nodes per cluster is easier as compared to a homogeneous network. Cluster heads aggregate the data from different nodes and forward to the sink or in some cases an anchor node. Data aggregation results in huge reduction in amount of data to be transmitted. This reduces the energy consumed in communication and hence improves the lifetime of the network. The chances of a collision are very less in a clustered WSN as the number of nodes sharing the channel effectively is reduced as compared to a flat WSN. Similarly the chances of a missed detection or a false alarm are also very less as data is aggregated by cluster heads. In case of a node dying prematurely, re-clustering is feasible with quite less energy cost. Clustering also reduces the latencies associated with data transmission.

2. LITERATURE REVIEW

In this section we analyse some of the most prominent clustering protocols in wireless sensor networks. Low Energy Adaptive Clustering Hierarchy (LEACH) [5] is one such routing protocol for hierarchical networks where cluster heads are selected based on residual energy for every epoch & keeps on changing. This results in balancing the load offered to every node. The process of LEACH protocol is divided into rounds, where every round starts with a set-up phase followed by a steady state phase. In the set-up phase, clusters are created.

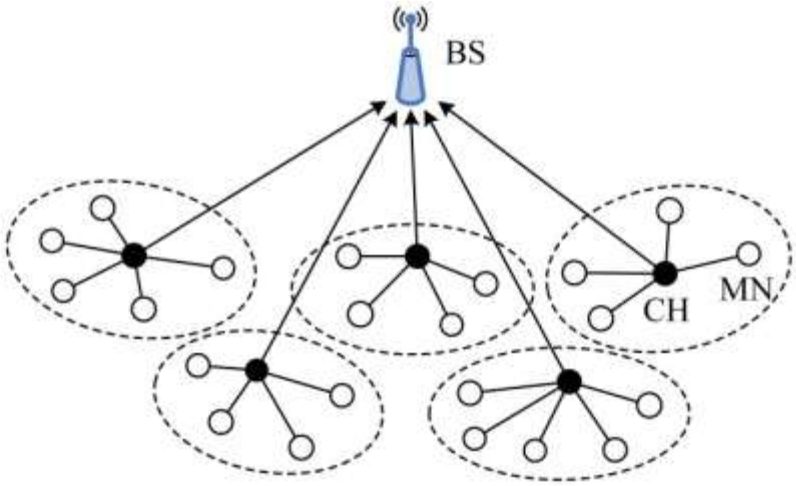


Figure 1 LEACH Topology[27]

Whether or not a node becomes a cluster head for a particular round depends upon the following threshold

$$T(n) = \begin{cases} \dfrac{P}{1 - P\left(r \bmod \frac{1}{P}\right)}, & if\ n \in G \\ 0, & Otherwise \end{cases} \quad (1)$$

Where, P is the desired fraction of cluster heads, r is round number & G is the set of nodes who have not been elected as cluster heads in previous 1/P rounds. If the random number generated by a node is less than the above threshold, the node becomes cluster head for the current round. Upon selection, such nodes broadcast their advertisement and the nodes who are not cluster heads select their respective cluster head for a particular round based upon the level of received signal strengths. After the set-up phase, the nodes transmit data to cluster heads on the basis of a TDMA schedule generated by the cluster head, as shown in figure 1. The procedure is repeated and a new cluster head is elected in further rounds. Several improvements of LEACH exist in literature e.g. TL-LEACH [6], E-LEACH [7], LEACH-C [8], T-LEACH [9] etc. Energy Efficient Clustering Scheme (EECS) [10], Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [11], Hybrid Energy-Efficient Distributed clustering (HEED) [12] are some other typical clustering protocols for hierarchical WSNs. The major difference between LEACH & HEED is that HEED does not take account of residual energy, instead, a ration of residual energy (E_{res}) to maximum energy (E_{max}) for cluster head selection. The authors in [13] improved HEED by optimizing the topology inside a cluster and also ensuring that the cluster sizes are balanced. Figure 2 shows graphical depiction to the distributed weight based energy efficient hierarchical clustering topology. The authors in [14] exploit heterogeneous nature of WSN for improvement in lifetime. Without requiring any knowledge about the entire network, the probabilities associated with nodes about becoming cluster head are evaluated. The research work in [15]-[19] are focused over improving lifetime in hierarchical WSNs. The authors in [20] develop algorithm in which the establishment of clustering communication is based on the residual energy of sensor nodes and distance among them. The authors in [21] address the problem of lifetime for large scale wireless sensor networks with big data gathering by making use of density for clustering. The authors in [22] take up rather different logic to improve lifetime of a large scale wireless sensor network. The major problem in statically clustered network arises only when heavy data is to be transferred, as it results in death of far-off nodes & the cluster head itself. Dynamic clustering overcomes this problem but has its own set of issues that need to be addressed. The authors in [22] make use of static clustering to reduce latencies, and receive the benefits of hierarchical networks and in order to reduce the number of packets for transmission to reduce energy consumption, they further make use of differential data dissemination.

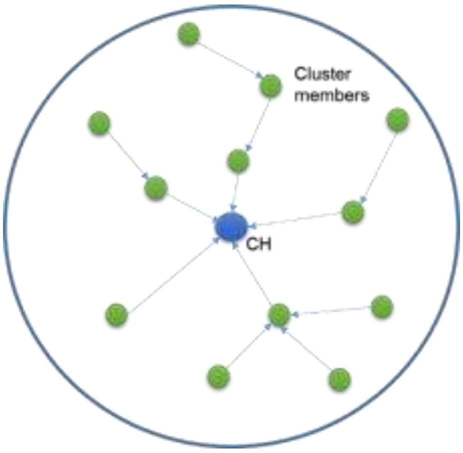


Figure 2 Distributed Weight-based Energy-efficient Hierarchical Clustering Topology

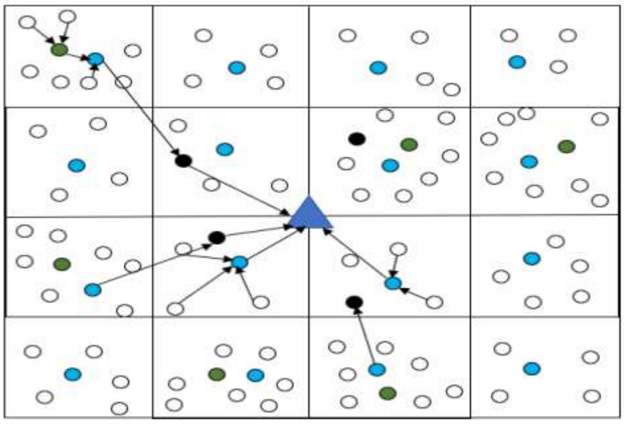


Figure 3 Topology for density based clustering algorithm [21]

Although the work proposed achieves a major improvement in lifetime, still, some major problems in this approach exist like overloading of cluster heads and death of nodes which are at far distances. In this paper we try to make use of the differential data dissemination and exploit reactive k-means clustering technique to make clusters.

3. PROPOSED WORK

We develop a protocol which possesses the positive properties of dynamic clustering and at the same time takes advantage of interim static clustering. We start with random deployment of nodes, depicted in Figure 4 as is the case with a majority of wireless sensor network applications. Then on the basis of K-means clustering algorithm, cluster head locations are identified. Nodes closest to the identified cluster head locations are selected as cluster heads in the set-up phase.

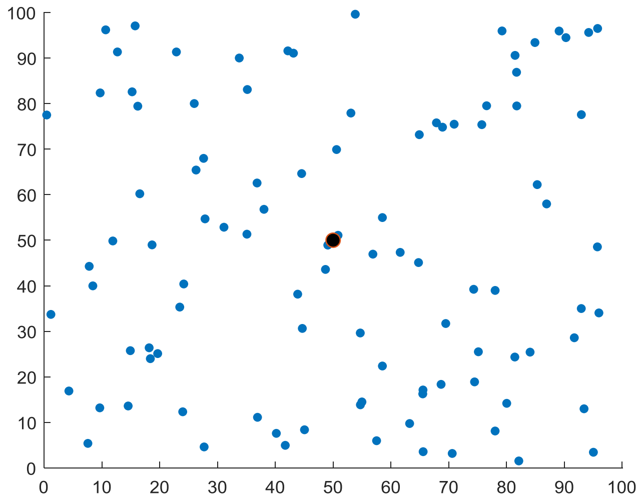


Figure 4 Randomly Deployed WSN with Sink at centre

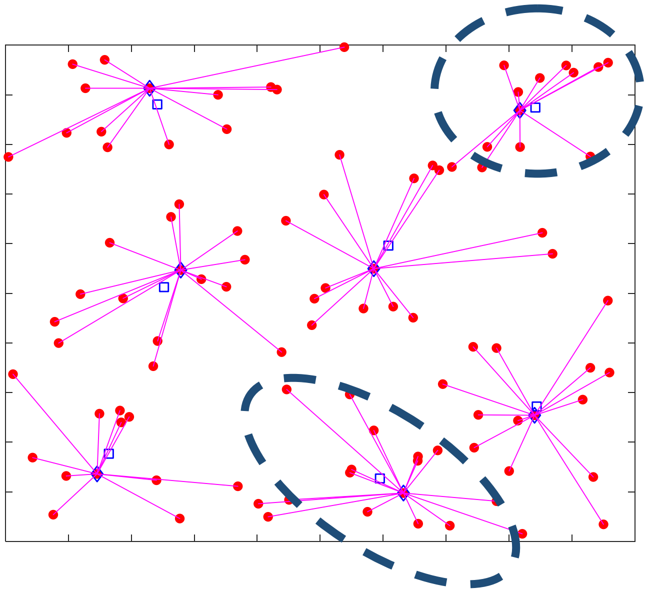
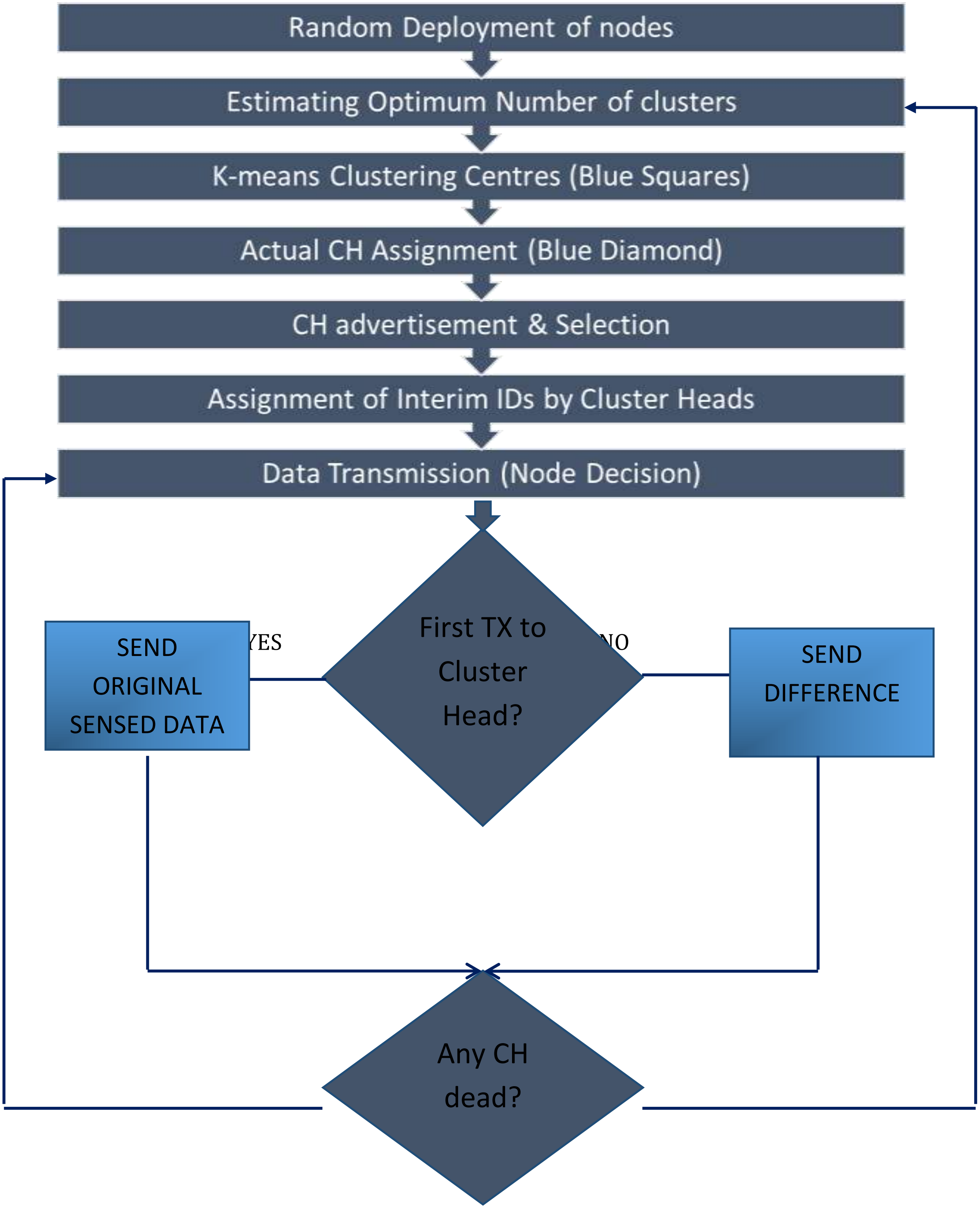


Figure 5 Initial K-mean Clustered Topology

Thereafter the selected cluster heads broadcast their advertisements to all nodes. The nodes select their cluster heads based on the received signal strengths. Temporary IDs are assigned by the cluster head to the nodes. In the steady phase, the nodes send their data. However, the nodes only send the full sensor data and the cluster head stores the data with predefined ID. Next time onwards the nodes do not send the complete data but only the change which requires a lot less packets as compared

Figure 8 K-means clustering for Differential Data Dissemination in WSNs



to a full-fledged transmission of data. Upon death of any one of the cluster heads, the network topology is changed again and the cluster heads are redefined. Figure 5 shows outcome of K-means clustering to the randomly deployed wireless sensor network. The blue coloured squares in the figure depict the K-mean clustering centres. The nodes closest to these centres are selected as cluster heads and are depicted by a blue diamond. Figure 6 shows the same WSN after re-clustering. The nodes who were cluster heads previously suffer early death and have been marked with an 'x' subsequently. The network remains static as long as a cluster head does not die and therefore avoids too much overhead as is required in algorithms like LEACH. Figure 7 shows the WSN with 40% of the nodes alive. It can be observed that the number of clusters has been reduced here to 4. This process is repeated until the entire network is dead. The procedures followed inside the network can be summed up through Figure 8 that represents flow chart of the proposed, K-means clustering algorithm for differential data dissemination in wireless sensor networks.

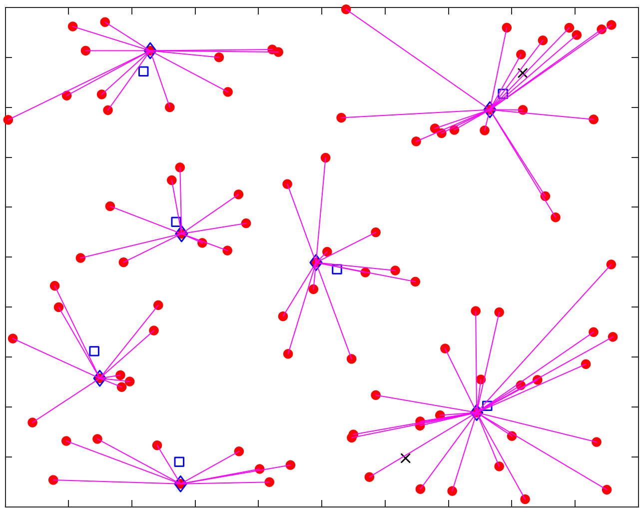


Figure 6 Re-Clustered WSN

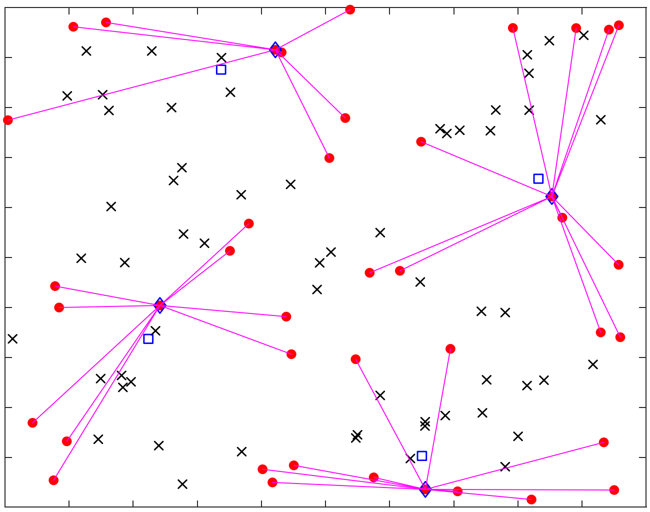


Figure 7 Re-Clustering with 60% Nodes Dead

4. RESULTS AND DISCUSSIONS

In this section we try to analyse performance of the proposed algorithm. MATLAB is used to simulate the proposed algorithm for the following parameters

S.No.	Parameter	Value
1	No. of nodes	100
2	Field Dimensions	100 x 100
3	1st Transmission Control Packet	1000 bits
4	1st Transmission Data Packet	6400 bits
5	2nd Transmission Control Packet	200 bits
6	2nd Transmission Data Packet	3200 bits

We make use of the radio model of [5] for energy calculations. The Optimal number of clusters is calculated as

$$C_{opt} = \frac{1}{d_{BS}^2} \sqrt{\frac{N_{alive}}{2\pi} * \frac{E_{fs}}{E_{mp}} * A_{field}} \quad (2)$$

Where, d_{BS} is the distance of CHs from BS, E_{mp} is the amount of energy consume by the multi paths & E_{fs} is the energy consumed in free-space transmission. A_{field} is the area of the field. We compare the following algorithms

S.No.	Algorithm	Homogeneous/Heterogeneous	Existing/Proposed
1	DDD [22]	Heterogeneous	Existing
2	LEACH[5]	Homogeneous	Existing
3	SEP[14]	Homogeneous	Existing

4	Algorithm1	Homogeneous	Proposed
5	Algorithm2	Heterogeneous	Proposed
6	Algorithm3	Heterogeneous	Proposed

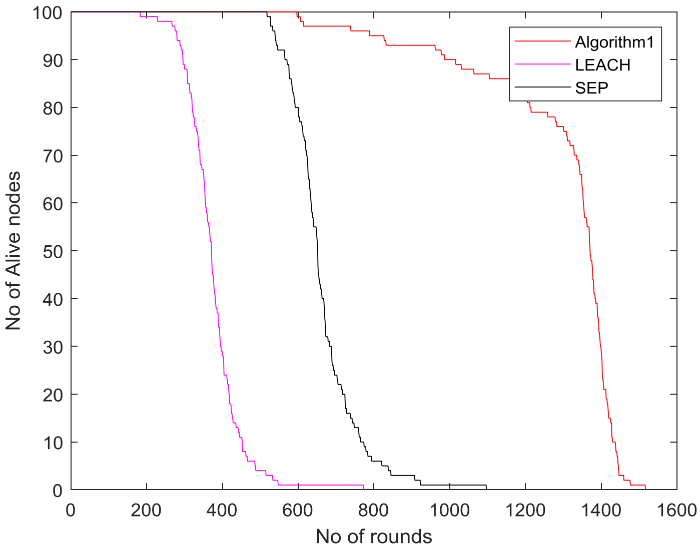


Figure 9 Lifetime of Proposed Vs Existing Algorithms

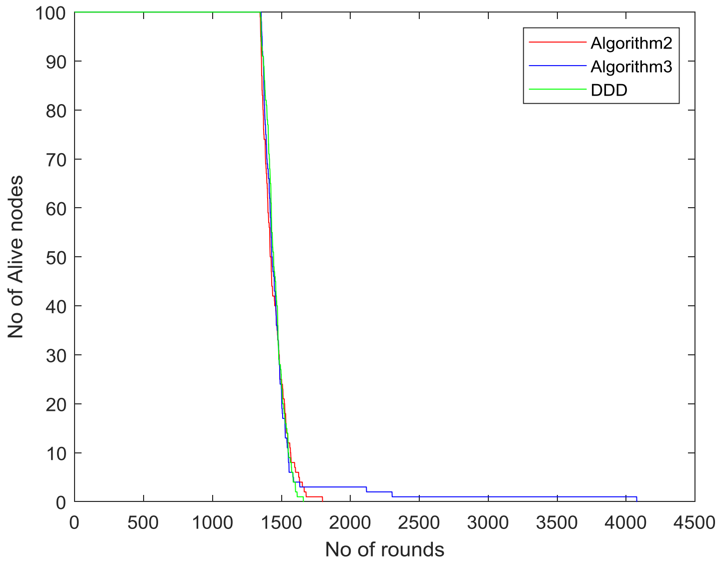
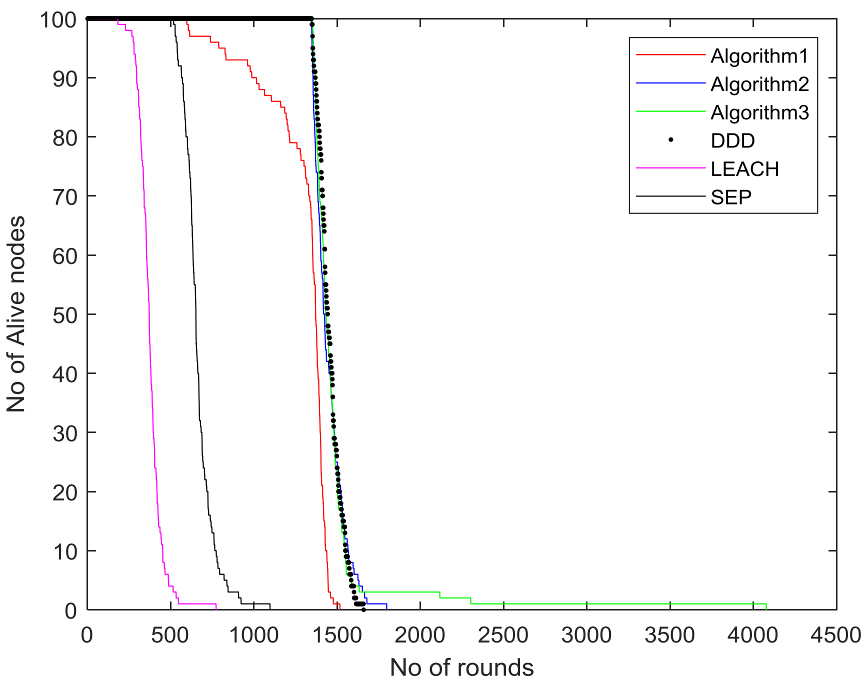


Figure 10 Lifetime comparison of algorithm 2 & 3 with DDD

Algorithm 1 is explained in section III and involves K-mean based cluster head selection from the same set of nodes (homogeneous). Algorithm 2 involves placement of anchor nodes as compared to [22] by selecting K-means cluster centres. Algorithm 3 basically is an iterative version of algorithm 2, where, the cluster centres are updated whenever any node in the network dies. It can be observed from figure 9 that the proposed algorithm significantly improves lifetime of the network as compared to the existing LEACH & SEP protocols. It may be observed that the proposed algorithm provides a huge amount of stability period. Next we compare the performance of algorithm 2 & algorithm 3 with the work done in [22].We assume an initial energy of 0.25 J. It can be observed from the figure 10 that the algorithm 3 outperforms both the algorithm 2 & the Figure 11 Performance analysis of proposed algorithms



work in [22]. While algorithm 2 closely follows the stability region of the work in [22], still the lifetime offered by algorithm 2 is more than DDD. Finally, we analyse the performance of all algorithms in figure 11. Out of all, algorithm 3 serves the best performance at the cost of advanced nodes.

5. CONCLUSION

The proposed work extends the work done in [22] to both homogeneous & heterogeneous application scenarios. It was observed that the algorithm 3 which makes use of anchor nodes, making the network heterogeneous provided with the best performance with lifetime of the network as a parameter. Algorithm 2 performs very closely with DDD but still offers more lifetime. Algorithm 1 provides a homogeneous alternative to algorithm 3 with appreciable performance. In future work, the possibility of integrating chains inside a cluster may be explored. A detailed analysis is required for identification of epoch of a cluster. The work done focuses over the network layer only, for better performance, a cross-layered analysis is required.

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