Energy Efficient Homogenous Clustering Algorithm for Wireless Sensor Networks

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Abstract

Radio transmission and reception consumes a lot of energy in a wireless sensor network (WSN), which are made of low-cost, low-power, small in size, and multifunctional sensor nodes. Thus, one of the important issues in wireless sensor network is the inherent limited battery power within the sensor nodes. Therefore, battery power is crucial parameter in the algorithm design in maximizing the lifespan of sensor nodes. It is also preferable to distribute the energy dissipated throughout the wireless sensor network in order to maximize overall network performance. Much research has been done in recent years in the area of low power routing protocol, but, there are still many design options open for improvement, and for further research targeted to the specific applications, need to be done.

In this paper, we propose a new approach of an energy-efficient homogeneous clustering algorithm for wireless sensor networks in which the lifespan of the network is increased by ensuring a homogeneous distribution of nodes in the clusters. In this clustering algorithm, energy efficiency is distributed and network performance is improved by selecting cluster heads on the basis of (i) the residual energy of existing cluster heads, (ii) holdback value, and (iii) nearest hop distance of the node. In the proposed clustering algorithm, the cluster members are uniformly distributed and the life of the network is further extended.

Keywords

Wireless Sensor Networks, Cluster Head, Homogeneous Clustering Algorithm, Energy-efficient

1. Introduction

Recent technological advances in wireless communications, electronics, micro electro mechanical system (MEMSs), and micro sensor have enabled the development of low-cost, low-power, multifunctional tiny sensor nodes to communicate untethered in short distances. These tiny sensor nodes, which consist of sensing, data processing, and communicating components, leverage the idea of wireless sensor networks [1], [2]. These sensors have the ability to communicate either among each other or directly to an external base-station (BS). A Wireless Sensor Network (WSN) contains hundreds or thousands of these tiny sensor nodes for monitoring of specified parameters. These sensors have the ability to communicate either among each other or directly to an external base-station (BS). Each sensor node comprises sensing, processing, transmission, mobilization, position finding system, and power units.

Despite the innumerable applications of WSNs, these networks have several restrictions, e.g., limited energy supply, limited computing power, and limited bandwidth of the wireless links connecting sensor nodes. The fundamental goal of a WSN is to produce information from raw local data obtained

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(sensed data) by individual sensor node by prolonging the life time of WSN as much as possible and prevent connectivity degradation by employing aggressive energy management techniques. The design of routing protocol in WSNs is influenced by the limited power of sensor nodes that mandates the design of energy-efficient communication protocol with or without security.

Researchers have devised many protocols for communication, and security in wireless networks life infrastructure based networks, ad-hoc networks, mobile networks etc [2-16]. But as mentioned above, these protocols cannot be used directly due to resource constraints of sensor nodes for resources like limited battery power, communication capability, and computational speed. Much research has been done in recent years, investigating different aspects like, low power protocols, network establishments, routing protocol, coverage problems and the establishment of secure wireless sensor networks. But even after many efforts, there are still many design options open for improvement. Thus, there is a need to device a new protocol which enables more efficient use of scarce resources at individual sensor nodes for an application.

In this paper, we propose Energy efficient homogeneous clustering algorithm for WSN. We demonstrate that the homogeneous clustering algorithm extend the lifetime of sensor networks and try to maintain a balance energy consumption of nodes. The paper is organized as follows. Section 2 discusses the basic radio energy model. Section 3 summarizes the related previous works and their limitations. Section 4 describes the proposed homogeneous clustering algorithm with the help of illustrative examples. Simulation results are presented in section 5 while conclusions and suggestions for future work are given in section 6.

2. Radio Energy Model

Different assumptions have been made by researchers about the radio characteristics, including energy dissipation in transmit and receive modes. We assume that the energy consumption of the sensor is due to data transmission and reception. We use the same radio model as stated in [3], [7] and shown in Figure 1, the energy consumed in transmitting one message of size ***k*** bits over a transmission distance ***d***, is given by

$$E_{Tx}(k,d) = k\left(E_{elec} + \varepsilon_{Amp} d^{\lambda}\right) = E_{elec}k + \varepsilon_{Amp} k d^{\lambda} \quad (1)$$

Where k = length of the message

d = transmission distance between transmitter and receiver

E_{elec} = electronic energy

ε_{Amp}= transmitter amplifier

λ= path-loss component ($2 \leq \lambda \leq 4$)

Also, the energy consumed in the message reception is given by

$$E_{rx} = E_{elec}k \quad (2)$$

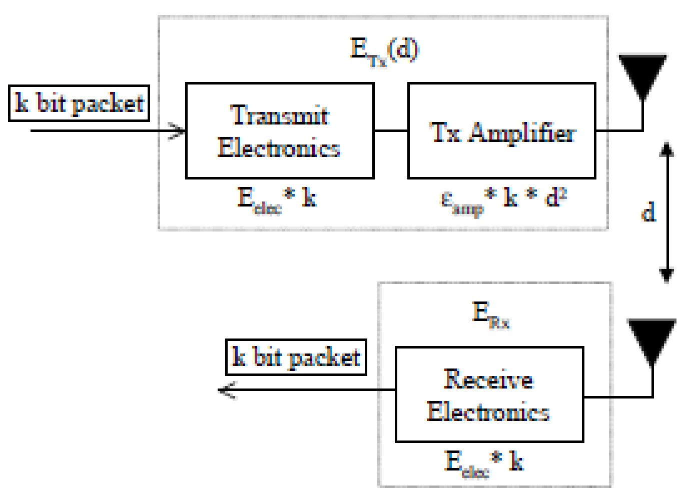

Figure 1: First Order Radio Energy Model

Hence, the total energy consumption when sensor receives a message and forwards it over a distance d is given by

$$E_{tot}(d) = k\left(2E_{elec} + \varepsilon d^{\lambda}\right) \tag{3}$$

3. Related Previous Works

A variety of protocols have been proposed for prolonging the life of WSN and for routing the correct data to the base station. Each protocol has advantages and disadvantages. These are not suitable for area monitoring applications. Battery power of individual sensor nodes is a precious resource in the WSN [4-5]. For example, the power consumed by a Berkeley mote to transmit 1-bit of data is equivalent to the computation of 800m instructions [4]. When the battery power at a sensor node expires, the sensor node discontinues its operations in the network. Therefore, preserving the battery power of the individual sensor nodes is one of the primary concerns that pervades the design and operations of the WSN. The larger life span for battery power of individual sensor nodes may be achieved by minimizing the number of communications. Clustering supports different communication pattern like one-to-one, one-to-all, one-to-any, one-to-many, and many-to-one. For the cluster based wireless sensor network, the cluster information and leader election (called cluster head, CH) are the basic issues. The leader of cluster coordinates the communication among the cluster members and manages their data.

The leader election problem originally appeared in the token ring networks (distributed systems) for managing the token [6]. Designing the leader election algorithm for both the ad hoc networks and wireless sensor network is a challenging task and very complex because thousands of sensor nodes are distributed in a region in uncontrolled and unorganized way. According to the way that data are collected, cluster based WSNs classified into three broad categories namely (i)homogeneous sensor networks, (ii) heterogeneous sensor networks, and (iii) hybrid sensor networks

In homogeneous sensor networks, all the sensor nodes and base stations are identical in terms of hardware capability and initial battery power. In this method, the static clustering elects cluster heads (CH) only once for the entire lifetime of the network. This results in overload on cluster heads. As proposed in LEACH [3], [7], the role of cluster heads is randomly and periodically rotated over all the nodes to ensure the same rate of dissipation of battery power for all the sensor nodes.

In heterogeneous sensor networks, two or more different types of sensor nodes with different hardware capabilities and battery power are used. The sensor nodes with higher hardware capabilities and more battery power compared to other sensor nodes act as cluster heads. Yarvis et al. [9] proposed a three-layer architecture for heterogeneous WSNs. In this architecture, the top layer contains only one sink that receives sensed data and analyze them. The second layer includes sensors with no energy constraint. These sensors, called line-powered sensors, have unlimited energy resources by connecting them to a wall outlet. The third layer contains battery-powered sensors that are 1-hop away from line-powered sensors. The rationale behind this architecture is that the sensors closer to the sink in a multi-hop sensor network with many-to-one delivery consume more energy than all other sensors in the network, and thus should be line powered. There is no communication among battery-powered sensors in order to save their energy, and hence no battery-powered sensor can play the role of a data forwarder on behalf of other sensors. This architecture requires a sufficient number of line-powered sensors.

In a hybrid sensor networks, several mobile base stations work cooperatively to provide fast data gathering in a real-time manner. Mobile ad hoc networks (MANETs) assume that every node is able to move at their own pace. Even with the constraints in terms of energy, processing, transmission range, and bandwidth, routing from a source base station to a destination base station is accomplished by using MANET protocols in hybrid WSNs [11]. Hybrid sensor networks can achieve longer lifetime and can also improve the efficiency of data gathering [9-10].

As explained in [8], many greedy algorithms have been proposed to choose cluster heads in ad hoc networks and wireless networks, which are based on the criteria such as (i) lowest-ID clustering algorithm, (ii) highest-connectivity clustering algorithm, (iii) least clustering change algorithm, and (iv) weighted clustering algorithm

The lowest ID (LID) clustering algorithm is a 2-hop clustering algorithm [20], During execution of this algorithm, a node periodically broadcasts the list of nodes that it can hear (including itself). A node, which only hears the nodes with IDs higher than itself from the 1-hop neighborhood, declares itself as the cluster head. It then broadcasts its ID and cluster ID. A node that can hear two or more cluster heads (that lies within the transmission range of two or more cluster heads) is a gateway node; otherwise, it is an ordinary node or a cluster head. In LID based greedy algorithms [13], [18], [19], a unique identity is assigned to each node and chooses the node with lowest identity as cluster head. Various simulation results have shown that the LID clustering algorithm is more stable in an environment in which the network topology changes frequently [14].

Highest-connectivity (HCN) clustering algorithm elects the node with the highest connectivity (degree) in a neighborhood as the cluster head [12], [14-15]. The connectivity of a node is the number of links to its 1-hop neighbors. HCN and Lowest-ID (LID) are based on the Linked Cluster Algorithm [13]. As compared to LID algorithm, HCN incurs a higher message overhead because more information about connectivity is exchanged [14], [16]. Thus, the throughput is low in HCN approach. However, the drawback of LID is that there may be quick power drainage of the cluster head node and Gateway nodes.

List clustering change (LCC) algorithm is proposed to minimize the frequency of cluster head change where cluster stability is the major consideration under certain circumstances [21]. The LCC clustering algorithm is robust in an environment in which the network topology changes frequently. It has low routing overhead and latency. However, the load distribution would be unfair for all nodes.

The weighted clustering algorithm (WCA) is based on a combined weight metric, which includes one or more parameters such as the node degree, node speed, distances with respect to a node’s neighbors, battery life, and the time spent as a cluster head [17]. Each node broadcasts its weight value to all other nodes. A node is chosen to be cluster head if its weight is the highest among its neighbors; otherwise, it joins a neighboring cluster. In the event of a tie, the LID algorithm is applied. This algorithm shows good load balancing because the algorithm restricts the number of nodes in the cluster. However, since a node has to wait for all the responses from its neighbors to make its own decision, the latency and the overhead induced by WCA are very high.

All of the above heuristics algorithms are suitable for a specific application rather than for generic wireless mobile networks. These algorithms do not lead to an optimal election of cluster heads because each deals with only a subset of the parameters that can possibly impose constraints on the network.

Node clustering mechanism in wireless ad hoc networks has been investigated in the past in order to enhance network manageability, channel efficiency, and energy economy. Many heuristic-based node clustering algorithms have been proposed in which some of the more popular algorithms are (i) Linked cluster algorithm, (ii) Energy-efficient adaptive clustering, and (iii) Energy-efficient distributed clustering.

In the Linked Cluster Algorithm (LCA) [22], all nodes in the network are organized into a set of node clusters and each node belongs to at least one cluster. Every cluster has its own cluster head, which acts as a local controller for the other nodes in the cluster. The cluster heads are linked via gateway nodes to connect the neighboring clusters and to provide global network connectivity. A node becomes the cluster head if it has the highest ID among its neighboring nodes, or if it has the highest ID in the neighborhood of one of its neighbors. This highest ID linked cluster algorithm yields poor clustering when the nodes are arranged in the order of their identities; that is, all but one node becomes a cluster head. Another improved version of LCA is greedy algorithm LCA2 [23], which elect a node as a cluster head using LID mechanism. The disadvantage of both of these linked cluster mechanisms is that the cluster head load is not uniformly distributed among all the nodes. Another limitation of LCA is its relatively high control message overhead because the nodes have to broadcast their Nodes-heads list. Further, LCA does not consider the node mobility, adaptive transmission range, and power efficiency issues.

Low-energy adaptive clustering hierarchy (LEACH) is a popular energy-efficient adaptive clustering algorithm that forms node clusters based on the received signal strength and uses these local cluster heads as routers to the base station [24]. LEACH is an application-specific data dissemination protocol that uses clusters to prolong the life of the wireless sensor network. LEACH utilizes randomized rotation of local cluster heads to evenly distribute the energy load among the sensors in the network [3], [7]. LEACH uses three techniques namely (i) randomized rotation of the cluster heads and corresponding clusters, (ii) localized coordination and control for cluster set-up and operation, and (iii) local compression to reduce global communication. LEACH clustering terminates in a finite number of iteration, but does not guarantee good cluster head distribution and assumes uniform energy consumption for cluster heads.

Another popular energy-efficient node clustering algorithm is the hybrid, energy-efficient, and distributed (HEED) clustering approach for ad hoc sensor networks [25], [26]. The proposed primary goals of HEED are (i) prolonging network lifetime by distribution energy consumption, (ii) terminating the clustering process within a constant number of iterations, (iii) minimizing control overhead, and (iv) producing well-distributed cluster heads and compact cluster. HEED periodically selects cluster heads according to a hybrid of two clustering parameters namely the residual energy of each sensor node as primary parameter and intra-cluster communication cost as a function of neighbor proximity or cluster density as secondary parameter. The primary parameter is used to probabilitistically select an initial set of cluster heads while the secondary parameter is used for breaking ties. HEED results in good load balancing. Clustering process terminates within a constant number of iterations. The HEED clustering improves network lifetime over LEACH clustering because LEACH randomly selects cluster heads (and hence cluster size), which may result in faster death of some nodes. The final cluster heads selected in HEED are well distributed across the network and the communication cost is minimized. In yet another energy-efficient clustering protocol, the authors proposes for prolonging the life of the wireless sensor network by dividing the network into clusters. The cluster heads are selected on the basis of primary parameter as hold back period and secondary parameter as the number of hops, to restrict the size of the cluster [8].

4. The Proposed Homogeneous Clustering Algorithm

The emphasis of our approach is to increase the life span of the network by ensuring a homogeneous distribution of nodes in the clusters so that there is not too much receiving and transmitting overhead on a Cluster Head.

4.1 Basic assumption for the clustering algorithm

- The base station (BS) is located far from the sensors and immobile.
- All nodes in the network are homogenous and energy-constrained.
- All nodes are able to send data to BS.
- The BS has the information about the location of each node.
- Cluster-heads (CHs) perform data reception, compression and transmission.
- At the start energy of all nodes is at the maximum level.
- In the first round, each node has a probability p of becoming the cluster head.
- A node which has become cluster head shall be eligible to become cluster head after $1/p$ rounds.
- Assume 100 nodes in the network.
- Each node has same energy E_{max} and consumes equal energy for transmission and reception
- Nodes in the network are not dynamic while the Cluster Heads (CHs) are being selected

4.2 Proposed Algorithm

Step#1: In the first round, BS collects information regarding location of all the nodes in the network. Depending on the density and geographical layout of the network, it virtually divides the network into

10 zones as shown in Figure 2. The objective behind this method is to ensure uniform selection of CHs throughout the layout of the network.

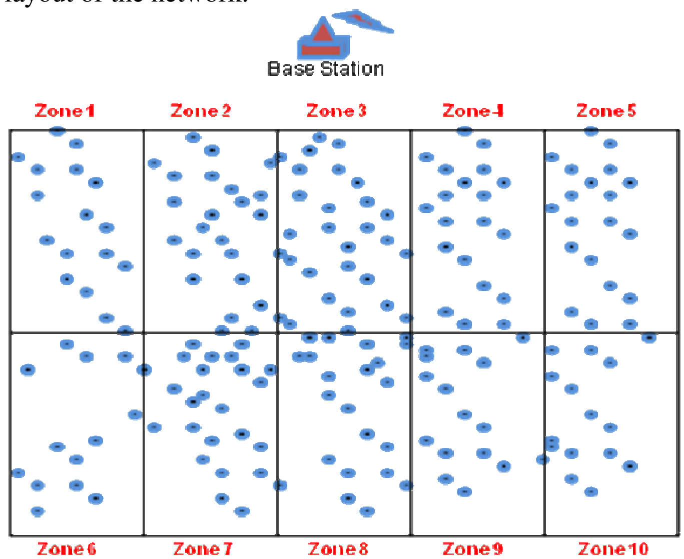

Figure 2: Virtual Distribution of Network into Zones

For example:

Zone 01 = {node12, node 45, node 67 …. node 87}

:

Zone 10 = {node2, node 23, …. node 78}

Step#2: Since we have assumed that initially all the nodes have same maximum energy (E_{max}), the nodes in each zone have a probability *p* (1/number of nodes in the zone) of becoming a CH. Hence, from each zone, randomly a cluster head (CH) is selected randomly as shown in Figure 3.

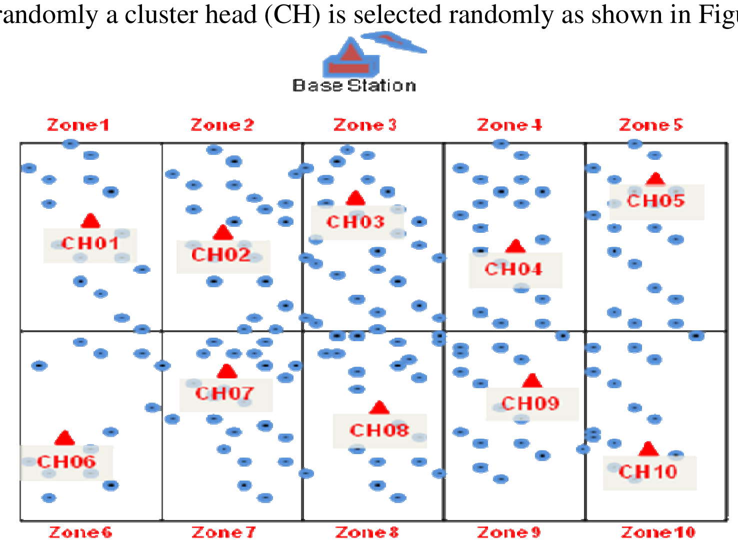

Figure 3: Selected Cluster Heads

Step#3: Once the CHs are formed, it broadcasts its identity to all the other nodes in the network to accept its joining request and form actual clusters. For example, CH7 and CH12 broadcast its identity to all the nodes in the network as shown in the Figure 4.

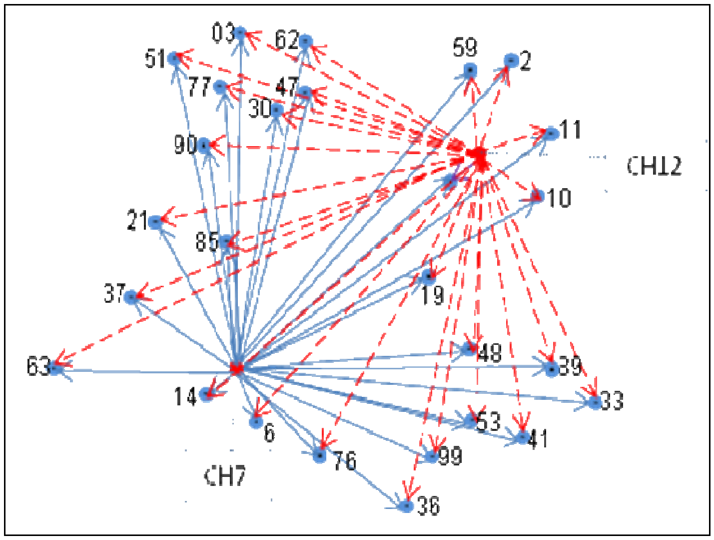

Figure 4: Broadcasting of its Identity by Selected CHs to all nodes

Step#4: The nodes which receive the joining request analyses the signal strength of the request signal. Signal strength of the CH request depends on the distance between CH and node, and physical barrier between the CH and node. Depending on the level of the signal each node sends an acknowledgement to the most preferred CH. Each CH waits for the joining request from the nearby nodes. Figure 5 illustrates joining of nodes with the CH. Left out nodes will try to join other CH nearest to it.

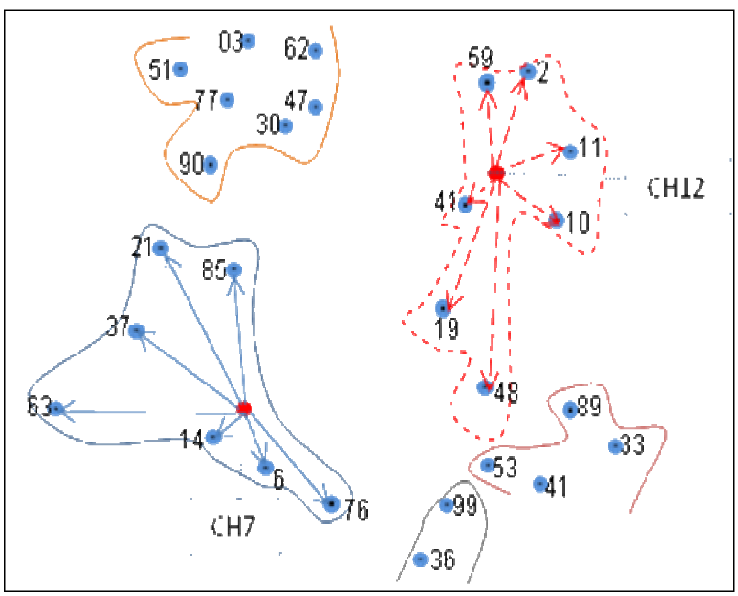

Figure 5: Nodes analyzing the signal strength from the CHs

4.3 Final Cluster Formation

Clusters are formed, as shown in the Figure 6, once the acknowledgement form the node is received by the CH.

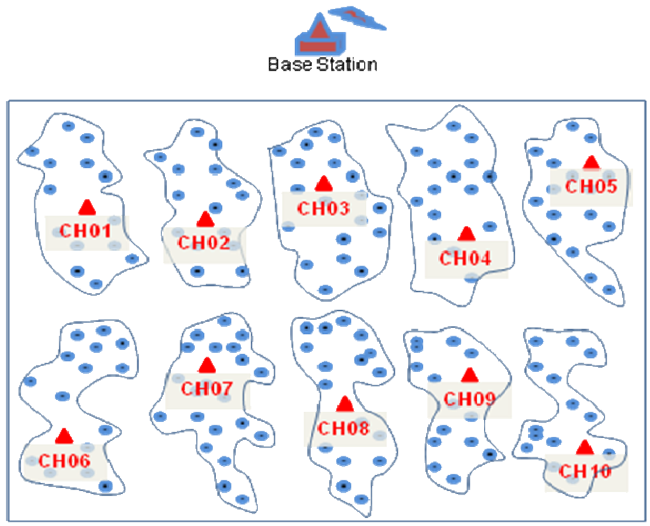

Figure 6: Final Cluster Formation

Step#5: The CH prepares the data sending schedule and sends it to its members within the cluster.
Step#6: The CH receives data from each node, compresses the data and sends it to the BS.

4.4 New Cluster Head (CH) Formation

New CH is selected by checking the residual energy of existing CHs. If it is below a threshold level (T), new CH is to be selected depending on the following criteria:

- A node has not become a CH for the past ($1/p$) – 1 rounds.
- The factor ($E_{Current}$)/(E_{Max}) should be nearest to one; ($E_{Current}$=current residual energy of the node and E_{Max}=initial energy level of the node)
- The most preferred next CH is the node nearest to the existing CH (hop, h=1). Figure 7 illustrates formation of new CH and re-orientation of the cluster.

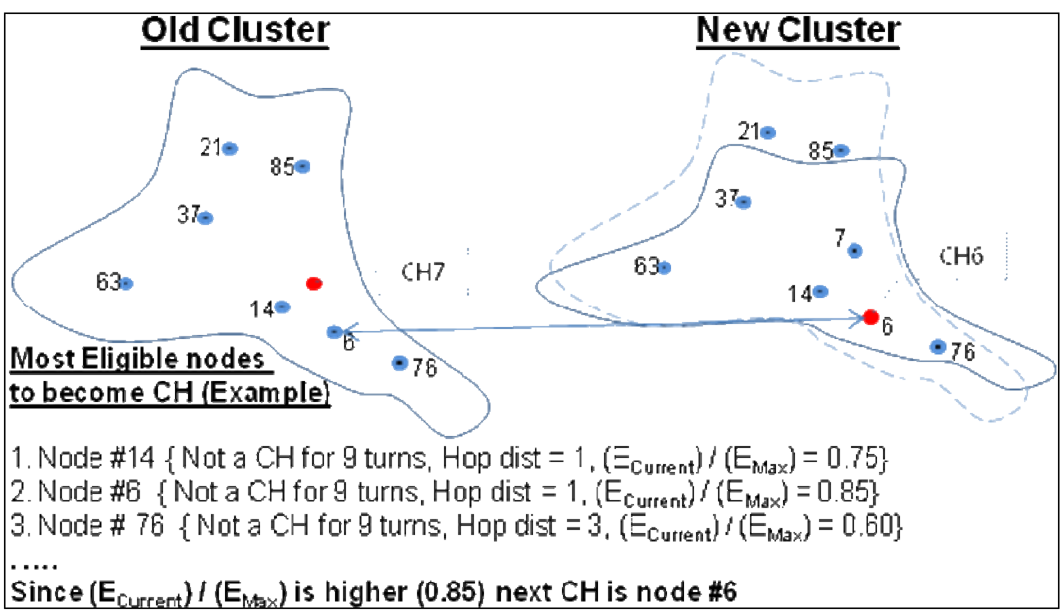

Figure 7: Re-orientation of the Cluster in view of new CH Selection

Flow chart of the proposed algorithm is shown in Figure 8.

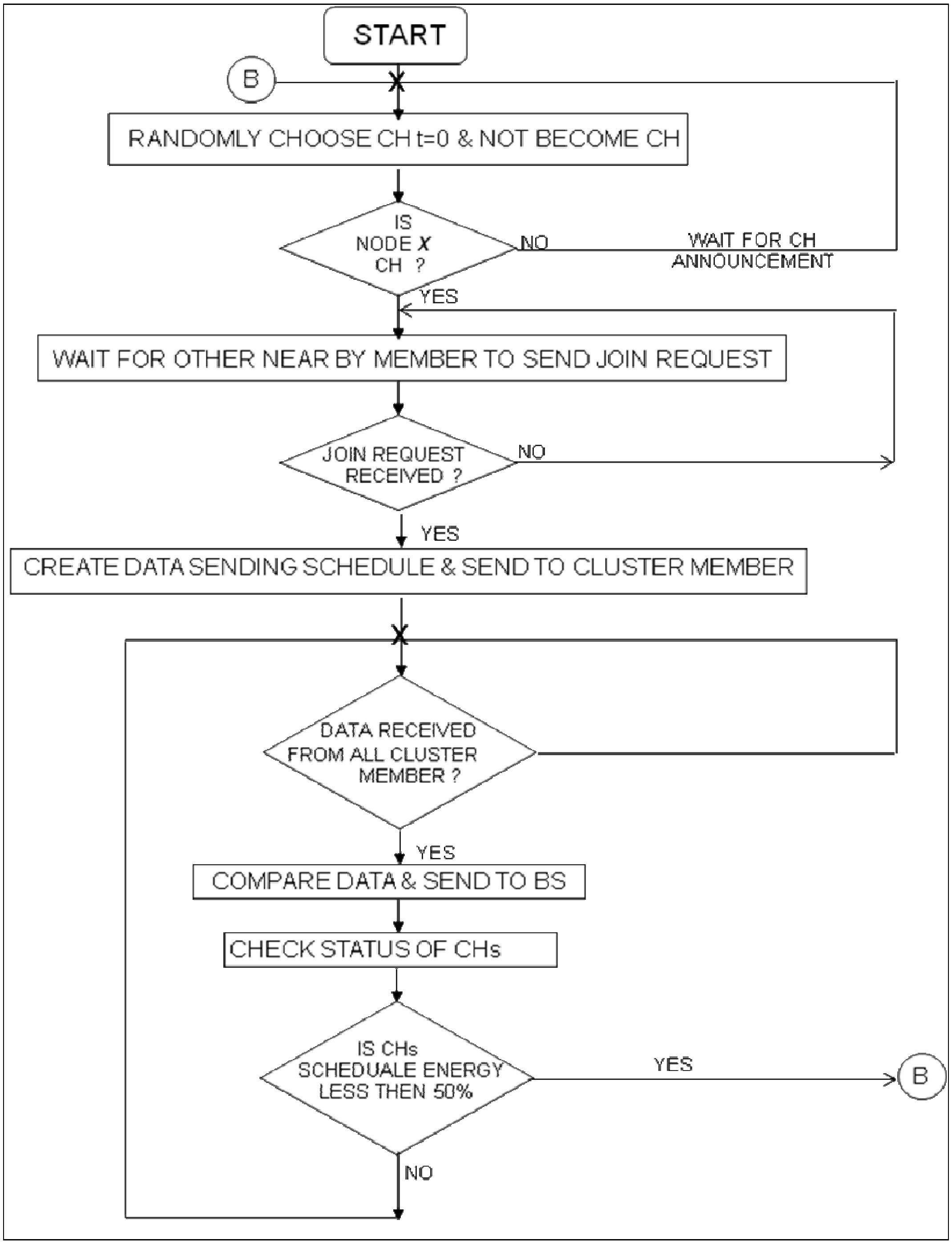

Figure 8: Flowchart of Proposed Algorithm

5. Simulation Results

In the normal random selection method, number of cluster members is non-uniform resulting in loading of a CH. As a result, the network has to form clusters more frequently. In the new proposed homogeneous clustering algorithm method, since the cluster members are uniformly distributed and thus, the life of the network is more extended. To simulate the result of energy consumed by both normal random clustering and proposed homogeneous clustering, let us take an example as shown in Figure 9.

Case 1 – Power Consumed by Random Selection Method

- As shown in Figure 9, the clusters formed in the random selection method consist of 30, 5, 15, and 50 numbers of nodes as cluster members.
- Power consumption assumed for each receive and transmit is 50 *nJ/bit.*
- Let us assume a 10 *KB* message is being sent by each member node to its cluster head (CH) per *mS*.
- Let us assume that after data compression, energy consumed by a CH to send the data to the Base Station (BS) is 50% of the energy spent to receive the same volume of data from its member nodes.
- The power consumption in the random selection method for cluster head CH04 can be calculated as

$$\begin{aligned} E_{consume} &= (E_R \times \text{Data Packet} \times \text{number of member nodes}) + E_T \\ &= (E_R \times \text{Data Packet} \times \text{number of member nodes}) \\ &\quad + (E_R \times \text{Data Packet} \times \text{number of member nodes})/2 \\ &= (50 \times 10^{-9} \times 10 \times 10^3 \times 50) + ((50 \times 10^{-9} \times 10 \times 10^3 \times 50)/2) \\ &= \mathbf{37.5\ mJ/mS} \end{aligned}$$

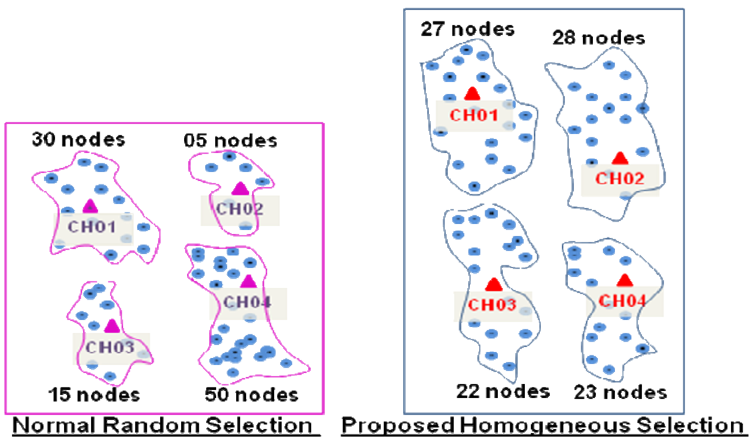

Figure 9: Comparison of Normal Random and Homogeneous Selection methods

Case 2 – Power Consumed by Proposed Homogeneous Selection Method

- As shown in Figure 9, the clusters formed in the proposed homogeneous selection method consists of 27, 28, 22, and 23 numbers of nodes as cluster members because of homogeneity.
- Same power consumption of 50 *nJ/bit* is assumed for each receive and transmit functions.
- Let us assume that same 10 *KB* message is being sent by each member node to its cluster head per *mS*.
- Let us also assume again that after data compression, energy consumed by a CH to send the data to the Base Station is 50% of the energy spent to receive the same volume of data from its member nodes
- The power consumption in the homogeneous selection method for cluster head CH02 may now be calculated as

$$\begin{aligned} E_{consume} &= (E_R \times \text{Data Packet} \times \text{number of member nodes}) + E_T \\ &= (E_R \times \text{Data Packet} \times \text{number of member nodes}) \\ &\quad + (E_R \times \text{Data Packet} \times \text{number of member nodes})/2 \\ &= (50 \times 10^{-9} \times 10 \times 10^3 \times 28) + ((50 \times 10^{-9} \times 10 \times 10^3 \times 28)/2) \\ &= \mathbf{21\ mJ/mS} \end{aligned}$$

We compare the performance of the proposed homogeneous clustering algorithm against normal random selection method in terms of energy consumption for sending as shown in Table 1.

Table: 1 Comparison of Power Consumptions

Message Size (MB)	Power consumed in Random Selection Method (J/mS)	Power consumed in Proposed Homogeneous Selection Method (J/mS)	Message Size (MB)	Power consumed in Random Selection Method (J/mS)	Power consumed in Proposed Homogeneous Selection Method (J/mS)
0.01	0.0375	0.021	0.11	0.4125	0.231
0.02	0.075	0.042	0.12	0.45	0.252
0.03	0.1125	0.063	0.13	0.4875	0.273
0.04	0.15	0.084	0.14	0.525	0.294
0.05	0.1875	0.105	0.15	0.5625	0.315
0.06	0.225	0.126	0.16	0.6	0.336
0.07	0.2625	0.147	0.17	0.6375	0.357
0.08	0.3	0.168	0.18	0.675	0.378
0.09	0.3375	0.189	0.19	0.7125	0.399
0.1	0.375	0.21	0.2	0.75	0.42

As shown in Figure 10, the battery power consumption for different size of message transmission is less in the proposed algorithm in comparison of the random selection method.

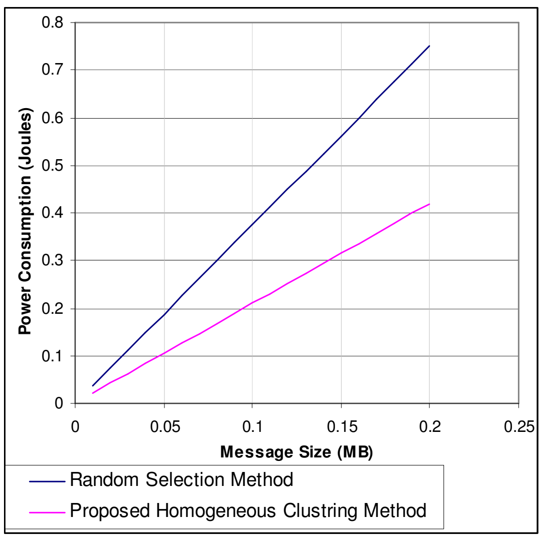

Figure 10: Power consumption with respect to message size

6. Conclusion

In this paper we have illustrated a homogeneous clustering algorithm for wireless sensor network that saves power and prolongs network life. The life span of the network is increased by ensuring a homogeneous distribution of nodes in the clusters. A new cluster head is selected on the basis of the residual energy of existing cluster heads, holdback value, and nearest hop distance of the node. The homogeneous algorithm makes sure that every node is either a cluster head or a member of one of the clusters in the wireless sensor network. In the proposed clustering algorithm the cluster members are uniformly distributed, and thus, the life of the network is more extended. Further, in the proposed protocol, only cluster heads broadcast cluster formation message and not the every node. Hence, it prolongs the life of the sensor networks.

Battery power being scarce resources of sensors, energy efficiency is one of the main challenges in the design of protocols for WSNs. The ultimate objective behind the protocol design is to keep the sensors operating for as long as possible, thus extending the network lifetime. The factors affecting cluster formation and CH communication are open issues for future research. This investigation will be highly useful for energy efficient wireless sensor network.

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