Maximizing Lifetime of Homogeneous Wireless Sensor Network through Energy Efficient Clustering Method

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Abstract

The main purpose of this paper is to develop a mechanism to increase the lifetime of homogeneous sensor nodes by controlling long distance communication, energy balancing and efficient delivery of information. Energy efficiency is a very important issue for sensor nodes which affects the lifetime of sensor networks. To achieve energy balancing and maximizing network lifetime we divided the whole network into different clusters. In cluster based architecture, the role of aggregator node is very crucial because of extra processing and long range communication. Once the aggregator node becomes non functional, it affects the whole cluster. We introduce a candidate cluster head node on the basis of node density. We introduce a modified cluster based model by using special nodes called server nodes (SN) that is powerful in term of resources. These server nodes are responsible for transmitting the data from cluster head to the base station. Our proposed algorithm for cluster head selection based on residual energy, distance, reliability and degree of mobility. The proposed architecture is more scalable and proposed algorithm is robustness against even/uneven node deployment.

Keywords: *Server node (SN), cluster head (CH), Network lifetime.*

1. INTRODUCTION

A Wireless sensor network (WSN) is composed of large numbers of tiny low powered sensor nodes and one or more multiple base stations (sinks). These tiny sensor nodes consist of sensing, data processing and communication components. The sensor nodes sense, measure and collect ambient environment conditions, they have the ability to process the data and perform simple computation and send the processed information to the base station either directly or through some intermediate point called gateway. Gateway can be used for fusion and removing the anomalies and to get some conclusion from the collected data over a period of time. Wide range of application can be found in [1, 2].

Sensor nodes are resource constrained in term of energy, processor and memory and low range communication and bandwidth. Limited battery power is used to operate the sensor nodes and is very difficult to replace or recharge it, when the nodes die. This will affect the network performance. Energy conservation and harvesting increase lifetime of the network. Optimize the communication range and minimize the energy usage, we need to conserve the energy of sensor nodes [1, 2].Sensor nodes are deployed to gather information and desired that all the nodes works continuously and transmit information as long as possible. This address the lifetime problem in wireless sensor networks. Sensor nodes spend their energy during transmitting the data, receiving and relaying packets. Hence, designing routing algorithms that maximize the life time until the first battery expires is an important consideration.

Designing energy aware algorithms increase the lifetime of sensor nodes. In some applications the network size is larger required scalable architectures. Energy conservation in wireless sensor networks has been the primary objective, but however, this constrain is not the only consideration for efficient working of wireless sensor networks. There are other objectives like scalable architecture, routing and latency. In most of the applications of wireless sensor networks are envisioned to handled critical scenarios where data retrieval time is critical, i.e., delivering information of each individual node as fast as possible to the base station become an important issue. It is important to guarantee that information can be successfully received to the base station the first time instead of being retransmitted.

In wireless sensor network data gathering and routing are challenging tasks due to their dynamic and unique properties. Many routing protocols are developed, but among those protocols cluster based routing protocols are energy efficient, scalable and prolong the network lifetime [3, 4].In the event detection environment nodes are idle most of the time and active at the time when the event occur. Sensor nodes periodically send the gather information to the base station. Routing is an important issue in data gathering sensor network, while on the other hand sleep-wake synchronization are the key issues for event detection sensor networks.

In the clustered environment, the data gathered by each sensor is communicated either by single hop or multihop to base station. In cluster based architectures, at times, each cluster has their own leader node that collects the aggregated data from the non leader nodes and is responsible for the data transmission to the base station. Clustering approach increases the network life time, because each node do not directly communicate with the base station and hence overcome the problem of long range communication among the sensors nodes. To improve the overall network scalability, cluster based architecture can share the traffic load equally among all the nodes in various clusters, due to this the end to end delay between the sensor nodes and command node can be reduced [5]. Many critical issues associated with clustering architecture system because of the non-uniformly distribution of the sensors in the field. Some cluster heads may be heavily loaded than others, thus causing latency in communication, decreasing the life time of the network and inadequate tracking of targets or events.

Self organization of the nodes with in cluster for a randomly deployed large number of sensors was considered in recent years emphasizing the limited battery power and compact hardware organization of each sensor module. To send the information from a high numbers of sensors nodes to base station, it is necessary to be a cost effective and group all the nodes in cluster. It is necessary to examine a list of metrics that determine the performance of a sensor network. In this paper, we propose a strategy to select an efficient cluster head for each cluster on the basis of different parameters. Our proposed strategy will be better in terms of data delivery and energy balancing as shown in Fig 1.

The focus in this paper is to assess the role of strategic sensor node placement (clustering, cluster head selection) on the data delivery of a network. In this regard, Section 2 discusses related work. Section 3 describes the methodology, section 4 describes the analytical discussion, and section 5 presents conclusion and future works.

2. RELATED WORK

In wireless sensor network energy efficient communication is a matter of survival; as a result research mainly focused towards energy efficient communication, energy conservation, prolonging network lifetime. Various routing techniques have been introduced, but clustering architecture is one of the most dominant, and scalable. In [6], node should become a cluster head by calculating the optimal probability, in order to minimize network energy consumption has been proposed. Heinzelman et al [7] introduced a hierarchical clustering algorithm for sensor networks called LEACH. It uses distributed cluster formation for a randomized rotation of the cluster-head role with the objective of reducing energy consumption that increases the network life time and data delivery. LEACH uses TDMA/CDMA, MAC to reduce inter and intra cluster collisions. Uppu et al [8] introduced a technique of backup heads to avoid re-clustering, secondary membership heads to eliminate redundant transmission and optimum distance hopping to achieve network efficiency in terms of life time and data delivery.

Balanced cluster architecture are used to maximize the life time of the network by forming balanced cluster and minimize the total energy consumed in communication and also the number of hop is not fixed and depends upon the spatial location of sensors[An energy constrained multi-hop clustering algorithm].L. Ying et al [9] developed an algorithm for cluster head selection based on node residual energy and required transmission energy. In [10], uneven load in network is minimized by cluster size adaptation using cluster ID based routing scheme. Cluster head maintain information of a node with maximum residual energy in its cluster. It ensures the location of cluster head (CH) approximately at center of cluster. In case of uneven deployment, it is not necessary that most of the nodes are in the center of the cluster. In this way, the distance between CH and sensor nodes will be increased.

A cluster-based routing protocol called Energy Efficient Clustering Routing (EECR) [11] select cluster head on the basis of weight value and leads to a more uniform distribution evenly among all sensor nodes. In energy constrained case, the traffic pattern and remaining energy level condition the routing scheme may be adoptive. Cluster heads selection is an NP-hard problem [12]. Thus, in the literature, the solution is based on heuristic approaches. Efficient clustering algorithms do not require regular topology re-construction and this will lead to regular information exchange among the nodes in the network. HEED [13] is another distributed clustering approach. In this approach, the cluster heads are selected periodically on the basis of two parameters, the residual energy and cost incurred during the intra clustering communication.

In [14] some resource rich nodes called gateways are deployed in the network and performing fusion to relate sensor reports. Member nodes of each cluster communicate with base station only through gateway nodes. MECH [15] avoids the uneven member distribution of cluster and reduced the long range communication between cluster head and base station. MECH suffer by Energy consumption in each round.

TEEN [16] based on LEACH, the transmission is less frequently and the sensor nodes sense the media contiguously. After cluster formation and cluster head selection process, CH broadcasts two thresholds value, called hard threshold and soft threshold as the sense attributes. Hard threshold is the minimum possible value of the sense attribute that triggers the nodes to switch on its transmitter and transmit. Thus, the hard threshold reduces the number of transmission and allows the nodes to transmit only when the sensed attribute is in the range of interest. The soft threshold further reduces the number of transmissions when there is little or no change in the value of sensed attributes. The number of packets transmission is controlled by setting the soft threshold and hard threshold. However the main disadvantage of this scheme is that when periodic reports are needed and if the threshold is not received, the user will not get any data from the network at all.

3. METHODOLGY

3.1 System Model and Problem Statement

The sensor nodes are highly resource constrained. Energy is one of the major issues of the sensor nodes. In wireless sensor network most of the energy is consumed during transmission and it is further increased with the distance, as energy consumption is directly proportional to the square of the distance among the nodes. In order to minimize energy consumption and increase lifetime of the network, we must keep the distance under consideration and it is possible by the architecture design of the network and efficient routing schemes. Scalability is also another issue, as they may contain hundreds or thousands of nodes and this issue are addressed in cluster based architecture particularly in LEACH [7]. There are few areas in LEACH [7] that can be improved and to make it more energy efficient and scalable. Avoiding the creation of new routing table and selection of cluster head in each round significantly reduces the amount of energy consumed. In cluster based architectures, cluster head are over loaded with long range transmissions to the base station [10] and with additional processing responsibility of data aggregation. Due to these responsibilities, cluster heads nodes are drained of their energy quickly. It is unsuitable in the case of homogenous wireless sensor networks that cluster heads are regular nodes but they communicate for longer distance with the base station and also the cluster head that are near to the base station are drained of their energy quickly because of inter cluster communication. This leads to energy imbalance among the clusters. For a broad analysis of our proposed scheme, we have developed a system model based on the energy consumption during transmission. In most of short range applications, the circuit energy consumption is higher than transmission energy. Energy efficient communication techniques mainly focus on minimizing the transmission energy, while in long range applications the transmission energy is dominant in the total energy consumption. The transmission energy generally depends on the transmission distance. The findings by [23] that different performance parameters are designed to minimize the energy consumption and to prolong the network lifetime. These parameters are described as follows:

3.1.1 Distance (D) to Base Station

"D" is the summation of all distances from sensor nodes to the BS. This distance is defined as follows:

$$D = \sum_{i=1}^{m} (x_{1s} + x_{2s} + \ldots + x_{is})$$

i.e.

$$D = \sum_{i=1}^{m} (x_{is}) \qquad (1)$$

Where "x_{is}" is the sum of distance from the node "i" to the Base Station. For a larger network, try to keep this distance minimum because most of the energy will be wasted. However, for a smaller network the nodes near to base station directly send the information may be an acceptable option.

3.1.2 Cluster Distance (C)

C is the summation of the distances from the member nodes to the cluster head (CH) and the distance from the cluster head to the server node (SN). For a cluster with k member nodes, the cluster distance C is defined as follows:

$$C = \sum_{i=1}^{k} (x_{1h} + x_{2h} + \cdots + x_{ih}) + (x_{h1sn} + x_{h2sn} + \cdots + x_{hisn})$$

i.e.

$$C = \sum_{i=1}^{k} (x_{ih} + x_{ihsn}) \qquad (2)$$

Where “x_{ih}” is the distance from node “i” to the cluster head (CH) and “x_{ihsn}” is the distance from the cluster head to the server node (SN). For a cluster that has large number of spreads nodes, the distance among the nodes ‘i’ to cluster head (CH) will be more and the energy consumption will be higher. So keep the cluster size small to reduce energy dissipation and C should not be too large. This metric will keep control the size of the clusters. The Equation.3 shows the total distances “T_{dist}” from cluster member ‘i’ to cluster head and from cluster head (CH) to server node (SN) and from server Node to Base station (BS).

$$T_{dist} = \sum_{i=1}^{m} (x_{ih} + x_{ihsn} + \dots + x_{snb}) \qquad (3)$$

3.1.3 Total Dissipated Energy (E)

The total dissipated energy “E_{total}” shows the energy dissipated to transfer the aggregated messages from the cluster to the BS. For a cluster with k member nodes, the total dissipated energy can be calculated follows:

$$E_{total} = \sum_{i=1}^{m} \left(E_{T_x ih} + E_{T_x hsn} + K \times E_R + E_{T_{snb}} \right) \quad (4)$$

The fist part of Equation.4 show the energy consumed to transmit messages from member nodes to the cluster head. The second part shows the energy consumed to transmit aggregated messages by cluster head to server node SN to receive messages from the member nodes. Finally, the fourth term “ETsnb” resents the energy needed to transmit from the SN to the BS.

3.1.4 Residual energy

The energy dissipated in previous round by the cluster head preferably les then residual energy of a node. Equation for residual energy of node i is described in [17]. The individual node energy (lifetime of node) can be calculated by the formula as presented in [18] is:

$$Ti = \frac{E_b}{\sum_{j \in Si} eij \sum qij} \qquad (5)$$

Where ‘Ti’ is the node lifetime, ‘E_b’ is the initial energy of the battery ‘eij’ is energy required for transmission of one information unit, ‘qij’ is the rate at which information is generated at node i, ‘S_i’ is the set of neighbor nodes of node i. Based on the node lifetime, the network lifetime can be computed by:

$$Tsys = \max_{i \in N} Ti = \max_{i \in N} \frac{E_b}{\sum_{j \in Si} eij \sum qij} \qquad (6)$$

Where ‘T_{sys}’ is the system life time, ‘N’ is the number of nodes in the network.

3.2 Proposed Cluster Based WSN Architecture

We have introduced a resource reachable node called server node (SN). It has the ability to cover long transmission range. Server node (SN) is deployed in a location where all the nodes of each cluster are easily reachable. If it is not reachable, it is recommended to add another server node (SN). Due to extra processing capability sever node (SN) are responsible for selecting cluster head from candidate nodes. The purpose of introducing SN is to closely monitor the operation of sensor nodes in a cluster and command them for specific operations as shown in Fig 1.

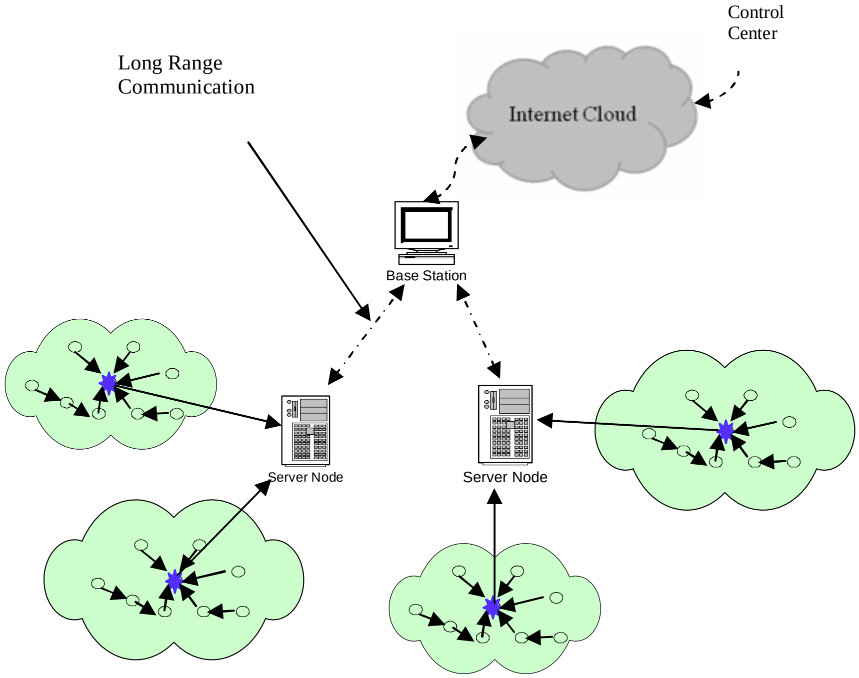

FIGURE 1: Modified Cluster Based Architecture

3.3 Cluster Formation and Node Deployment

The main purpose of clustering the sensor nodes is to form groups so as to reduce the overall energy spent in aggregation, communicating the sensed data to the cluster head and base station. There are various methods proposed for clustering, but K-mean [19] is found to be the most efficient for clustering. Fig 1 shows the formation of different clusters and the assignment of nodes to each cluster. K-mean clustering technique assigns nodes to the cluster having the nearest centroid. K-mean algorithm uses Euclidean distance formula to calculate distance between centroid and other objects Fig. 2.

$$D_{i,j} = \sqrt{\left|x_{i1} - x_{j2}\right|^2 + \left|x_{i2} - x_{j2}\right|^2 + \cdots \left|x_{ip} - x_{jp}\right|^2} \qquad (7)$$

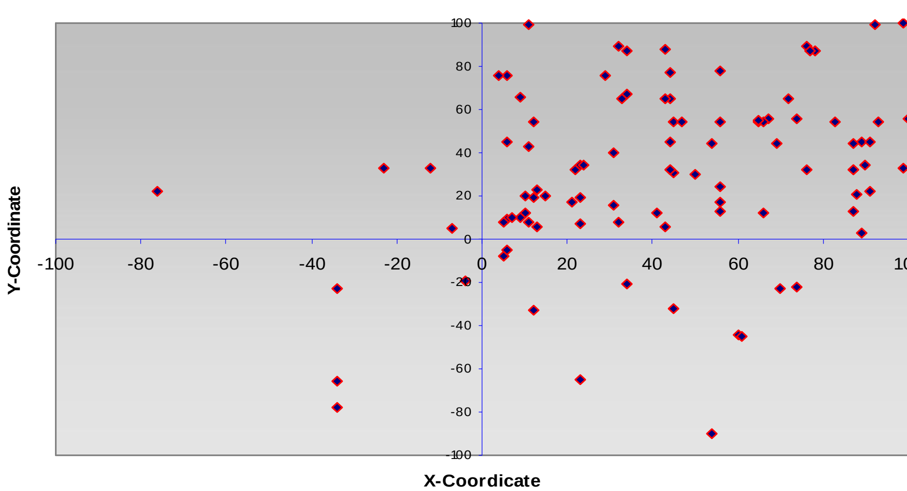

FIGURE 2: 100 Nodes Random Network

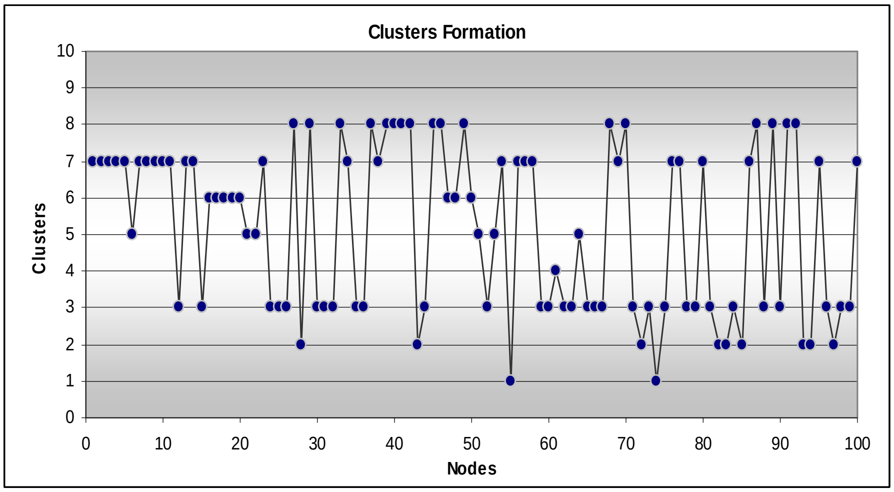

FIGURE 3: Cluster Formation

K-mean is computationally efficient and does not require the user to specify many parameters. The number of clusters and the nodes assigned to each cluster is shown in Table 1.

Cluster	**Nodes**
1	2
2	9
3	31
4	1
5	6
6	8
7	26
8	17
Valid	100
Missing	0

Table I: Number of Cases in each Cluster

	Clusters							
	1	2	3	4	5	6	7	8
X	-34.00	99.00	91.00	-76.00	-34.00	54.00	34.00	9.00
Y	-78.00	100.00	22.00	22.00	-23.00	-90.00	-21.00	66.00

Table II: Cluster Centroids

3.4 Selection of Candidate Cluster Head

The selection of cluster head becomes highly challenging when there is an uneven distribution of sensor nodes in clusters. In order to make the cluster head (CH) selection algorithm more accurate, we first identify the candidate sensor nodes for cluster head and then select the best among them. In order to select candidate cluster heads from each cluster, we use the K-theorem. The philosophy behind the K-theorem is to select a candidate CHs based on the bunch of sensor nodes as there is an uneven distribution Fig. 4.

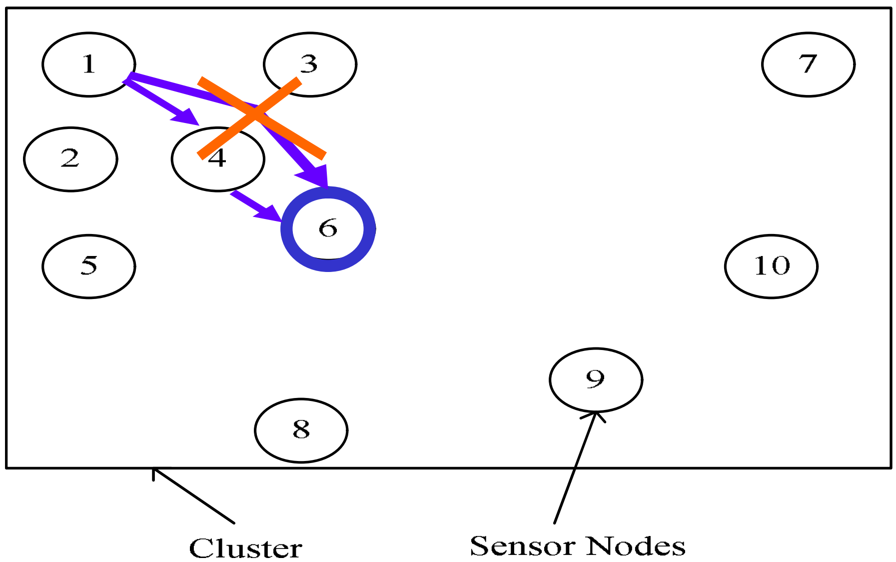

FIGURE 4: Selection of Candidate Cluster Head

The server node (SN) set the value of ki for each cluster. The value of ki is relative to the node density in a cluster and ratio (i.e. r) of the cluster heads in a WSN. It is the product of the number of nodes in a cluster (i.e. ni) and ratio r. The value of r can vary from 0.01 to 0.99 but it should not be more than 0.50. The lesser the value of ki, the greater the probability of getting a local optimal is. The value of ki determines the ki number of best sensor nodes as candidate CHs.

For each sensor node deployed in the cluster, we choose its ki nearest neighbors based on distance. The distance between sensor nodes can be calculated through received signal strength indicator (RSSI) that is described in detail in [20] or any other localization technique [21, 22]. When the number of immediate (1-hop) neighbors is less than ki and distance is greater than the transmission range then multihop route is preferred. Multihop route is preferred over direct because of less energy consumption.

The server node (SN) adopts the procedure detailed below in order to select candidate CHs for each cluster. The server node (SN) maintains a table for each cluster, listing all the sensor nodes present in the cluster. It maintains ki nearest neighbors for each node and the frequency of occurrence of each node is maintained in the table. The ordered list of sensor nodes based on their frequency is shown in Table. III i.e. Si. The minimum frequency required in cluster i to be the CH (i.e. Ki) is calculated based on weighted mean of frequencies and 1 is added for better result. Weighted mean is calculated by product of each frequency of occurrence into number of sensor nodes having that frequency. The value of Ki is rounded to the nearest integer if required. The sensor nodes having frequency Ki or greater are identified as candidates for CH i.e. Ci. The best candidates for cluster head would always be equals to value of ki i.e. 3 in this case.

Node ID	$k_i = 3$ List of Terminals with its K-Nearest Neighbor	Frequency of Occurrence
1	1) 2, 3, 4	3
2	2) 1, 4, 5	4
3	3) 1, 4, 6	5
4	4) 2, 3, 6	6
5	5) 2, 4, 6	4
6	6) 3, 4, 5	7
7	7) 3, 9, 10	2
8	8) 5, 6, 9	2
9	9) 6, 8, 10	4
10	10) 6, 7, 9	3

Table III: List of nodes with their K-nearest neighbors and their frequency of occurrence

Sorting {Si = Ordered list of sensor nodes, where i is the frequency of occurrence}

S2 = (7, 8), S3 = (1, 10), S4 = (2, 5, 9), S5 = (3)

S6 = (4), S7 = (6)

Ki = [Weighted Mean] + 1

= [(2*2)+(3*2)+(4*3)+(5*1)+(6*1)+(7*1) / 10] + 1

= [(4 + 6 + 12 + 5 + 6 + 7) / 10] + 1

= [(40) / 10] + 1➔ 4 + 1

Ki = 5

So, the best nodes for candidate cluster head in cluster are: Ci = {3, 4, 6} when ki = 3.

3.5 Cluster Head Selection

We describe a cluster head selection algorithm which is energy efficient in Fig.5. Suitable cluster-head selection makes the network efficient and increases the life time and data delivery of the networks.

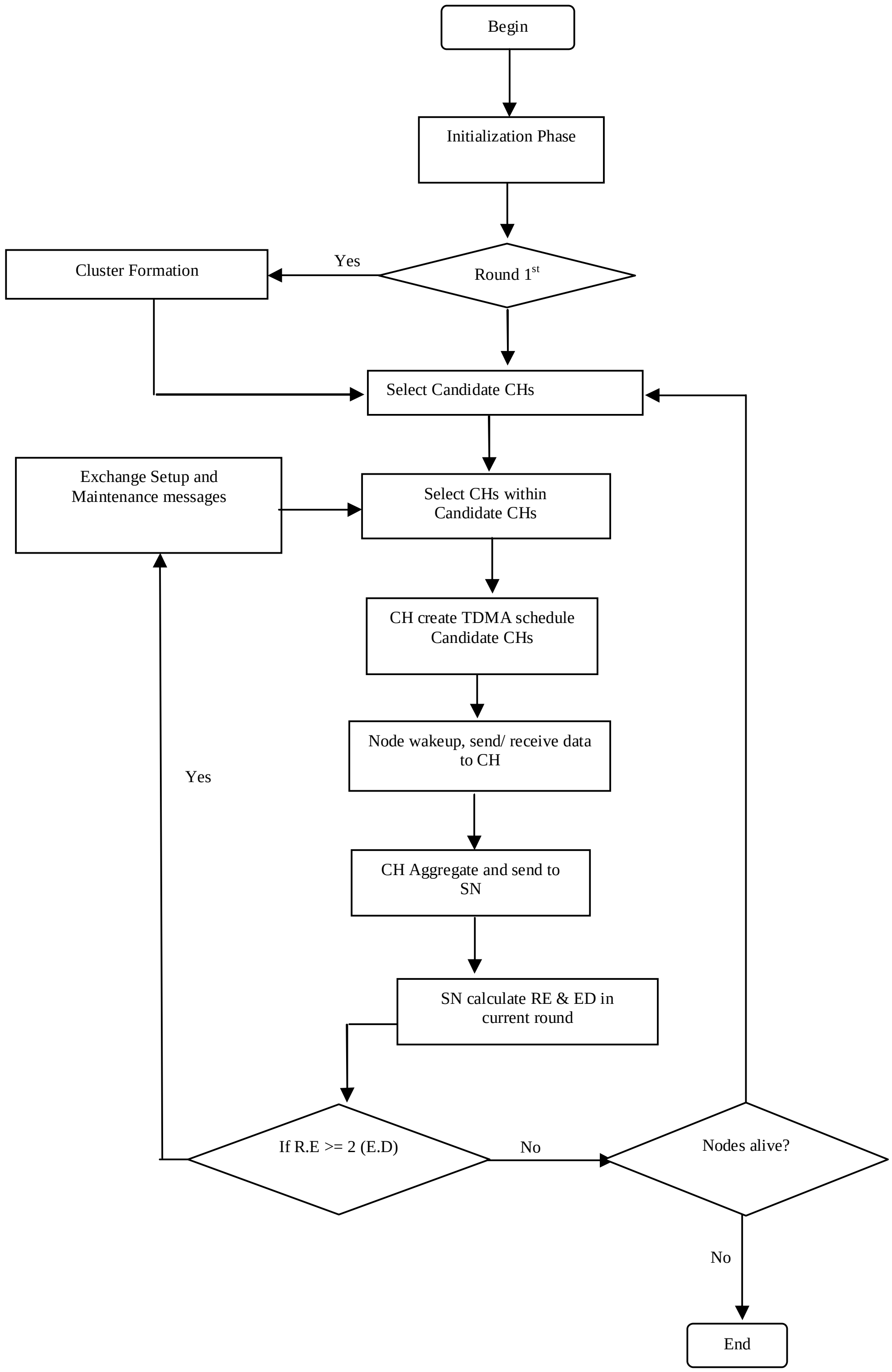
Begin
Initialization Phase
Round 1st
Yes
Cluster Formation
Select Candidate CHs
Exchange Setup and Maintenance messages
Select CHs within Candidate CHs
CH create TDMA schedule Candidate CHs
Node wakeup, send/ receive data to CH
Yes
CH Aggregate and send to SN
SN calculate RE & ED in current round
If R.E >= 2 (E.D)
No
Nodes alive?
No
End

FIGURE 5: Flow Chart of Cluster Head

4. ANALYTICAL DISCUSSION

In our methodology the idea is to distribute the load of long range transmission from CH to the SN. This will conserve energy at CH and ultimately lead to increase in the life time of wireless sensor network. The problem is when CHs are burdened with extra processing by gathering information from non cluster heads and as a result the CHs are drained of their energy quickly. There is no need to have inter-cluster multihop communication because each cluster head is able to directly reach the SN. In this way, the CHs near the BS or SN does not have to take extra responsibility of transmitting other clusters information. They just have to transmit their own data. This will lead to energy balancing among the clusters that was previously a problem. The modified architecture can be more scalable as we just need to add extra SN if network density or distance is high.

The proposed algorithm describes the selection process of CHs. The benefit of using K-Theorem is that it minimizes the communication and reduces the long range intra-cluster communication by selecting the best nodes for cluster heads from the location where network density is higher.

5. CONSLUSION & FUTURE WORK

Energy efficiency is the most important design consideration for wireless sensor networks and its optimum utilization is a challenge in its own regard. We achieved energy efficiency through efficient cluster head selection algorithm. We divide sensor nodes into clusters through by using K-Mean. Our model is simple, efficient and less costly and can scale well to large networks. The findings of this research can be summarized as follows. We believe that this will not only minimize the communication cost but will also increase the reliability of the network.

- A good clustering technique is one that achieves an energy balance in the network and maximum data delivery.
- The main factor for energy balance and data delivery is the efficient clustering and cluster head selection.
- Optimization of data delivery depends upon the optimum level of energy of CH neighbor's nodes. Our work can be extended to analyze the performance for other parameters. i.e. latency, throughput and efficient routing techniques.

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