Energy-Efficient Multi-Level Hierarchical Routing Protocol for Homogeneous Wireless Sensor Network

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Abstract

Wireless Sensor Networks (WSNs) have paved the way for a new arena of monitoring and gathering information. One of the most significant criteria for smooth operation of WSNs is the limited energy supply of the sensor nodes. Numerous elegant energy-efficient routing protocols have been proposed in the literature for solving this problem, e.g. LEACH [1], PEGASIS [2], Hierarchical PEGASIS [3], LEFC [4], CFC [8]. But these protocols seem to suffer from transmission overhead. In this paper we propose Multilevel Hierarchical Routing Protocol (MHRP), a new energy-efficient hierarchical routing protocol, for homogeneous wireless sensor network. Mathematical analysis reveals that Multilevel Hierarchical Routing Protocol (MHRP) outperforms LEACH [1] by 683% longer lifetime for the period when WSN remains fully functionally operational. So far lifetime is concerned MHRP performs equal to that of CFC [8] but it uses 4.26% less energy than CFC [8]. MHRP uses fixed cluster and multiple designated first-level cluster-head (CH) nodes at the center of each cluster. Designated first-level CHs transmit data to the designated second-level CHs located at the center of WSN area. Designated second-level CHs transmit data to the designated third-level CHs located at the nearest position of the base-station within the WSN area. Eventually the third-level CH nodes transmit data to the base-station. In all three levels of designated cluster-head nodes only one node remains in active state and performs the duty of the CH. Rest of the designated cluster-head nodes of each level remain in sleep state and just prior to the death of current CH node of a level, another one from among the designated cluster-head nodes of that level take over the responsibility of the CH. In all three levels of designated cluster-head nodes data is transmitted to the next level CH only after data fusion is done. This scheme reduces transmission overhead and increases the lifetime of the WSN significantly.

Key words:

Wireless Sensor Network; Hierarchical Routing of Wireless Sensor Network; Homogeneous Wireless Sensor Network Routing Protocol; Multilevel Hierarchical Routing of Wireless Sensor Network.

1. Introduction

A Wireless Sensor Network (WSN) usually comprises of hundreds or thousands of replenishable sensor nodes spreading like a web in the field. These sensor nodes have embedded sensors in them for sensing various forms of energy e.g. sound, light, heat. These sensor nodes are capable of transmitting and receiving data to each other or directly to a base-station (BS), usually located outside the WSN area. BSs are assumed to have comparatively stable power supply. WSNs generally suffer from several drawbacks e.g. limited computing power, limited energy supply and limited bandwidth for data transmission. Energy efficiency of the sensor networks is an important research topic and the lifetime of WSNs could be considered as the most significant performance in the WSN [6]. Since wireless communications consume significant amounts of battery power, sensor nodes should spend as little energy as possible receiving and transmitting data [2].

A typical application in a sensor web is gathering of sensed data at a distant base station (BS) [2]. Like LEACH [1], PEGASIS [2] and CFC [8] our model sensor network has the following properties:

- The BS is fixed at a far distance from the sensor nodes.
- The sensor nodes are homogeneous and energy constrained with uniform energy.
- The energy cost for transmitting a packet depends on the distance of transmission.
- Each sensor node has power control and the ability to transmit data to any other sensor node or directly to the BS

In each round of this data-gathering application, all data from all nodes need to be collected and transmitted to the BS, where the end user can access the data [2]. The LEACH [1] protocol furnished a prodigious solution to this problem. Approximately 5% nodes randomly declare themselves as CHs in each round. Clusters are formed dynamically in each round. CHs receive and fuse data in each round and transmit it to the base-station (BS). LEACH uses a TDMA/CDMA MAC to reduce inter-cluster and intra-cluster collisions [5]. The PEGASIS [2] protocol presented a marvelous solution to the same problem. Instead of forming clusters, PEGASIS forms a chain among the sensor nodes and ensures that each sensor node transmits and receives only one message in each round. This reception and transmission occurs only with a close neighbor. In each round only a single node transmits data to the BS. Obviously different nodes perform this responsibility of transmitting to the BS in different rounds. PEGASIS performs better than LEACH

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by about 100% when 1% of nodes die [2]. Hierarchical PEGASIS [3] is an extension to PEGASIS, which aims at decreasing the delay incurred for packets during transmission to the base station and proposes a solution to the data gathering problem by considering energy x delay metric [7]. In order to reduce the delay in PEGASIS, simultaneous transmissions of data messages are pursued here. Hierarchical PEGASIS has been shown to perform better than the regular PEGASIS scheme by 60% [3]. PEGASIS/ HIERARCHICAL PEGASIS assumes that all nodes maintain a complete database about the location of all other nodes in the network. But the method through which the node locations are obtained is not outlined [5]. In addition, the single leader can become a bottleneck [5]. LEFC [4] presented another magnificent solution to this data-gathering problem. LEFC combines LEACH and FCA [6] to propose low-energy fixed clustering scheme to improve energy efficiency. In order to reduce the energy dissipation, LEFC uniformly divides the sensing area into fixed clusters where the cluster –head is deployed at the center of the cluster area [4]. Moreover, to improve the energy efficiency in the cluster based on the fixed clustering, the cluster head is elected by the LEACH scheme [4]. LEFC outperforms LEACH with more 60% network lifetime. LEFC is a GPS based solution but GPS free solution is always preferred [5]. CFC [8] uses fixed cluster and multiple designated cluster-head nodes at the center of each cluster. CFC [8] outperforms LEACH [1] by 683% longer lifetime for the period when WSN remains fully functionally operational. But there is still a data transmission overhead and there is scope for reduction in energy consumption. In this paper we attempt to present a new energy-efficient Multilevel Hierarchical Routing Protocol (MHRP), for homogeneous WSN. MHRP was developed by modifying CFC [8]. MHRP uses fixed cluster and multilevel designated cluster-head nodes. Like CFC [8], our scheme eliminates the overhead of dynamic cluster formation or chain formation. It also reduces data transmission overhead and reduces the energy consumption.

2. Radio Model for MHRP

In our scheme we use the same first order radio model which has been used in LEACH [1] and PEGASIS [2]. Radio dissipates E_{elec}= 50 nJ/bit to run the transmitter or receiver circuitry and $\in_{amp}$= 100pJ/bit/m^2 for the transmit amplifier to achieve an acceptable signal to noise ratio. The radios have power control and can expend the minimum required energy to reach the intended recipients. We assume that transmitter electronics ($E_{Tx\text{-}elec}$) and receiver electronics ($E_{Rx\text{-}elec}$) are equal. We assume, $E_{Tx\text{-}elec} = E_{Rx\text{-}elec} = E_{elec}$ = 50 nJ/bit. Transmit Amplifier, $\in_{amp}$ = 100 pJ/bit/m^2.We also assume an energy loss of r^2 due to channel transmission. Thus to transmit a k-bit message a distance d using our radio model, the radio expends:

$E_{Tx}(k,d) = E_{elec} * k + \in_{amp} * k * d^2$ and to receive this message, the radio expends:

$E_{Rx}(k) = E_{elec} * k$

In our analysis, we used a packet length k of 2000 bits. There is also a cost of 5 nJ/bit/message to fuse messages. Like LEACH [1], we also assume that all sensors are sensing the environment at a fixed rate and thus always have data to send to the end-user. We assume initial battery energy to be 0.25 Joule/node.

3. Detailed Procedure of MHRP

Our routing scheme at first divides the entire WSN area into number of small squares or grids. In our scheme, the size of the WSN area is 50m X 50m as shown in figure 1. Base station (BS) is located at (25, 150), which is at least 100m from the nearest node. Each square represents a cluster and each square is of the same size. The number of clusters should be as close to as possible equal to the optimal percentage of cluster heads. In our scheme, the whole WSN area has been divided into four clusters and A, B, C, D are the centers of the squares. But according to LEACH [1] the optimal number of CHs for a 50m x 50m WSN area containing 100 sensor nodes is 5%. So the number of clusters in our scheme is very close to the optimal percentage. On average there will be 25 active nodes per cluster in our scheme i.e. 100 active nodes in the entire WSN area.

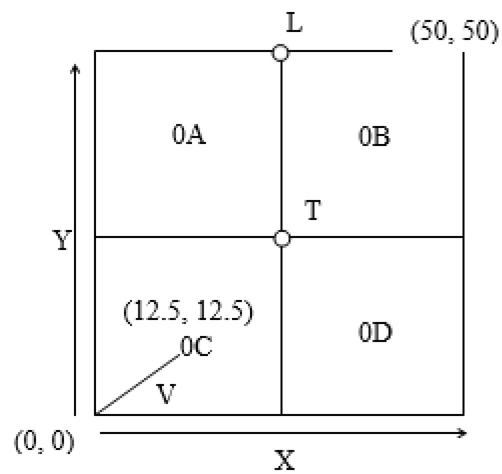

Fig. 1 Four cluster areas of MHRP protocol

In our scheme, we use dedicated sensor nodes to operate as cluster heads (CHs). There are two types of nodes in our scheme: one type of nodes will only work as non CH nodes and the other type of nodes will only work as CH nodes. A node will come to know from its MAC layer whether it is a non-CH or first-level CH or second-level CH or third-level CH node. To create a multilevel hierarchy of the CHs, locations A, B, C, D will be used as the position of first-level CH. These are the centers of four clusters. Location T (25, 25) will be used as the position of the second-level CH. This is the center of the entire WSN area. Location L (25, 50) will be used as the position of the third-level CH. Location L (25, 50) is the nearest position of the base-station within the WSN area. Each first-level CH receives data from approximately 24 non-CH nodes, fuse the data and transmit the data to the second-level CH. Second-level CH receives data from 4 first-level CHs, fuse the data and transmit the data to the third-level CH. Third-level CH receives data from only one second-level CH, fuse the data and ultimately transmit data to the base-station. Since, there are total 4 clusters, as such 4 nodes will work as first-level CH nodes, one node will work as second-level CH, one node will work as third-level CH and rest 94 nodes will work as non CH nodes. In our scheme, at first only 94 non CH nodes will be randomly placed in the WSN area. Now the maximum distance between a non CH node and first level CH node is approximately 17.68 m. Again, the maximum distance between a first-level CH node and second-level CH node is approximately 17.68 m. But since each non CH node will only transmit data to the respective first-level CH node once in a round but each first-level CH node will receive data approximately from 24 non-CH nodes, fuse the data and transmit data to the second level CH once in every round. As such the life time of first-level CH nodes will be much shorter than those of non CH nodes. To ensure the longest lifetime of the network and to ensure that the non CH nodes and the last first-level CH node of each cluster die almost at the same time, our scheme uses multiple prospective first-level CHs at the center of each square or cluster. Among these multiple prospective CH nodes only one node will act as CH and rest of the prospective CH nodes will remain in sleep state. So that when one cluster head node dies, only then another node from among the prospective CH nodes can take over the responsibility of the CH and declare itself as new CH. As such, at any moment of time only 100 sensor nodes will actively participate in sensing and transmitting data i.e. at any moment of time only 100 sensor nodes will form the integral part of the WSN. How many prospective first-level CH nodes we need to place at the center of each square that we can determine a priori through calculation, which has been furnished below in the mathematical analysis section of this paper. Our scheme ensures that the last first-level CH node of each cluster dies almost at the same time when the last alive non CH head node dies. Similarly, our scheme uses multiple prospective second-level and third-level CHs. Among these multiple prospective CH nodes only one node will act as CH and rest of the prospective CH nodes will remain in sleep state. So that when one second-level or third-level CH node dies, only then another node from among the prospective CH nodes can take over the responsibility of the CH and declare itself as new CH. As such, at any moment of time only 100 sensor nodes will actively participate in sensing and transmitting data i.e. at any moment of time only 100 sensor nodes will form the integral part of the WSN. How many prospective second-level and third-level CH nodes we need to place that we can determine a priori through calculation, which has been furnished below in the mathematical analysis section of this paper. Thus, our scheme ensures that the last second-level CH node and last third-level CH node remains alive till the time last non CH node remains alive. At first, the 94 non CH sensor nodes are randomly placed over the entire WSN area. Subsequently, prospective first-level CHs are placed in a deterministic fashion at the centers of the 4 squares at location A, B, C and D within a circle of diameter 0.5m (50 centimeter). These prospective first-level CHs know from their MAC layer that they are dedicated first-level CHs. Other non CH nodes, which are not at the center of the square, never become CH and these nodes also know from their MAC layer that they are non CH nodes. Our calculation shows that we need to use 17 prospective first-level CHs at each A, B, C and D locations. We also need to use 4 prospective second-level CHs at location T (25, 25), which is the center of the entire WSN area. We also need to use 14 prospective third-level CHs at location L (25, 50). Location L (25, 50) is the nearest position of the base-station within the WSN area. So in total we need to use (4*17)+4+14= 86 prospective CHs. The total number of nodes we need to use in our scheme is (94+86) = 180. In our scheme, at first only 94 non CH nodes will be randomly placed in the WSN area. Rest 86 prospective CH nodes will be placed in a deterministic way at their appropriate locations. These locations are A, B, C, D, T and L. Similar to first-level CHs, the second-level and third-level CHs are also placed in a deterministic fashion at locations T (25, 25) and L (25, 50) within a circle of diameter 0.25m (25 centimeter). At the setup stage of the network, four fixed clusters will be formed keeping the prospective first-level CHs at the center of each cluster. Only one node will function as first-level CH for a cluster from among the prospective first-level CHs of that cluster. Other prospective first-level CHs will remain in sleep mode and will only become active at a predefined time as scheduled by the current first-level CH. The current first-level CH node will assign this predefined time to other prospective first-level CH nodes based on the distance between the first-level CH and the second-level CH i.e. it can assign this time based on the energy usage of first round. Once the energy level of this current first-level CH node goes below a threshold limit or that predefined time reaches, only then the current CH node assigns another node from among the prospective first-level CHs as the new first-level CH for that cluster. Then this new first-level CH remains in active state and the rest of the prospective CHs go to the sleep state. The same mechanism is applied in case of second-level CH and third-level CH. At any time only one second-level or third-level CH remains in active state and rest of the prospective second-level/third-level CHs remain in sleep state. These inactive prospective second-level/third-level CHs will only become active at a predefined time as scheduled by the current second-level/third-level CH. The current second-level/third-level CH node will assign this predefined time to other prospective second-level/third-level CH nodes based on the distance between the second-level CH and third-level CH or distance between the third-level CH and base station. Because based on the distance the second-level and third-level CHs will be able to determine the energy usage of first round. Once the energy level of the current second-level/third-level CH goes below a threshold limit or that predefined time reaches, only then the current second-level/third-level CH node assigns another node from among the prospective second-level/third-level CHs as the new second-level/third-level CH. Then this new second-level/third-level CH remains in active state and the rest of the prospective second-level/third-level CHs go to the sleep state. At the very first round, the elected first-level CH of each cluster will broadcast a message by declaring itself as a first-level CH and each non CH node will decide to which CH it wants to belong and ultimately clusters will be formed. Each CH broadcasts the message with the same energy. Throughout the lifetime of the network, each node will remain a member of the same cluster. As a result the size and shape of the clusters remain same and the node membership of a cluster remains static. Our scheme uses a TDMA/CDMA MAC to reduce intra-cluster and inter-cluster collisions as is done in LEACH [1].

4. Parameters of Calculation for MHRP

Maximum distance between the first-level CH and a non-CH node, $v = 17.68$ m. Because, $v^2 = (12.5)^2 + (12.5)^2$. But the diameter of the circle is 0.5m or radius 0.25m. As such v has been taken as 18m, because (17.68 +0.25)m is approximately 18m. Similarly, maximum distance between first-level CH node at C and second-level CH at T is approximately 18m. This is the case for locations A, B and D also. Distance between second-level CH node at T and third-level CH node at L is 25m.
Distance between third-level CH node at L and base-station is 100m.

5. Lifetime Calculation for Non-CH Nodes of MHRP

From Figure 1, Maximum distance between the first-level CH and a non CH node = v = 18m . Therefore, d=v=18m. Each node sends a single message to the CH in each round.
Cost for transmission of one message to the CH by a node (d=18m)
$= E_{elec} * k + \in_{amp} * k * d^2 = 0.0001$ Joule + 0.0000648 Joule = 0.0001648 Joule.
Considering initial battery energy to be 0.25 Joule/node, 0.25/0.0001648= 1516.99 rounds.
As such, a non cluster-head node is supposed to die approximately after 1516 rounds.
A non cluster-head node will also receive five messages at the setup phase of the network. Among these five messages, four messages are cluster-head declaration messages and one message for receiving the TDMA schedule. Cost for receiving one message by a node
$= E_{elec} * k = 0.0001$ Joule. Therefore, Cost for receiving five messages by a node
= 0.0005 Joule, which is equivalent to energy cost of transmission of three messages.
As such a non-CH node is supposed to die after 1516-3 = 1513 rounds in MHRP

6. Lifetime Calculation for First-Level CH Nodes of MHRP

Cost for transmission of one message to the second-level CH located at T by the first-level CH (d=18m)

$$= E_{elec} * k + \in_{amp} * k * d^2 = 0.0001648 \text{ Joule.} \qquad (i)$$

In our scheme, a cluster has approximately 25 nodes. So, each of the CH will receive 24 messages in each round. Cost for receiving 24 messages by a CH

$$= 24 * E_{elec} * k = 0.0024 \text{ Joule} \qquad (ii)$$

There is also a cost of 5 nJ/bit/message for data fusion. Total 24 messages will be received by the CH. Size of each message is 2000 bits. Energy cost for data fusion by the CH

$$= 5 * 2000 * 24 \text{ nJ} = 0.00024 \text{ Joule} \qquad (iii)$$

Total energy cost of a first-level CH node per round
= (i) + (ii) + (iii)

$$= 0.0028048 \text{ Joule} \qquad (iv)$$

Since the initial battery energy is 0.25 Joule/node, therefore a first-level CH remains alive for
= 0.25/0.0028048 rounds
= 89.13 rounds
= 89 rounds (Lower Bound) (v)

Lifetime of a non CH node is 1513 rounds We need to have first-level CH for entire lifetime of the WSN. Hence we need

= 1513/ 89 =17 CH nodes (vi)

Therefore, we need 17 CH nodes for each of the A, B, C, D locations. So, we need total =4*17

= 68 First-level CHs (vii)

But the very first first-level CH node will spend a little more energy than (iv). The reason behind is that it will have to transmit one CH declaration message and one TDMA schedule message at a distance of 54m. The distance between (12,12) and (50,50) is 54m., this is the maximum distance possible between a node and a first-level CH. Furthermore, each first-level CH node spends a little more energy, than (iv). The reason behind is that when the energy level of the current CH node goes below the threshold limit, at that moment the current CH needs to transmit one message at a distance d=0.5m for the other prospective first-level CHs. So, that a node from among the other prospective first-level CHs takes over as the new first-level CH. Again, for receiving this message other prospective CHs waste energy. Although the energy wastage for the above-mentioned reasons is negligible, yet the wastage has been already compensated by taking the lower bound (floor value) in (v).

7. Lifetime Calculation for Second-Level CH Nodes of MHRP

Distance between second-level CH node at T (25, 25) and third-level CH node at L (25, 50) is 25m. Cost for transmission of one message to the third-level CH by a second-level CH (d=25 m)

= $E_{elec} * k + \in_{amp} * k * d^2$

= 0.000225 Joule (viii)

In our scheme, we have four first-level CHs. As such second-level CH receives message from 4 first-level CHs in every round. Cost for receiving 4 messages by the second-level CH

= $4 * E_{elec} * k$

= 0.0004 Joule (ix)

There is also a cost of 5nJ/bit/message for data fusion. Total 4 messages will be received by the second-level CH in every round. Size of every message is 2000 bits. Energy cost for data fusion of 4 messages by the second-level CH

= 0.00004 Joule (x)

Total energy cost of second-level CH in one round

= (viii) + (ix) + (x)

=0.000665 Joule

Considering initial battery energy to be 0.25 Joule/node, the lifetime of a second-level CH

= 0.25/ 0.000665 rounds

= 375. 93 rounds

= 375 rounds (lower bound)

Lifetime of a non CH node is 1513 rounds. So, we need 1513/375 second-level CH nodes

= 4 second-level CH nodes (xi)

8. Lifetime Calculation for Third-Level CH Nodes of MHRP

Distance between third-level CH node at L(25, 50) and base-station at (25, 150) is 100m.

Cost for transmission of one message to the base-station by a third-level CH (d= 100 m)

= $E_{elec} * k + \in_{amp} * k * d^2$

= 0.0021 Joule (xii)

Third-level CH receives only one message per round. Cost for receiving one messages by the third-level CH

=$E_{elec} * k$

= 0.0001 Joule (xiii)

Cost of data fusion for one message by the third-level CH

= 0.00001 Joule(xiv)

Total energy cost of third-level CH in one round

=(xii) + (xiii) + (xiv)

= 0.00221 Joule

Considering initial battery energy to be 0.25 Joule/node, the lifetime of a third-level CH

= 0.25/ 0.00221 rounds

= 113.12 round

= 113 round (Lower Bound)

Lifetime of a non CH node is 1513 rounds. So, we need 1513/113 third-level CH nodes

= 13.38 third-level CH nodes.

Taking the upper-bound

= 14 third-level CH nodes. (xv)

9. Calculation of total nodes and total energy required to implement MHRP

Total nodes required to implement MHRP
=Number of non CH nodes +
number of first-level CH nodes +
number of second-level CH nodes +
number of third-level CH nodes
= 94+ (vii) + ((xi) + (xv)
= 94+68 + 4 + 14
= 180 nodes

Since every node has initial battery energy of 0.25 Joule,
So total energy required to implement MHRP
= 0.25 * 180
= 45 Joule

10. Parameters of Calculation for LEACH

From LEACH [3], it is evident that for a 100 node random topology of WSN within a 50m X 50m area, the optimal number of cluster-heads to have in the system is 5%. Therefore, desired percentage of cluster-heads, P = 0.05 and 1/P = 20. Using the threshold T(n) of LEACH [3], each node becomes a cluster-head at some point within 1/P =20 rounds and once a node becomes CH, it cannot become CH for the next 1/p=20 rounds. That means for every 20 rounds, a node in LEACH, operates as CH once and operates as non-CH for 19 times. Minimum distance between the BS and a node is 100m [3]. We assume, that the maximum distance between the CH and a non-CH node v = 18 m. Although in some cases it is supposed to be more or less than 18m. But v =18m has been taken for convenience of calculation. Because in case of CFC the maximum distance between the CH and a non-CH node v = 18 m. We consider initial battery energy to be 0.25 Joule/node, Message size K= 2000 bits, E_{elec}= 50 nJ/bit, $\in_{amp}$= 100 pJ/bit/m^2.

E_{Tx} (K,d) = E_{elec} * k + $\in_{amp}$ * k * d^2
E_{Rx} (k) = E_{elec} * k

11. Energy Cost Calculation for a non-CH node of LEACH in 19 Rounds

In LEACH, there are total five CHs in each round. Therefore, each of the 95 non-CH nodes receives 5 messages from the CHs, through which the non-CH nodes come to know which are the CHs. Each non-CH node sends a message to its respective CH, informing that it wants to be a member of that cluster. Each non-CH node receives a TDMA schedule from its respective CH. Each non-CH node sends its collected data to the CH.

Therefore, in each round a non-CH node transmits total (1+1) = 2 messages and
in each round a non CH node receives total (5+1) = 6 messages.
For simplicity we have assumed, that the distance between the CH and a non-CH node is 18 m. Therefore, d = 18m. However, in practical situation it may be more or less than 18m. But in case of our simulation the actual distance between the CH and a non-CH node has been calculated and used in the simulation.
Cost for transmission of one message to the CH by a node (d=18m) = E_{elec} * k + $\in_{amp}$ * k * d^2
= 0.0001 Joule + 0.0000648 Joule = 0.0001648 Joule
Cost for transmission of two messages to the CH by a node (d=18m)
= 0.0003296 Joule (xvi)
Cost for receiving one message by a node = E_{elec} * k = 0.0001 Joule.
Cost for receiving six messages by a node
= 0.0006 Joule (xvii)
Total energy cost for each round for a non-CH node
= (x) + (xi) =0.0009296 Joule
Total energy cost for 19 rounds as non-CH
= 0.0176624 Joule (xviii)

12. Energy Cost Calculation for a CH node of LEACH in One Round

Each CH node broadcasts an advertisement message to the rest of the nodes declaring itself as a CH. In each cluster there are total 20 nodes. Among these 20 nodes 19 are non-CH nodes and 1 is CH node. Therefore, each CH receives 19 messages from the non-CH nodes. Through these messages non-CH nodes inform their respective CHs that they want to belong to that cluster. Each CH broadcasts a TDMA schedule for its respective non-CH nodes. Each CH receives approximately 19 messages from the non-CH nodes through which it receives the data of the non-CH nodes. Each CH transmits a message to the BS for sending data.
As a result, in each round a CH transmits total (1+1+1)= 3 messages.
In each round a CH receives total (19+19) = 38 messages.
Minimum distance between the BS and a node is 100m.
Cost of transmission of one message at a distance of 100m
= E_{elec} * k + $\in_{amp}$ * k * d^2 =0.0001 Joule + 0.002 Joule
=0.0021 Joule (xix)

The size of the WSN area is 50m x 50m. The CH declaration message and the TDMA schedule message of any CH should reach all the nodes. Therefore, the value of d is equal to the length of the diagonal of the field, i.e. d=70.71m.

Cost of transmission of two messages at a distance of 70.71m

= 2 * (E_{elec} * k + $\in_{amp}$ * k * d^2)

= 2*0.00109998 = 0.00219996 Joule (xx)

Cost for receiving 38 messages

= 38* (E_{elec} * k) =(38* 0.0001) Joule = 0.0038 Joule (xxi)

Total cost for transmission of 3 messages and reception of 38 messages

=(xix) + (xx) + (xxi) = 0.00809996 Joule (xxii)

There is also a cost of 5 nJ/bit/message for data fusion. Total approximately 19 messages will be received as data by the CH. Size of each message is 2000 bits.

Energy cost for data fusion of 19 messages by the CH

= 5* 2000*19 nJ = 0.00019 Joule (xxiii)

Total cost for transmission of 3 messages, reception of 38 messages

and data fusion = (xxii) + (xxiii) = 0.00809996 Joule + 0.00019 Joule

= 0.00828996 Joule (xxiv)

This cost (xxiv) is incurred by each node only for one round when it acts as a CH.

13. Average Energy Cost of One Round in LEACH for a Node

Energy cost for total 20 rounds in LEACH

= (xviii) + (xxiv) = 0.02595236 Joule (xxv)

Average energy cost for one round in LEACH

= 0.02595236/20 Joule = 0.001297618 Joule

14. Lifetime Calculation of a Node in LEACH

Considering initial battery energy to be 0.25 Joule/node,

0.25/ 0.001297618 = 192.66 rounds (xxvi)

Taking the upper bound (Ceiling value) of (xxvi) it becomes 193 rounds.

That means in LEACH, nodes are supposed to die just after 193 rounds, even earlier for the nodes which are further away from the BS. Since, the non CH nodes of MHRP remain alive for 1513 rounds and the nodes of LEACH remain alive for 193 rounds, therefore MHRP increases the lifetime of a WSN 683% than that of LEACH [1].

15. Comparison of Results Based on Mathematical Analysis

Now if we compare the results of our mathematical analysis with that of CFC [8], we find the following information:

Table 1: Lifetime of WSN

	LEACH	CFC	MHRP
Number of rounds the WSN remains fully operationally functional	193	1513	1513

Table 2: Total Energy Used

	LEACH	CFC	MHRP
Joule	25 (0.25 Joule x 100 nodes)	47 (188 nodes)	45 ((180 nodes)

It shows MHRP, our scheme, increases the lifetime of the WSN 7.83 times longer than that of LEACH. That means our scheme outperforms LEACH by 683% longer lifetime. Again, it shows that our scheme reduces the energy consumption by 4.26% than that of CFC. Because CFC uses 47 Joule but our scheme uses 45 Joule.

16. Conclusion

In this paper MHRP, a new energy-efficient multi-level hierarchical routing protocol for homogeneous Wireless Sensor Network (WSN) is proposed to prolong the lifetime of cluster-based WSN and to reduce the energy consumption. The proposed protocol, MHRP, uses fixed clusters and multilevel designated cluster-head nodes. Our scheme eliminates the overhead of dynamic cluster formation or chain formation. Although in MHRP we need to use 80 additional nodes i,e. instead of total 100 nodes in LEACH, we need to use total 180 nodes in MHRP. But that increases the lifetime of a WSN 683% longer than that of LEACH [1]. On the other hand though the lifetime of CFC [8] and MHRP is equal but MHRP reduces the energy consumption by 4.26% than that of CFC [8]. This improvement is significant in case of WSN.

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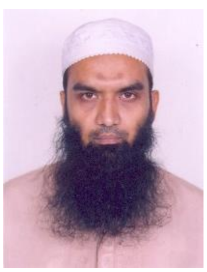

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