A New Clustering Protocol Based on Energy Band for Wireless Sensor Networks

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***Abstract*—Clustering techniques help to prolong the life of wireless sensor network, especially in hostile environment where battery replacement of individual sensor nodes is not possible after their deployment in the given target area. Clustering techniques also provide good load balancing, and in-network data aggregation. This paper introduces and analyzes a new clustering protocol in the wireless sensor networks based on energy band. The entire target area is divided into energy band which enables a node to estimate the energy with which it can transmit to the head node and head node to another head node towards a base station resulting in a prolonged life for the wireless sensor networks.**

I. Introduction

The continuous enhancement in communication, computation and hardware technologies enable new devices known as sensor nodes [1]. A Wireless Sensor Network (WSN) is a group of sensor nodes, which execute some monitoring task in a collaborative and autonomous manner. The sensor node has capability of communication, computation, and sensing the physical world irrespective of its size. The size of sensor nodes varies from some cm*cm to mm*mm. The main design concern for any applications of wireless sensor networks is the limited energy supply, limited computation capability and communication range of sensor nodes as compared with other computing and communicating devices [2], [3]. Lifetime of wireless sensor network depends on lifetime of battery of individual sensor nodes. In multi-hops WSN, each node plays dual role as data sender and data router. One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation by employing aggressive energy management techniques.

Rest of the paper is organized as follow. Section 2 introduces clustering. Next, section 3 discusses related work. Next, section 4 describes the proposed solution. Next, section 5 analyzes the proposed solution. Finally, section 6 concludes this paper and proposes future work.

II. Clustering

Cluster may be defined as follows:
Definition: In a wireless sensor network, cluster is a group of sensor nodes in which one node will act as a cluster head, and remaining nodes will act as member nodes. The groups either may be overlapped or may be non-overlapped. Formally, cluster may be defined as a communication network that is undirected graph G = (V, E), where V and E represent vertices (sensor nodes) and edges (communication between nodes) respectively. Clustering techniques divides V into collection of subsets $V_1, V_2, ...V_n$. These subset either may be overlapped or may not be overlapped. Clustering enables the frequency reuse, a similar concept in a cellular network environment amongst non overlapping cells[4]. For example, the same time/frequency division multiplexing can be reused across non-overlapping clusters. Clustering helps in reducing the number of exchanged communications in wireless sensor network resulting in low consumption of battery power of individual sensor nodes. This increases the life span of the wireless sensor network. The subsequent subsection discusses the related work in clustering protocol for wireless sensor networks.

III. Related Work

Many greedy algorithms have been proposed to choose cluster heads in ad hoc networks, and wireless sensor networks. They are based on the criteria of Highest-Degree, Lowest-ID, Highest-ID, Highest-ID and Lowest-ID, and Node-Weight, Residual energy, Probability, and any combination of these. The clustering techniques can also be classified based on cluster size, namely Single hop, and Multi-hop.
Linked Cluster Algorithm (LCA) [5] elects node as a cluster head if it has the highest identity among all nodes within one hop. LCA2 [6] is advanced version of LCA. The Weighted Clustering Algorithm (WCA) [7] elects a node as cluster head if it has highest weight among all the nodes (weight is the summation of node-degree (neighboring nodes), degree-difference, sum of the distances with all of its neighboring nodes, mobility rates of the nodes, and life span of battery). ”DCA [8], and DMAC [9] elects cluster heads based on Node-Weight greedy algorithm. LEACH [10](Low-Energy Adaptive Clustering Hierarchy) elects cluster heads based on randomly generated value between 0 and 1. If this randomly generated value is less than threshold value then the node becomes cluster head for the current round. In all of the above algorithms [5], [6], [7], [8], [9], [10] have two main drawbacks. First, these algorithms are not suited for the wireless sensor networks having more numbers of node, may be more than 100 nodes. Second, they are not suited for multi hops cluster. Min-

Max D-Cluster [11] uses 2d, namely floodmax, and floodmin, rounds of flooding to elect cluster heads where d is the number of hops of a member node from its cluster head. HEED (Distributed Clustering in Ad-hoc Sensor Networks: A Hybrid, Energy-Efficient Approach) [12] periodically selects cluster heads according to a combination of their residual energy, and communication cost. Distributed Weight-Based Energy-Efficient Hierarchical Clustering (DWEHC) [13] is modified version of the HEED. It claims to provide more balanced cluster size and intra cluster topology. Cluster based self-organization management protocols for wireless sensor networks [14] protocol uses ”20/80 rule”, which will determine the ratio of total number cluster heads and total number of member nodes. This rule tries to control the total number of cluster heads in a wireless sensor network. A new energy-efficient clustering protocol for wireless sensor networks [15] claims that it is more energy-efficient in comparison to above said algorithms based on the greedy approaches. This protocol selects cluster heads based on randomly generated holdback value. Energy Efficient Hierarchical Clustering (EEHC) [16] techniques synthesizes hierarchy among clusters.
The selection of cluster heads in the above methods is based on different types of greedy approaches which may not be energy efficient. They also do not clarify about their density of cluster heads with respect to total number of sensor nodes in the given target area. Hence, this paper tries to propose a new clustering technique in which density of cluster heads and their position in the target area are taken into account.

IV. Proposed Solution

The aim of this paper is to design a new clustering protocol for the wireless sensor networks based on energy band.
The system should be designed in such a way that each node while transmission consumes least amount of energy. This will help in increasing the lifetime of the WSN. In the proposed solution, each node will be aware of the power at which it should transmit its sensed data so as to assure the complete transfer of the data to the head node concerned, thus adhering to the minimum energy transmission constraints. Following are the challenges in the proposed solution:

1) Power management: In any wireless sensor networks the major area of concern is the management of power at each node. The proposed protocol is designed so that the transmission power of each node is, minimum.
2) Clustering technique: Considering the power management factor it is difficult to group the nodes in a certain region. Therefore the design should be such that the regions formed dissipates minimum power while transmission (whether node to node or node to base station).
   - Selection of head: The most important part of sensor network protocol is the selection of the head; therefore the design should be such that the node selected as head must dissipate the minimum power for transmission.
   - Maintaining a optimal head to member ratio: In any wireless sensor network the head to member ratio should optimum, it should be such that no node whether head or member dissipate unnecessary power while transmission.
   - Transmission constrains: One of the most difficult problem in designing a wireless sensor network is how a node (whether member of the same region or head of the region) compute the amount of power at which it should transmit so that the head node, it is concerned with, receives a healthy signal.
   - Change of head: Another problem that arises in wireless sensor network is when the present head reaches its threshold power value. In this case a new head is to be assigned to that cluster. The criterion of selection of the new head is an area of concern

The following paragraph discusses the proposed solution in detail. Consider a wireless sensor network scenario as shown in Fig. 1. There is a base station and a number of sensor

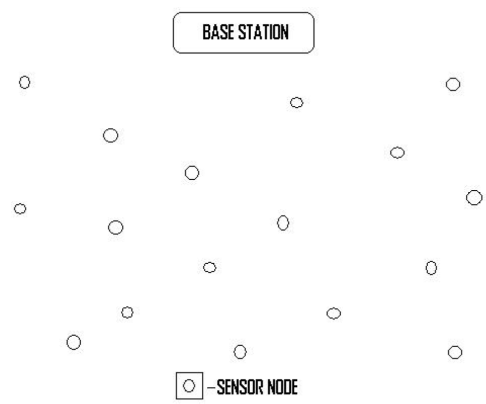

Fig. 1. Wireless sensor network

nodes deployed randomly in the given target area. Initially the base station broadcasts a message containing its identification as shown in the Fig. 2. This message basically makes each

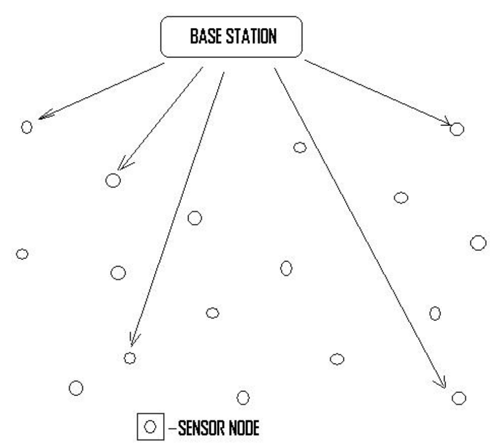

Fig. 2. Base Station Broadcasts message

node aware of the base station to which it is supposed to communicate. This process is called base station realization. After receiving the message, each node sends an acknowledgement packet to the base station at a certain power say W. Each acknowledgment packet contains its node id, X Co-ordinate, and Y Co-ordinate. Here as all the nodes are at a random distance from the base station, all of them transmit the acknowledgement at the same power but the base station receives each message at different power because of transmission loss, fading etc. Now, the base station is aware of distance of each node from itself. For instance, for the node 1 the power received by the base station is x. Hence, the transmission loss between the base station and the node 1 is (W-x). So when the base station needs to send a packet to the node 1 it should transmit at ((W-x) + a) where 'a' is the average power at which any node can receive a healthy signal for regeneration. This process is called as node realization as shown in Fig. 3. After the node realization process, the base station is aware of maximum and minimum power among acknowledgement packets received. The base station forms a logical energy band of the complete scenario. To physically divide the nodes into levels, the base station uses the X and Y Co-ordinate of each node resulting in regions for hierarchical transmission.

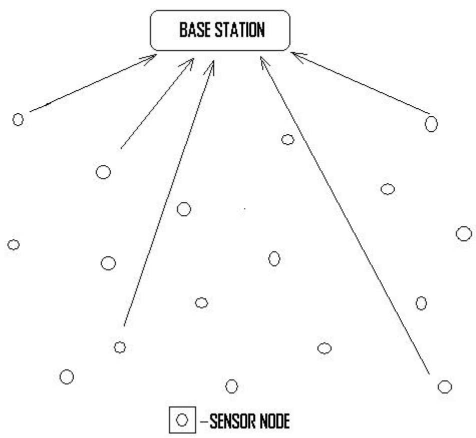

Fig. 3. Node realization process

The target area gets divided into smaller regions of n units along both the axis (X and Y) with respect to base station. The value of n depends on size of target area. All the nodes that come under a certain level are considered as one cluster. The node from which maximum power is received by the base station is considered as the first node of the first region or level, this first node is initially assigned as the head node of the region. The role of head node is on rotation basis. The division of the target area is achieved in such a way that all the nodes which are in a cluster have almost the same power dissipation while transmitting the packet to the head node directly. The base station is static. The base station calculates the distance between itself and all the nodes, as the base station knows the coordinates of all the nodes. The calculated distances help in deciding the levels. This process is known as physical level distribution of nodes and is shown in Fig.4. After the physical level distribution process, the proposed technique selects heads for each level based on maximum power received from each level. While declaring the head for a level, the base station transmits the message with the power at which the farthest node of the next level can also receive the message in healthy state. This is done so that whoever is the head of the next level comes to know about the node to which it should behave as a member and transmit all its data to it. In the head declaration packet, the base station includes the node-id of the head, the level-id, maximum power received from the level, and minimum power received by the base station from its next level. From this data, each node of the next level comes to know about the head node of the previous level. Each node of the next level can also calculate the power at which it transmits to the head node of the previous level. Let P be the transmission power for each node of the lower level to the head node of the just above level, then $P = (W_1 + W_n) + a$ Where W_1 and W_n, are the maximum and minimum power information respectively, *'a'* is the average power at which a node can receive a healthy signal for later regeneration and accurate data information.

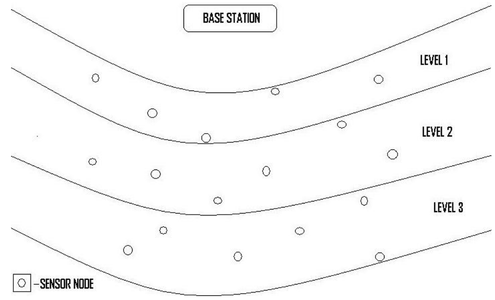

Fig. 4. physical level distribution of nodes

This process is known as level head declaration as shown in Fig. 5. The process starts with selecting the head for the first level, then second level and so on. After all the levels are assigned with a head, the system is ready for actual data transmission. Each member node of a particular level sends all its data to its head. Now, the head aggregates all the data along with its own sensed data and sends it to the head of the next level towards base station using hierarchical manner as shown in Fig. 6. In the proposed solution, each node

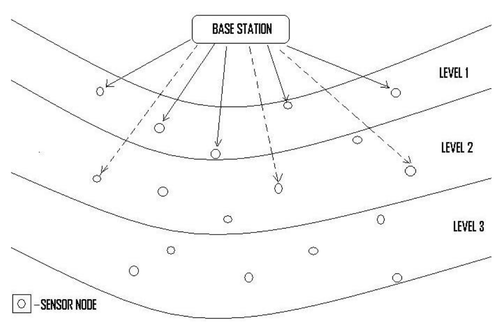

Fig. 5. Cluster head declaration process

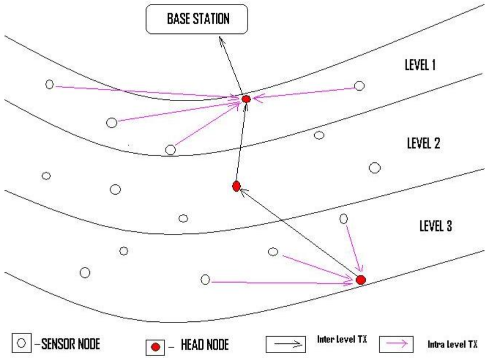

Fig. 6. Message transmission towards base station

belonging to each level sends its remaining power information with its data packet periodically in order to change the role of the head node. With this, the base station has information about remaining power at individual nodes level wise. When required, the base station searches its database for a node with next maximum power left for that level and thereby assigns it as the new head. The base station passes this message to the next level also as discussed during head declaration process. It can be visualized that in a particular level it may happen that a particular member node is far off from the head node and for this problem the transmission power for each node is $P = (W_1 + W_n) + a$. This power consumption is large. To eliminate this problem, the proposed solution uses a Grid node which is a kind of sensor node programmed differently. The Grid node helps to create sub-regions in individual level. During the node realization process, each node broadcasts the acknowledgement. The Grid node also receives this acknowledgment and calculates the sub-regions in a level. As the Base station creates physical band, here the Grid node acts accordingly. It also creates levels from the energy received by it. This grid node and the base station forms a right angle at the centre of the target area as shown in the Fig. 7. Both the grid node and the base station are placed

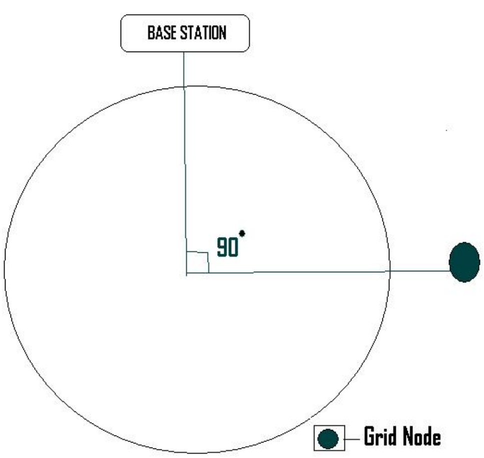

Fig. 7. Base station Vs. Grid node

orthogonally resulting in the orthogonal levels. This helps the proposed solution in creation of sub-regions (clusters) having equal distribution of the energy levels. All the nodes of a particular cluster have a same Y-co-ordinate id. Here the base station according to its creation of levels provides each node of a particular level with a same X-co-ordinate id. Now, The grid node calculates the y-co-ordinate value for each cluster and send it to the base station so that it comes to know about the y-co-ordinate value of each clusters. Now the base station selects the cluster head for each cluster. The base station maintains a database of these values for each node belonging to each cluster of a particular energy level. Now in this case, the x and y co-ordinates basically represents the energy band co-ordinates. The value of x-co-ordinate is the power loss between the farthest and nearest node in accordance with base station. The value of y-co-ordinate is the power loss between the farthest and nearest node in accordance with the grid node. Thus it has a cluster with power loss co-ordinate values x and y as shown in the Fig.8. Where $x = W - W_1, y = W - W_2$;

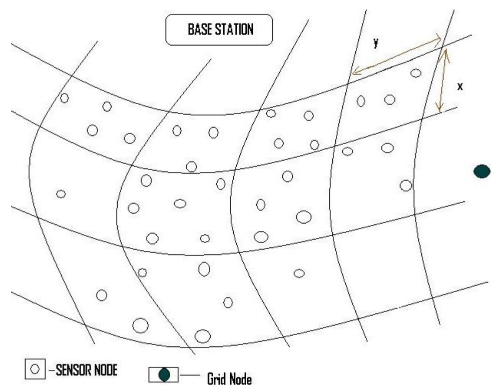

Fig. 8. Power level distribution

W = The power at which all nodes transmits the ACK packet. W_1 = the power loss from the farthest node of that region to the nearest node of that region (in accordance with the base station). W2=the power loss from the farthest node of that region to the nearest node (in accordance with the grid node). The grid node broadcasts the value of maximum and minimum energy received by it for each level. The base station with the help of this information calculates the value of 'x' and 'y'. In this case the energy level distribution is equal for both base station al well as the grid node. $X = W_{max} - W_{min}$ (in accordance with the base station for each power level). $Y = W_{max} - W_{min}$ (in accordance with the grid node for each power region). As the power level distribution is equal for both base station and grid node so the 'x' and 'y' value will remain the same for each node in the scenario. This information is broadcasted to each node present in the target area by the base station.

In this approach a node will be the member of a head node only if its X-co-ordinate and Y-co-ordinate ids are same as that of head node. Remember X-co-ordinate id and x-co-ordinate values are two different things. The final communication in this approach will take place as shown in the Fig.9. Now, any member node of a cluster transmits the sensed data to

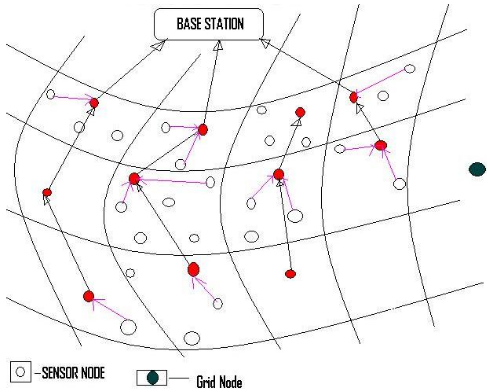

Fig. 9. Hierarchical transmission

its respective cluster head with ((x + y) + a) energy (say Z). One head to another head sends the data with ((2x+y)+ a) energy (say L) as shown in Fig. 10. Law of triangle says

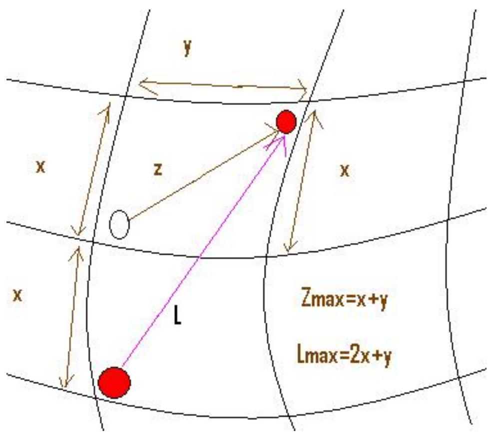

Fig. 10. Power loss due to head to head transmission

that if two sides of a triangle are of length 'x' and 'y' then the third side cannot exceed '(x + y)'. Thus the maximum power loss between a member node and its corresponding head node cannot exceed the value '(x + y)'. Similarly for communication between two head nodes the power loss cannot exceed the value '(2x+y)'. In this approach the base station initially creates a head for each node taking into consideration the maximum power received by it from that region. This message is provided to the head. The head then broadcasts this message with such a power that it can be received by each node at the next bottom level, which can be achieved by transmitting at ((2x+y) + a) power as discussed above.

In this approach as shown in Fig.9, the data transmission takes place in a hierarchical fashion. Here also first of all heads for the upper level will be created by base station then for the next level and so on. When a head is created for one region, the data reaches to the next level nodes. Now, at the next level all the nodes know about its above level heads and logically assign themselves as the member of that node irrespective of the sub-region. The base station assigns another head at the same level but different sub-region. This message will also be received by each node at the next level irrespective of the sub-region. Now each node of each sub-region will compare the power received by it in the head selection message sent by base station. And each node will reassign itself as the member of a head from which it received the maximum power. That is to say each node of each sub-region will be member of that head from which it can receive maximum power. But it should be kept in mind that no head of a particular power level will be member of a head belonging to the same power level. Mathematically it can be said that a head while making itself a member of another head node it should compare X-co-ordinate ids. This process is also explained in the Fig.9.

V. Analytical Observation

The proposed solution supports multi-hop communication. In order to have lesser power consumption in multi-hop transmission in comparison to direct transmission, a simple model is discussed using the Fig.11. In the Fig.11, three nodes

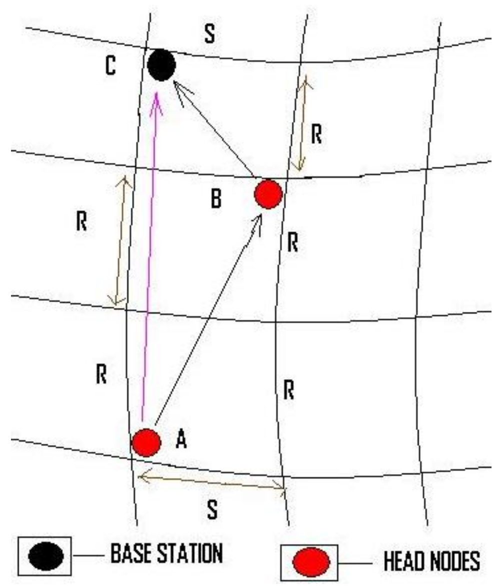

Fig. 11. Comparison between LEACH and the Proposed Solution

are considered as "A','B' and 'C'. Here it is assumed that node 'C' is the Base station. And nodes 'A' and 'B' are two heads belonging to two different regions. The side distances of each region is named as 'R' and 'S'. Now it is known that power is inversely proportional to the square of the distance between the two communicating nodes. Now in the Fig.11, it is shown that the node 'A' can communicate with the node 'C' by two ways, one through the node 'B' and another is direct communication. A condition of 'R' and 'S' is to be generated so that power loss due to multi-hop communication is lesser than the direct communication. For this to be true the following condition should be obeyed [17]:

Suppose node density of entire WSN is 'Q'. Area of a subregion is $R * S$. Assume that There are approximately five nodes in each subregion. So,

$$R * S = 5/Q \qquad (1)$$

$$AB^2 + BC^2 < AC^2 \qquad (2)$$

$$From\ Fig.11,\ it\ is\ clear\ that$$

$$AB^2 = S^2 + 4R^2 \qquad (3)$$

$$BC^2 = S^2 + R^2 \qquad (4)$$

$$AC^2 = 9R^2 \qquad (5)$$

$$Now,\ from\ equation (2)$$

$$9R^2 > (S^2 + 4R^2) + (S^2 + R^2) \Longrightarrow (\frac{S^2}{R^2}) < 2 \qquad (6)$$

If this condition is fulfilled then multi-hop power loss will always be lesser than direct communication power loss. Now the grid node sends the Base Station with the 'S' value by using, the process. The Base Station using equation (6) and (1) calculates the value of 'R' and accordingly divide the region.

A. Comparison between LEACH protocol and the proposed solution

Routing procedure: LEACH uses DIRECT TRANSMISSION of data from cluster head to the base station, whereas the proposed solution uses hierarchy based multi-hop routing. This helps to aggregate the data at each intermediate cluster head. This will remove redundancy resulting in energy saving which is one of the most important design constraints of the WSN. In LEACH, each node transmits the data to the base station and hence we do not consider the duplicate data. Thus the duplicate data may be transmitted resulting in energy wasting.

Cluster formation: The LEACH selects cluster heads randomly while the proposed solution selects cluster heads on the basis of energy band. In the LEACH, cluster head may be very far from the individual nodes hence energy dissipation of individual node may vary significantly. Whereas, in the proposed solution, energy dissipation of individual node is same approximately.

Distribution of cluster heads throughout the target area: In LEACH there is a chance that the cluster heads may be concentrated in a particular region since cluster heads selection is based on randomly generated value but in the proposed solution, there is a uniform distribution of cluster heads into virtual clusters. This makes sure that the cluster heads are relatively uniformly spread throughout the target area.
Range of the network: LEACH protocol is suitable for small target area as it uses direct transmission of data from cluster heads to base station while the proposed solution may work for a larger size target area also as cluster heads send their data to base station in hierarchical multi-hop fashion.

VI. CONCLUSION AND FUTURE WORK

This paper proposed a new clustering algorithm based on energy consideration. It tries to prolong the lifetime of the wireless sensor network. The proposed solution support hierarchical multi-hop routing. This paper also compares the design trades between the proposed solution and well known LEACH protocol [10].
The proposed solution can be extended for hierarchical routing protocol. This can also be modified for secured wireless sensor network by using two-level security mechanism.

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