MHUCR: Mutli Hop Uniform Clustering Routing Protocol for Energy Efficient WSN

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Abstract

This paper presents an energy efficient routing protocol for wireless sensor network called Mutli Hop Uniform Clustering Routing Protocol (MHUCR). The proposed MHUCR protocol balances the energy consumption of all nodes in the network and prolong the network lifetime. In MHUCR, three types of nodes in the network are assumed. These nodes are defined as, Normal Node (NN), Cluster Head (CH), and Super Node (SN), and *each type has a different energy level. The CH has a fixed number of members, and NN sends a request to join to the CH that has fewer member numbers, close to it, and have a high residual energy as metrics. The SN is assumed to be a near to the Base Station (BS) to overcome the problem of nodes that is near to the BS, which dies faster than distant nodes. MHUCR has the capability to adapt and find another path, in case any change occurs, CH fails or dies. Four different scenarios using MATLAB are implemented to evaluate and investigate the performances of the proposed protocol. Simulation results show that the proposed MHUCR protocol improvement rate of in terms of nodes still alive was 98% when compared with LEACH protocol and 91.5% when compared with LEACH-C protocol and 78.2% when compared with DECA protocol and 67.5% when compared with I-LEACH protocol and 41% when compared with W-LEACH protocol.*

Keywords: WSN, LEACH, MHUCR, Energy-Efficient Routing, Clustering, W-LEACH

1. Introduction

Nowadays, Wireless Sensor Network (WSN) are considered as a one of the most essential technologies due to its used in several applications such as military, health care, industrial and agricultural. WSN consists small, low-cost and low power wireless sensor nodes that operate on battery. These sensor nodes have the ability to measure the specific parameters in the environment such as, temperature, pressure, motion, sound, *etc.*, [1]. The main task of WSN is monitoring the environment. The sensor nodes can communicate among themselves using radio signals. A sensor node consists of four unites sensing, processing, communication and power supply. The processor unit responsible for processing and storing collected data. The sensing unit gathers data from the environment using sensors and converts the data from analog to digital signals using the analog to digital converter (ADC). Communication unit is responsible for providing a communication channel from one node to another node in the network using a transceiver. Lastly, the power-supply unit that is responsible for providing energy to the nodes using a battery that means limited energy resources, and energy must be used in sparingly a way [2]. The communication unit of the sensor node loses the highest power. Therefore, a research in WSNs is mostly focused on designing a protocol that needs as a little power as

possible when communication. Sensor nodes are usually random deployment in inaccessible place and replacement of the energy source are not feasible. Accordingly, an energy efficient routing protocol is a key design issue that needs to be enhanced, in order to improve the life span of the network [3, 4].

In articles, many routing protocols have been proposed and designed for WSNs where energy is an important metric in design issue [2]. General, the routing techniques are classified under three categories based on the underlying network structure: flat, hierarchical, and location-based-routing. In flat-based routing, all nodes have the same function in the network. In location based routing, sensor nodes must be awareness of location to route data across the network by using Global Positioning System (GPS) or any other technique. In hierarchical-based routing, however, nodes will play different roles within the network; the sensor nodes are divided into groups, called clusters. Each cluster has a one node that acts as a leader, called a cluster head (CH), as shown in Figure 1. Clustering in WSN has many advantages, such as: the CH can discard the redundant data, and this leads to reduce the energy consumption by decreasing the number of packet that needed to send to the BS. Clustering makes routing more simply because only the CH needed to find the optimal path to the BS. Therefore, requiring a lesser routing information clustering will improve the scalability of the network and additionally, conserve communication bandwidth as the sensor nodes communicate with their CHs only [5].
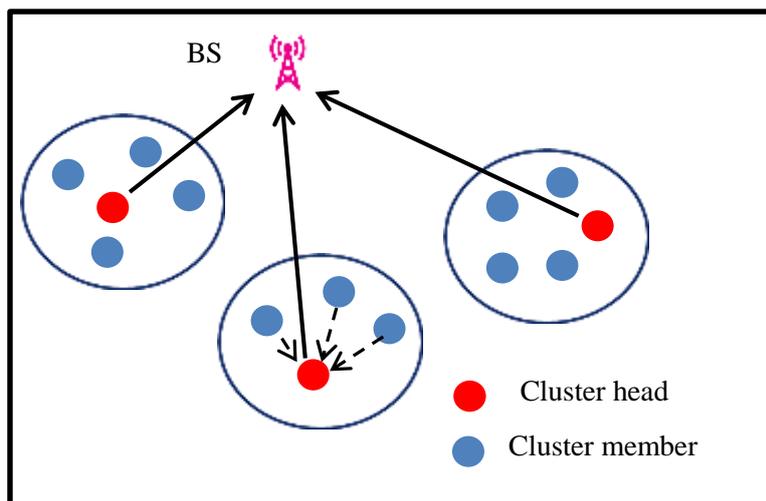

Figure 1. Clustering in WSN

Routing in WSN faces a number of challenges such as: network may have a large number of sensor nodes and deployment in ad-hoc manner; all nodes send data directly or indirectly to the BS. Power source is limited and in some applications, sensor nodes are able to move and change their location.

The objective of this paper is to propose an energy-efficient and reliable routing protocol for WSN using three types of nodes, and each type has a different energy level. SN has a higher energy and placed near to the BS to solve the problem of nodes that are closed to the BS that dies faster than the distant nodes. CH acts as cluster leader, and has a fixed number of members depended upon the number of NN in entire a network. NN acts as a cluster member. To achieve balance in the network, NN connects to closest SN or closest CH that has more energy and has fewer members.

The rest of the paper is structured as follows. Section 2 summarizes related work. Section 3 presents the system model. Section 4 presents the propose protocol. Section 5 shows the simulation results that show the advantages of the proposed protocol. Section 6 is a conclusion of the paper.

2. Related Works

Sensor nodes are with limited energy resources need the energy efficient routing protocol to increase the network lifetime as much as possible. Routing is the process of choosing a route within a network to send the data to the sink node in an energy awareness method to conserve energy. Many clustering protocols have been proposed for WSN. Low Energy Adaptive Clustering Hierarchy (LEACH) protocol [6] is a one of the first hierarchical routing approaches for sensor networks. LEACH selects a few sensor nodes work as CHs in each round, in such a way that each node in the network will operate as cluster head and rotates this role to balance the energy conception of nodes. Optimal number of cluster heads is estimated to be 5% of the total number of nodes. The work of LEACH is separated into two phases, setup phase and steady state phase. In the setup phase, the CHs are selected. In the steady state phase, the data send to the BS. In setup phase, the node chooses a random number between 0 and 1. The node becomes a CH for the current round if the number is less than the following threshold $T(n)$ that is calculated as shown in Eq. (1),

$$T(n) = \begin{cases} \frac{P}{1-P\left(r\,mod\frac{1}{p}\right)} & if \quad n \in G \\ 0 & otherwise \end{cases} \tag{1}$$

Where, p is a percentage of CHs, r the current round, and G the set of nodes that have not been cluster heads in the last $1/p$ rounds.

CH broadcasts to their neighbors in the network the advertisement message for announcing I a CH for the current round. If a node receives one advertisement message from one cluster head, then it automatically becomes a member of that cluster. Nodes may receive more than one advertisement message from many CHs in the network and decide which cluster to be joined based on received the Received Signal Strength Indication (RSSI). Nodes who want to join to the cluster, inform the CH. The CH will create a cluster and use TDMA schedule for the member node that want to transmit the sensed data. In the steady state phase, the sensor nodes begin sensing and transmitting data to the CHs. The CHs aggregate data from the nodes in their cluster and sending these data to the BS. At the end of the steady state phase, the network repeats the setup phase again to enter into another round and selecting a new node to act as CH.

The LEACH reduces the power consumption and increase the network lifetime by clustering. Through the steady state phase, only the CHs are active all the time. A cluster member in a cluster is active only during its allocated time slot and in the setup phase. This leads to minimize the energy consumption of a node. However, LEACH uses single-hop routing where each CH sends data directly to the sink if sink is far from CH, the CH needs to consume high energy to send data to sink. Therefore, the LEACH is not appropriate to the networks deployed in the wide areas. In addition, choosing a CH randomly without relying on the remaining energy of the CH and the distance between the CH and the BS is considered as a weakness point. In [7], LEACH-C uses centralized clustering algorithm. The BS collects information from the network nodes to make clustering and routing, after that, the BS send the information of clustering and routing to the sensor nodes in the network. Therefore, at the beginning of each round, the BS must have the location information and the residual energy of every node.

The authors in [8], proposed a new method to Optimize Low Energy Adaptive Clustering Hierarchies (OLEACH) that improve the existing LEACH by selecting cluster according to the residual energy of nodes dynamically. In [9], the author proposed a protocol, Hybrid Energy-Efficient Distributed clustering (HEED) that use residual energy and node density (i.e., number of neighbors) as a metric for cluster selection to achieve power balancing. The HEED clustering increases the network lifetime over LEACH clustering because LEACH randomly selects CHs. In [10], the authors have suggested

distributed routing algorithms and clustering. The cluster formation is based on the residual energy of CHs, distance between the member sensor nodes to their CHs and the distance from the CHs to the BS, but did not take into account that the CH near the BS is dying faster than the distant CH.

In [11], the author studies LEACH protocol, and puts forward energy-LEACH and multi-hop LEACH protocols. Energy-LEACH protocol improves the way of choice a CH, makes some nodes have more residual energy as CHs in next round. Multi-hop LEACH protocol improves communication mode from single hop to multi-hop between CH and sink. Simulation results show that energy-LEACH and multi-hop LEACH protocols have better performance than LEACH protocols. In [12], the authors proposed a new modified enhanced LEACH algorithm that computes the threshold value based on the total energy of nodes in the network for next round, as shown in Eq. (2).

$$T(n) = \left\{ \frac{P}{1 - P\left(r \bmod \frac{1}{p}\right)} \times \frac{Eo}{Etotal} \right\} \qquad if \ n \in G \qquad (2)$$

Where, *Eo* is the initial energy of node and *Etotal* is the sum of energy level of all nodes. A comparison between traditional LEACH and proposed LEACH in [12] has been done based on the network lifetime. In [13], the authors proposed routing algorithm I-LEACH that selects sensor nodes act as CH according to higher residual energy, more neighbors, and lower distance from the BS. The WSN lifetime is increased as compared to LEACH and LEACH-C algorithms. In [14], the authors have been proposed routing algorithm that provided a fair chance to nodes that have higher energy to become a cluster head. In [15], the authors proposed a differential evolution based clustering algorithm for WSN. The aim of this proposed [15] is extend network lifetime by avoiding the earlier death of highly loaded CHs. The death of the first CH can be delayed by choosing a CH that has less energy, and then reducing the number of members for that CH by move those members to another CH. The reader can find more details for survey papers that study and analyze different hierarchical routing protocols in [16] and [17]. The protocols in previous related works do not take into consideration the number of member in each cluster. Maybe one of the clusters consist five members and the other nine members, and this leads to an imbalance of energy conception. In addition, the previous related works did not address the problem of nodes close to the base station, which dies faster than distant nodes because the nodes near to the BS always use as intermediate node for transmission data to the BS.

3. System Models

3.1. Energy Model

There are different methods exist for describing the energy consumption in WSN. At most, the energy expended for amount of *K* bit data is calculated using Eqs. (3) and (4) [7]:

$$E_{TX}(k, d) = E_{elec} \times k + \varepsilon_{amp} \times k \times d^2 \qquad (3)$$

$$E_{RX}(k) = E_{elec} \times k \qquad (4)$$

Where, E_{TX} represents the energy required for transmission one packet, E_{RX} represents the energy required for received one packet, E_{elec} is the energy needed for modulating or demodulating one bit. ε_{amp} is the consumed energy of amplifier, k represents the packet size and d represents the distance between a sender and a receiver.

3.2. Network Model

In the MHUCR, three types of node deploy randomly over a square area is assumed. Each type has different level of energy. The type of nodes as following: Normal Node (NN) has less energy because it only sends data to the nearest CH or nearest SN. CH has energy more than NN because it receives data from cluster member and sends the received data to the nearest CH or nearest SN. Super Node (SN) has high energy and solar panel for renewable energy. SN receives data from CH and nearest NN and send the received data to the nearest SN or to the BS. A node can compute the distance to another node based on the RSSI. The BS (*i.e.*, sink node) located in the center of sensor filed, and the CH and SN use multi-hop routing to send data to that BS. Similar to LEACH, gathering the data is divided into rounds. In each round, all sensor nodes sense environment and send data to CH or SN. Between two rounds, nodes turn off their radios to save energy.

4. Propose MHUCR Psrotocol

Limit energy of WSN motivates to propose MHUCR in order to increase the network lifetime as much as possible. Several assumptions are made in the proposed model; these assumptions are described as follows:

• All sensor nodes include NN, CH and SN, in addition to the BS are stationary after deployment and location unaware.

• All nodes have similar capabilities (processing/communication), but are different in terms of energies in case of heterogeneity.

• Nodes distribution is random in sensor filed.

• The number of BS depends on the size of WSN.

• CH nodes broadcast advertising message within the communication range of a sensor node. The advertising message consists of cluster head identifier (CH_ID), residual energy, distance to the BS and the number of members they have.

• All normal nodes have received at least two advertising message.

• NNs send request message to join to CH that has maximum residual energy, closest to her, less distance to the BS and has lower number of members.

• If CH has max number of members, NN sends data to the second closer CH or to SN.

• If CH dies, the members of this CH send data to second nearer CH or to SN.

Figure 2 shows the pseudo-code of MHUCR.

```
Begin
   1.   // broadcast advertisement message
        SN broadcast message " I SN, and distance to BS"
        CH broadcast message " I CH, residual energy, distance to
        the BS and number of member that has "
   2.   // NN find closer to it depend on RSSI and find best CH to
        join him
      if (near to SN )
           Send data to SN
      else if ( near to CH)
         {
           if (the near CH have max number of member or die )
                 Send data to second near CH
           else
                 Send data to near CH
         }
```

```
   3.    //CH find closer to it depend on RSSI
       if ( near to SN )
          {
             Send data to near SN
          }
       else if (closer to another CH )
          {
             if ( closer CH die)
                Send data to second closer to it
             else
                Send data to closer CH
          }
   4.    // SN find closer to it depend on RSSI
       If (closer to BS)

          {
                Send data direct to BS
          else
                Send data to closer SN
          }
End
```

Figure 2. MHUCR Pseudo-Code of

5. Experiment Results

The MHUCR protocol is implemented using MATLAB software. To investigate the performance of the MHUCR, four scenarios have been applied. The first scenario presents the performance of MHUCR. In the second, third and fourth scenarios a comparison with other protocols, such as, W-LEACH [14], LEACH [6], DECA [15], I-LEACH [13], and LEACH-C [7] are implemented. In each scenario, the experiments are performed with different values of number of nodes, initial energy of nodes, packet size, max number of member in each CH, and the area of sensor filed. In all scenarios, a node is dead if its energy level reaches to 0 joules.

Table 1. Simulation Parameters of the Four Scenarios

Parameter	First Scenario	Second Scenario	Third Scenario	Fourth scenario
Normal Nodes(NN)	80	84	100	180
CH nodes (CH)	20	16	15	20
Number of node (NN+CH)	100	100	115	200
Super Nodes (SN)	8	8	8	8
Max clusters member	4	5	6	9
Sensor filed	200×200 m	50×50 m	200X200 m	200X200 m
Initial energy of NN	0.9 joule	0.5 joule	2 joule	0.5 joule
Initial energy of CH	4 joule	3 joule	10 joule	5 joule
Initial energy of SN	10 joule	6 joule	15 joule	15 joule
E_{elec}	100 nJ/bit	50 nj/bit	50 nj/bit	50 nj/bit
ε_{amp}	100 pJ/bit	100 pj/bit	0.0013pj/bit	0.0013 pj/bit
ε_{fs}	0.013 pJ/bit	10 pj/bit	10pj/bit	10 pj/bit
Packet size	1600 bit	2000 bit	4000 bit	4000 bit

(A) First Scenario

(B) Second Scenario

(C) Third Scenario

(D) Fourth Scenario
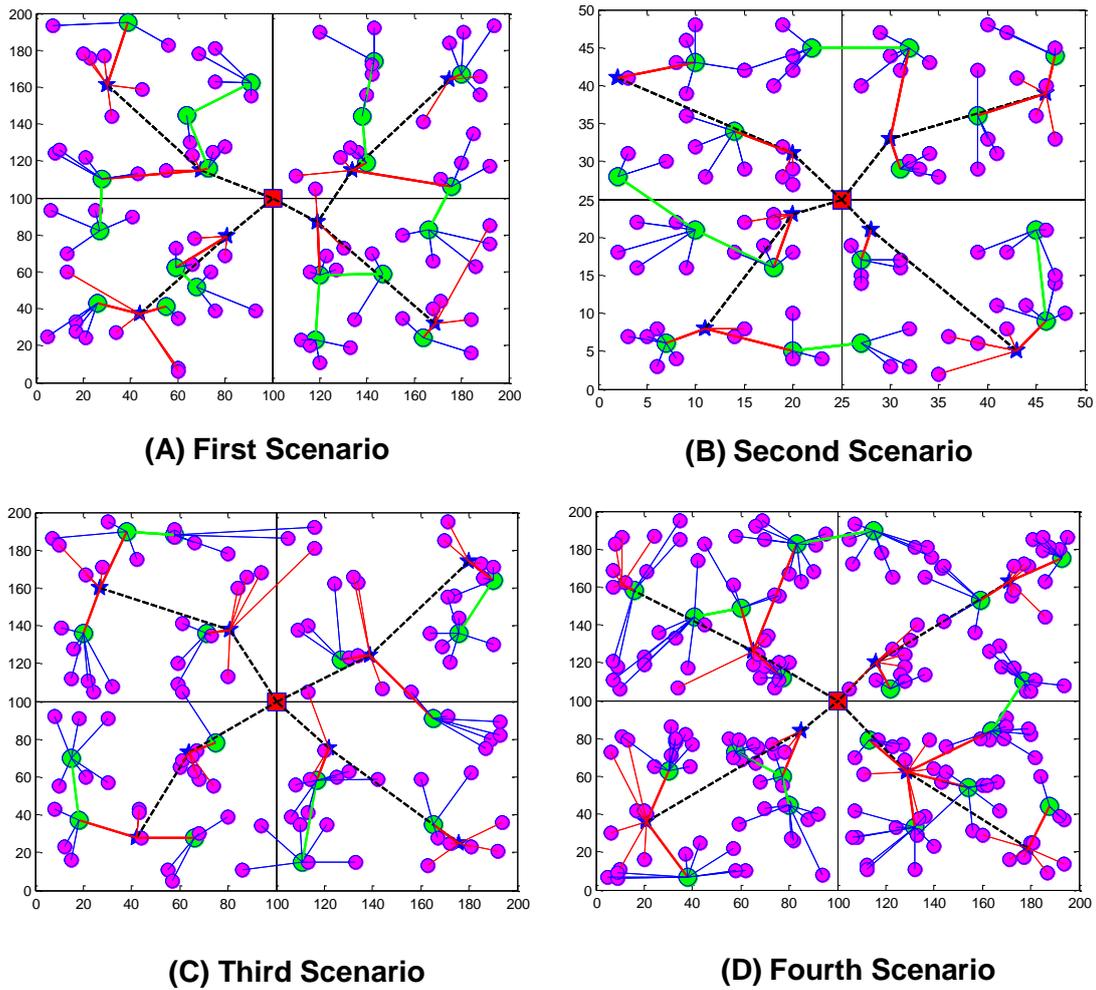
Figure 3. Network Topology of Four Scenarios where:

🟥 **Base Station**   🟢 **Cluster Head**

⭐ **Super Node**   🟣 **Normal Node**

5.1. First Scenario

The parameters values that are used in the first scenario are summarized in Table 1. The wireless sensor nodes are distributed randomly within an area of 200×200 m². The position of the BS is chosen at the center of that area with coordinates (100, 100). Figure 3(A) captures a random snapshot of nodes distribution from a randomly chosen simulation Figure 4(A) shows the number of nodes that still work (i.e., live) versus the number of rounds for the proposed MHUCR protocol. The figure demonstrated that the number of nodes that still live would be decreased when the number of rounds increases. For the 1400 round, the number of nodes that still live is 95, while it is 71 and 43 for 3000 and 4000 rounds, respectively. As shown in Figure 4(A), there is about 50 % of nodes number still live at the 4000 round.

Figure 4(B) shows the residual energy versus the number of rounds when the area of the sensor field is changed to study the effect of the distance on the amount of energy consumed, the remaining energy decreases when increased the area of the sensor field because the greater the transmission distance, the greater the energy consumed in each

round, where the energy is consumed by the sensitivity and the sending and receiving of data.
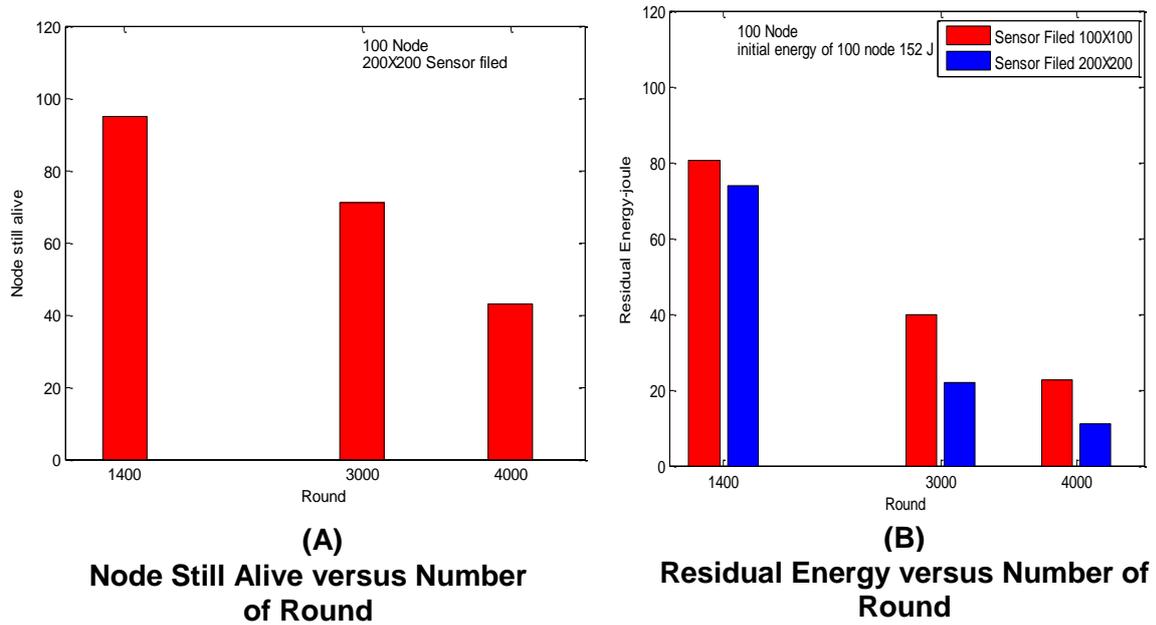

(A)
Node Still Alive versus Number of Round

(B)
Residual Energy versus Number of Round

Figure 4 (A, B). Simulation Results of the First Scenario

Figure 5 shows the simulation results that obtained from the first scenario for the MHUCR that compared with the improved W-LEACH [14] in relation of node that still alive versus number of round. Figure 5 shows that, when the number of rounds is 1400, the number of node that is still alive is 98 for improved W-LEACH, and it is 89 for MHUCR. However, at 3000 round, the number of nodes that is still alive are 71 for MHUCR, and 30 for improve W-LEACH. The results show that the improvement rate of the MHUCR protocol in terms of nodes still alive was 41% when compared with W-LEACH protocol.
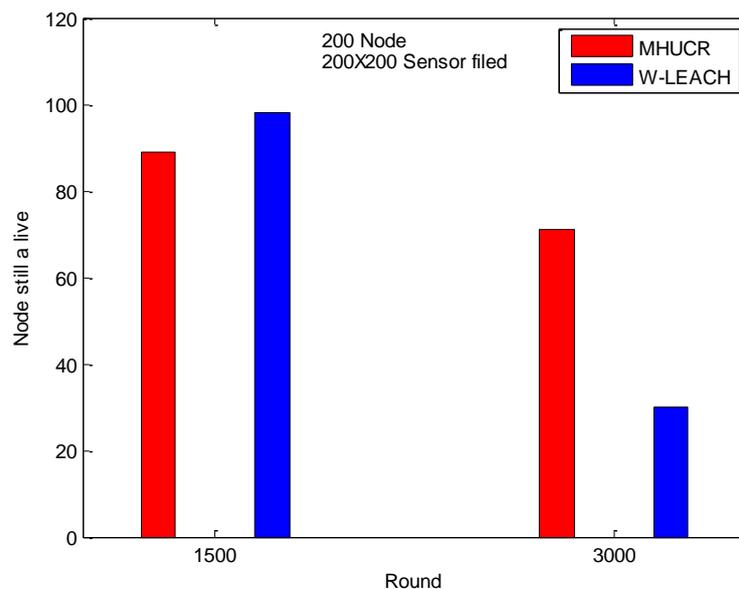

Figure 5. Simulation Results Comparison between MHUCR and Improved W-LEACH Protocol

5.2. Second Scenario

The values of the system parameters used in the second scenario are summarized in Table 1. The sensing field is 50×50 m^2 and the position of the BS is taken at the center of that area. In this scenario, a comparison between MHUCR and LEACH [6] is made. Figure. 3(B) shows the capture of a random snapshot of nodes that randomly distributed. The differences between the first and second scenarios are that, in the second scenario, the area of sensor filed is reduced to examine the effect of distance on sensor nodes and change the number of CH, max number of member for each CH, initial energy of all nodes, and the packet size.

Figure 6 shows the comparison results in relation of node still alive and round. Note that the number of nodes that still alive after run 1400 round in LEACH is equal to zero, while in MHUCR, there are 98 nodes still alive (from 100 nodes). The advantage of this result since the MHUCR take into account that NN send request join to CH that have less member and closer to it and have higher residual energy. Thus, this leads to a balance in energy dissipation in whole network. Figure 6 is illustrations the number of nodes that still alive for MHUCR in case 3000 and 4000 rounds is 90 and 88, respectively. To investigate the performance of the MHUCR, and to check at which round all nodes will be dead under the parameters that are shown in Table 1, the simulation program running at different number of rounds. The simulation results show that at 5000 round all nodes will be dead while in the LEACH, all nodes are already dead at 1400 round. In conclusion, the MHUCR increases the network lifetime. The results show that the improvement rate of the MHUCR protocol in terms of nodes still alive was 98% when compared with LEACH protocol
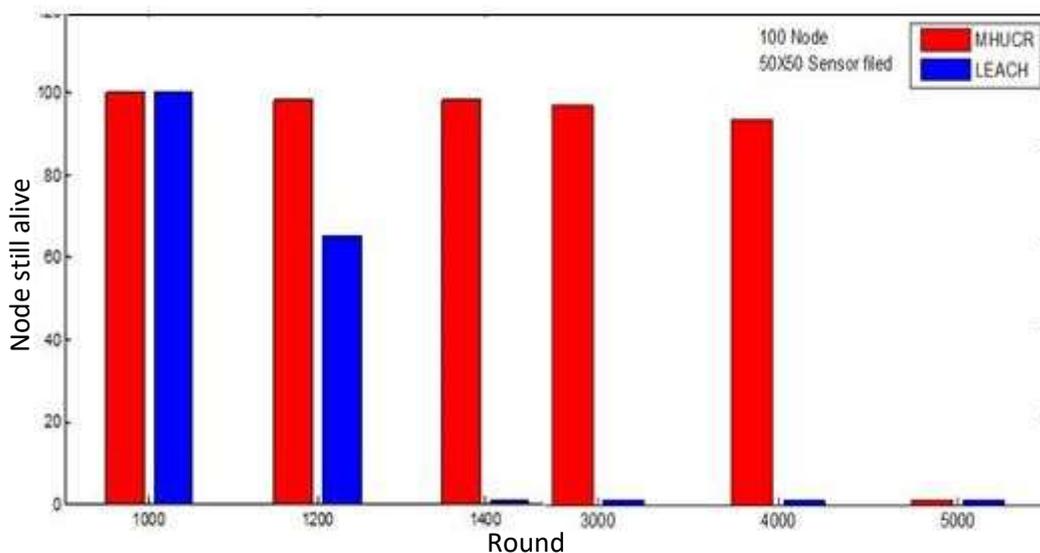

Figure 6. Simulation Results Comparison between MHUCR and LEACH Protocols

5.3. Third Scenario

Table 1 shows the values of the system parameters that are used in the third scenario. In this scenario, the sensing field is 200×200 m^2 and the position of the BS is at the center of that area. A comparison between MHUCR and DECA [15] is presented. Figure 3(C) shows the capture of a random snapshot of nodes that randomly distributed for third scenario. In this scenario, the number of sensor nodes, initial energy of all nodes, max

number of member for each CH, and packet size are increased to study the effect of change these parameter on number of node still a live and network lifetime.

Figure 7 shows the comparison results between the MHUCR and DECA in relation of node still alive and round. Figure 7 shows that the number of nodes that still alive after run 1600 and 1800 round in DECA is equal to 75 and 25, respectively while in MHUCR, all nodes still alive (115 nodes). The advantage of this result since the MHUCR take into account that NN send request join to CH that have less member and closer to it and have higher residual energy. In addition, SN provides its effectiveness and ability to increase the lifetime of the network. Thus, this leads to a balance in energy dissipation in whole network. The results show that the improvement rate of the MHUCR protocol in terms of nodes still alive was 78.2% when compared with DECA protocol.
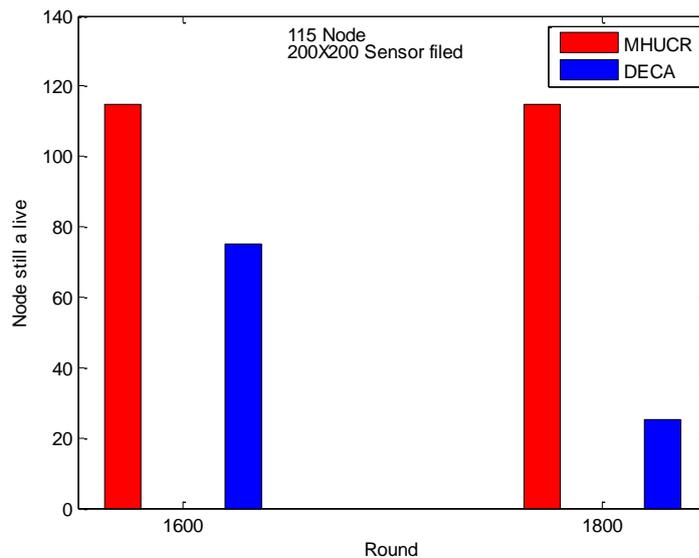

Figure 7. Simulation Results Comparison between MHUCR and DECA Protocols

5.4. Fourth Scenario

The values of the system parameters used in the fourth scenario are summarized in Table 1. The sensing field is 200×200 m^2 and the position of the BS is taken at the center of that area. In this scenario, a comparison between MHUCR with I-LEACH [13] and compare MHUCR with LEACH-C [7] is presented. Figure 3(D) shows the capture of a random snapshot of nodes that randomly distributed. In this scenario, we also increase the number of sensor node and change initial energy of all nodes, max number of member for each CH to study the effect of change these parameters on number of node still a live and network lifetime.

Figure 8 shows the comparison results in relation of node still alive and round. One can note, from Figure 8, that the number of nodes that still alive after run 1500 round in I-LEACH and LEACH-C is equal to 60 and 20 respectively, while in MHUCR there are 187 nodes still alive (from 200 nodes). In case the number of rounds is increased, all nodes of LEACH-C will be died, and 48 nodes remain with the I-LEACH, while 183 nodes remain alive with MHUCR and only four nodes died. The results show that the improvement rate of the MHUCR protocol in terms of nodes still alive is 91.5% when compared with LEACH-C protocol and 67.5% when compared with I-LEACH.
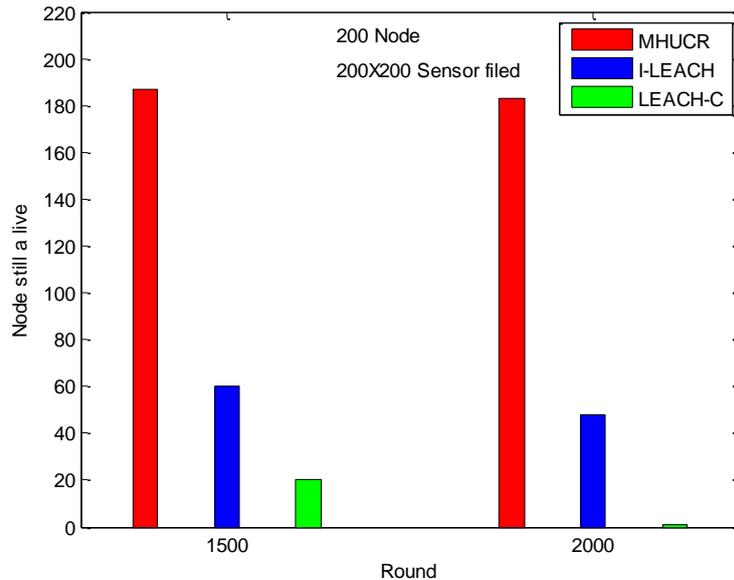
Figure 8. Simulation Results Comparison between MHUCR and I-LEACH, LEACH-C Protocols

6. Conclusion

Wireless Sensor Networks (WSN) is used in different applications in which the lifetime is the most important factor. Consequently, need to reduce the energy consumption in WSN to save limited energy and increase the lifetime of the network as much as possible. In this paper, we propose a Mutli Hop Uniform Clustering Routing (MHUCR) protocol to balance energy consumption in a whole network and use a limited energy in efficient manner to prolong network lifetime. The MHUCR has the capability to adapt and find another path, in case any change occurs, CH fails or dies. The performance of our proposed code, MHUCR, is evaluated using different scenarios with different parameters values. Comparisons are made between the MHUCR protocol with others protocols. Results indicate that the performance of the MHUCR is better than DECA, I-LEACH, LEACH-C, and Improved W-LEACH protocols in terms of nodes still alive and residual energy. MHUCR routing protocol improves the lifetime of the network and overcomes the problem of nodes that near to the BS that die quickly. In addition, simulation results show that the MHUCR protocol balances the energy consumption of all nodes and increases the network lifetime.

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