Energy Efficiency Mechanisms Using Mobile Node in Wireless Sensor Networks

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Abstract. A traditional network consists of gateway sensors which transmit data to the base stations. These nodes are considered bottlenecks in multihop-networks as they transmit their data as well as data from other nodes and hence they deplete faster in energy. One way to optimize energy efficiency in a WSN is to deploy a mobile base station which could collect data without a need for gateway nodes, and hence the multihop bottleneck would be minimized. We compare these two variations of WSN, one consisting of the multihop approach with gateway nodes, and we propose the other network structure, whereby a mobile base station collects data individually from each node using double Fermat's spiral model.

Keywords: energy efficiency, mobile base station, 3-level WSN structure, spiral pattern, pattern routing.

1 Introduction

Wireless sensor networks, due to their manner of operation, act as a bridge to the physical world. They have captured the attention and imagination of many researchers, leading to a broad spectrum of ideas, ranging from environmental protection and military applications.

A wireless sensor network is made up of spatially distributed sensors which are deployed on a wide range of area, and these sensors are used to monitor physical or environmental conditions such as temperature, pollution, pressure and motion. Sensor networks are keys in gathering information needed by smart environments. Each node in a sensor network is equipped with a radio transceiver, a small microcontroller and an energy source, mostly a battery. One of the most distinguished components of wireless sensors networks are the base stations. They have increased computational energy and communication resources. They act as gateways between sensor nodes and the end user.

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One of the core challenges in wireless sensor networks is the wise management of energy [1, 2]. Since the nodes are deployed without a support infrastructure, they only have finite energy reserves from a battery and manual energy replenishment is nearly impossible. The efficient management of energy is a critical issue in wireless sensor networks. There are many causes which lead to depletion of wireless sensor batteries which ultimately leads to network failure. Firstly, there is packet collision, leading to retransmission of corrupted packets which leads to additional energy consumption. Idle listening is another issue, as the nodes are always on and ready to receive any packet, thus the receiver and radio transmitter are always on. Thirdly there is a problem of overhearing, in which the nodes pick up data which is intended for other nodes. The fourth, and the most common cause of all, is multihopping, in which the nodes which are closer to the base station get depleted faster as they do the additional task of forwarding packets from other nodes in addition to theirs.

The bottleneck problem is an effect of multihopping [3]. An alternate solution to this is employing a mobile base station to the network. This can really balance the energy consumption and increase the efficiency of the network. This paper proposes a system where we deploy a robot as a base station into the network. The benefit of this is that we can have it move on a predetermined path and it will collect data from the various nodes scattered around the network. Its job will be that of a data gatherer. The network configuration proposed by us has the option of deploying multiple base stations as well, as we believe that will be a solution for the slow movement of the base station. The path of the moving base station is determined in such a way that all the nodes in the network can transmit data to it by determining the shortest distance between each node and the base station when it crosses the points on the path.

We will be evaluating activity of a multihopping network structure by varying the size of the network in terms of number of nodes. The evaluation criteria will be the energy of each node and the distance of the nodes from each other, which will determine the energy used to transfer. Then we will evaluate the same on the proposed network structure, that with the mobile base station and without gateway nodes. Comparisons will be made on the data transmission throughput obtained at end of each round under different setups and the amount of energy usage per round. The objective is to efficient and produces greater throughput.

The remainder of the paper is organized as follows. In section 2, we explore related works in this area. This is followed by section 3, where the methodology of the two structures is discussed, and the algorithms used to simulate and test results are formulated. Section 4 gives a view of the mathematical concepts used in the performance evaluation in the two cases. Section 5 conducts simulation analyses on the multihopping structure, and section 6 does the same for the proposed structure with mobile base station. This is followed by section 7 which presents energy and throughput based comparison between the two network structures. Section 8 concludes the paper.

2 Related Work

Several researchers working closely with the issue of energy efficiency have considered employing a mobile sink approach in different ways with different strategies while others propose strategies of solving problems within the multihopping structures.

Sarma et al. in their paper devise a communication protocol for different network topologies. The two main types of networks under their consideration are those with mobile base stations (BSs) and those with mobile nodes as well as BSs. They argue that the overall topology of the network is dynamic due to the sudden death of the nodes and availability of nodes. They propose a framework for the routing problem for the WSNs called Sensor system for Hierarchical Information gathering through Virtual triangular Areas (SHIVA) [2]. Akkaya and Younis address the issue of energy depletion in gateway nodes by presenting approaches to move the location of the gateway (sink) for optimized communication energy and timeliness. One of the proposed solutions is to move the gateway to an area where the volume of real-time data is high, and thus balance the traffic load among the nodes in that area. The basic issues like when and where the gateway should be relocated and how the traffic would be managed during its movement are also tackled [4].

Gandham et al. present an integer linear programming model to determine locations of multiple sinks in the network where new mobile base stations could be deployed to deal with the energy depletion due to gateway nodes, in addition to a flow based routing protocol. The locations of the base stations would be periodically changed [5]. Vass and Vidacs also propose strategies to position the mobile base stations in order to prolong sensor network lifetime. The use the strategies of minimizing the maximum transmission energy and minimizing the consumed energy and use these to determine convenient locations for the mobile BS [6]. Xing et al. propose the formation and deployment of rendezvous nodes in each node cluster in a network, whose function would be to aggregate the data from the sub-cluster of nodes and communicate with the base stations. This solves the problem of a slow moving base station around the network [7]. Jerew and Liang propose a similar solution whereby, an entire network is divided into clusters of nodes and the base stations visit these clusters to collect data. So that the base stations don't have to visit each and every node, each cluster of nodes is appointed a cluster head, which is chosen based on traffic and distance evaluations [8].

The energy provisioning problem for two-tier WSN has been studied [9], this approach proposed two level of WSN, i.e. relay nodes which content of aggregation and forwarding nodes. In this paper we extend this approach by proposing 3-level of WSN structure.

3 Mathematical Model for Energy Consumption

The mathematical concepts used in this section is the model used for energy consumption in nodes. We use the mathematical model that we proposed in [10]. In generally nodes are placed arbitrarily in space for the 3-level WSN structure and the radial propagation WSN structure. In the radial propagation WSN structure, the

Fermat's spiral or parabolic spiral follows are used and the equation is $r = \pm\theta^{1/2}$ where θ is the angle; r is the radius or distance from the center in polar coordinates. The general Fermat's spiral follows $r^2 = c\ 2\theta$. Fermat's spiral traverses equal annuli in equal turns. Vogel, H. in 1979 [11] proposed the full model as follows:

$$r = c\sqrt{n},\ \theta = n \times 137.508^0$$

where *n* is the index number of the cycle and *c* is a constant scaling factor. The angle 137.508° is the golden angle which is approximated by ratios of Fibonacci numbers [12, 13].

This study used the the radial propagation WSN structure modeling energy consumption of nodes as proposed in [10] and combine with Fermat's spiral path for two moving robot in reducing the energy consumptions. If nodes are placed arbitrarily in space and maximum transmission distance of a node and the number of energy levels are d and n , transmission distances r , for each level i can be written as

$$r_{i+1}^2 - r_i^2 = \frac{2}{3}\left(r_i^2 - \frac{r_{i-1}^3}{r_i}\right), r_n = d \tag{1}$$

where $r_0 = 0$ and $i = 1,2,\cdots,n-1$.

A node consumes energy E_i to transmit a signal to distance $r(r_{i-1} < r \le r_i, i = 1,2,\cdots,n)$. Let $r_0 = 0$, $v_0 = 0$ and $v_i = \frac{4}{3}\pi r_i^3$, then v_i is the sphere that is covered by energy level i and $v_i - v_{i-1}$ is the volume that a signal with the energy level i can reach but energy level $i-1$ does not. Now let E_{mean} can be written as follows.

$$E_{mean} = \frac{3}{4\pi d^3}\sum_{i=1}^{n} k r_i^2 (v_i - v_{i-1}) \tag{2}$$

$$= \frac{3}{4\pi d^3}\sum_{i=1}^{n} k r_i^2 \left(\frac{4}{3}\pi r_i^3 - \frac{4}{3}\pi r_{i-1}^2\right) \tag{3}$$

$$= \frac{k}{d^3}\sum_{i=1}^{n} r_i^2 \left(r_i^3 - r_{i-1}^3\right) \tag{4}$$

$$= \frac{k}{d^3}\left\{r_1^2\left(r_1^3 - r_0^3\right) + r_2^2\left(r_2^3 - r_1^3\right) + \cdots + r_n^2\left(r_n^3 - r_{n-1}^3\right)\right\} \tag{5}$$

Because $v_1, v_2, \cdots, v_n$ are linearly independent, we can take partial derivation of E_{mean} for each v_i to acquire $v_1, v_2, \cdots, v_n$ that minimize E_{mean}.

$$\frac{\partial E_{mean}}{\partial v_n} = \frac{k}{d^3}\left(5r_i^4 - 2r_{,}r_{i-1}^3 - 3r_{i+1}^2 r_1^2\right), i = 1,2,\cdots,n-1$$
$$\frac{\partial E_{mean}}{\partial v_n} = 0, \left(\therefore v_n = \frac{4}{3}\pi d^3\right) \tag{6}$$

The solution of above equation that make $\frac{\partial E_{mean}}{\partial v_i} = 0$ is as following:

$$0 = \frac{k}{d^3}\left(5r_i^4 - 2r_{,}r_{i-1}^3 - 3r_{i+1}^2 r_1^2\right) \tag{7}$$

$$= \frac{k}{d^3} r_i \left\{2\left(r_i - r_{i-1}\right) - 3r_i\left(r_{i+1}^2 - r_i^2\right)\right\} \tag{8}$$

Since $r_i \neq 0$, it can be written as

$$r_{i+1}^2 - r_i^2 = \frac{2}{3}\left(r_i^2 - \frac{r_{i-1}^3}{r_i}\right) \tag{9}$$

Therefore propagation distances r_i for each level i that minimize energy consumption can be written as

$$r_{i+1}^2 - r_i^2 = \frac{2}{3}\left(r_i^2 - \frac{r_{i-1}^3}{r_i}\right), r_n = d \tag{10}$$

where $r_i = 0$ and $i = 1,2,\cdots,n-1$.

4 The Algorithms of the 3-Level WSN Structure and the Radial Propagation WSN Structure

The aim of the study is to present an avid comparison between two distinct configurations of wireless sensor networks. One is the traditional multihopping sensor network, where we have gateway nodes which perform the extra work of forwarding the data from other nodes, and thus deplete their energy quicker. The other is the proposed network, where the concept of gateway nodes is excluded. Instead a mobile base station moving on a fixed path is employed which moves along its predetermined path and collects data from the nodes individually. In both of these configurations, the distance between node and the distance between the node and the BS play a major role in determining whether data transfer takes place or not.

4.1 The 3-Level WSN Structure

For evaluating and simulating the multihop network, we considered an approach which divides this network into 3 levels. The 3rd level will consist of nodes which are furthest away from the base station. They transmit their data to the 2nd level nodes, which act like an interface between level 3 and level 1. They partially perform the function of relay nodes and transmit their data and data from level 3, to level 1, which are the original relay nodes which transmit all the data to the base station. The algorithm for simulating this network and its operations in MATLAB, is given below.

```
// 3-level structure, calculating throughput and energy with distance

Input:
Coordinate (x1, y1): sensors position level 1
Coordinate (x2, y2): sensors position level 2
Coordinate (x3, y3): sensors position level 3
Energy e: energy available for a sensor

Output:
Total energy consumed in one run, E
Total bits transferred in one run, B'
Data Throughput

n1 = number of nodes on level 1;
n2 = number of nodes on level 2;
n3 = number of nodes on level 3;
en1 = energy for each node on level 1;
en2 = energy for each node on level 2;
en3 = energy for each node on level 3;
flags for level 1, f1 = 1;
flags for level 1, f2 = 1;
flags for level 1, f3 = 3;

initiate counter = 0;
initiate energy = 0;

//level 1
for i=1:n1 do
    counter+1;
    energy+1;
    energy at node -1;
    if energy at node = 0 then
       flag = 0
    end
end
```

```
//level 2
for i=1:n2 do
      for j=1:n1 do
         calculate the propagation distance nodes of levels 1 and 2;
         place them in array;
      end
end

for t=1:n1 do
     arrange nodes base on their distance;
     check flags of level 1 for transferability of data, and if yes, transfer;
     calculate the energy consumption after transferring data
     count if any die node
     calculate the throughput if any active node after transfer data
end

//level 3
repeat above level 2 procedure for level 3;
```

4.2 The Radial Propagation WSN Structure

For the proposed network, we have the network of nodes scattered around a field. We devise a spiral path for the mobile base station to follow. We devise paths for 2 mobile base stations to travel at same time. The nodes around the network on the other hand, calculate distances of points of the path where the BSs will pass, and find the closest path, and when the base station arrives at these points the data transmission takes place. The algorithm for this is given below.

```
//spiral structure, calculating throughput and energy along with distance in consideration, each node
//transmits 1 bit of data, and consumes energy proportional to distance between it and the base station

Input:
Coordinate (x, y): sensors positions
Energy e: energy available for a sensor
N is the total number of nodes in the network

Output:
Total energy consumed in one run, E
Total bits transferred in one run, B'
Data Throughput
```

```
Initiate x1 = 0, x2 = 100, y1 = 0, y2 = 100;
Find central location, x0 = (x1+x2)/2, y0 = (y1+y2)/2;

for i=1:N do
      find d, distance of points from the central location
      loop through points, locate closest node to the central location
end
coordinates (u,v), assign nearest point.
plot the data;

for i=1:6000 do
     plot spiral (path of the BS);
end

for j=1:100 do
     if x(j) is in the specified range then
        for k=1:n1 //n1 is the number of spiral plot points
             if xz(k) is in the range then
                d, calculate the propagation distance of spiral points from all nodes;
                find the minimum distance;
             end
        end
        save shortest distance in an array;
     end
end

//repeat the above procedure for the rest of data ranges along the entire grid

data = N; //total expected data
D = 0; E = 0;

for p=1:N do
      calculate en,
      calculate energy value based on number of hops according to the distance;
if energy at node > en then
           energy at node – en;
           calculate D+1;
           E+en;
      end
end
D = total data transferred;
E = total energy consumed;

Throughput = D/data;
```

5 Simulation Analysis of the 3-Level WSN Structure

In our experiments, we first conducted evaluation on the multihop structure of the wireless sensor networks. In these simulations random points were generated on a 100 x 100 grid and then divided into 3 regions, each indicating the 3 levels as per our definition of the structure of the network. Once the algorithm is run, it will find distances between nodes of each level, and transfer the data towards the nodes of shortest distance, provided energy is present. We conducted tests on different network sizes of 60 nodes, 120 nodes, 200 nodes, 300 nodes and 450 nodes respectively. The simulations of these networks are presented in Figures 1-5 below.

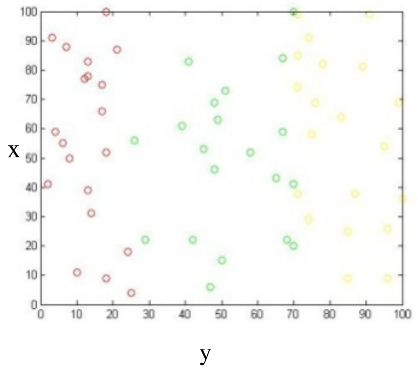

Fig. 1. Multihop structure for 60 nodes in100 x 100 grid

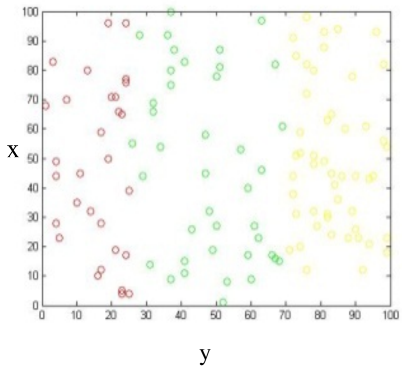

Fig. 2. Multihop structure for 120 nodes in 100 x 100 grid

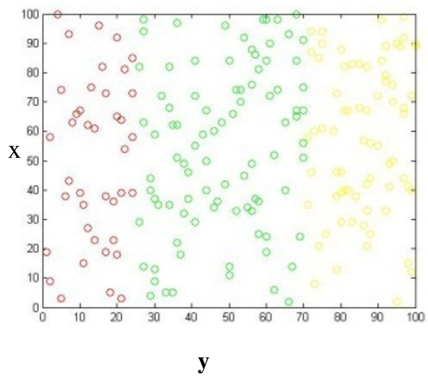

Fig. 3. Multihop structure for 200 nodes in 100 x 100 grid

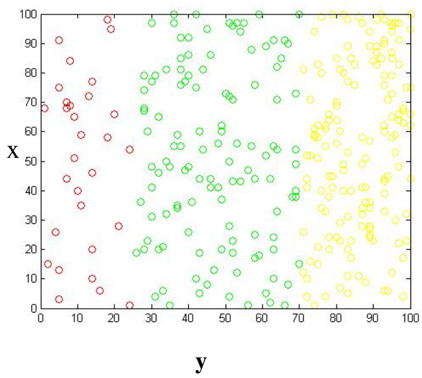

Fig. 4. Multihop structure for 300 nodes 100 x 100 grid

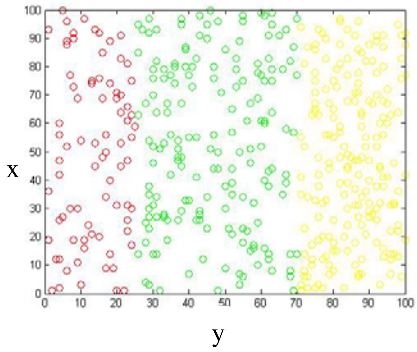

Fig. 5. Multihop structure for 450 nodes 100 x 100 grid

6 Simulation Analysis of the Radial Propagation WSN Structure

For our proposed solution, we are concentrating on reducing the energy wastage caused by the multihopping case of the relay nodes. The proposed network structure was simulated on a similar 100x100 grid, where the nodes were randomly generated and deployed all around the grid. Note that these are the same random nodes used for the 1st analysis, since we are comparing the results; the data has to be the same. The nodes were given the same random energy values. The network initially looks like the Figures 6 and 7.

Then, a central location was determined for the network structure and a point nearest to the central location was found out, so as to act as the starting points for the path of the base station.

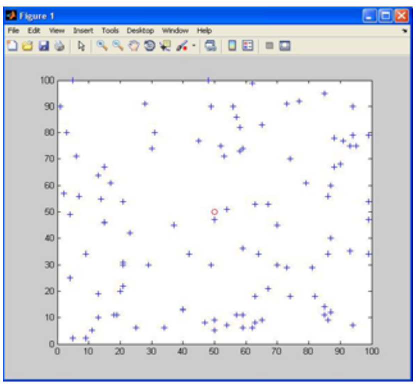

Fig. 6. Initiation state of the network

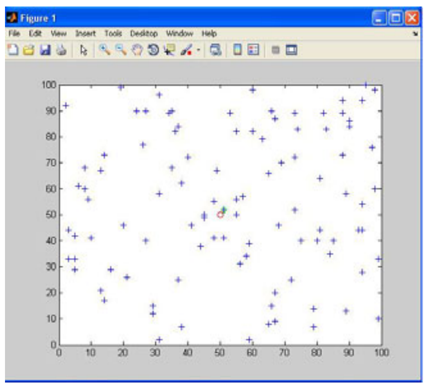

Fig. 7. Determined cluster head of the network

This is the followed by plotting the spiral paths of the base stations. As mentioned, the network does not have relay nodes, and so every node transmits its own data to the nearest point on the path of the base station, when the base station is travelling on that point. This was when we were attempting to save energy and maximize data transmission. In order to cover a wider area of nodes, we deploy 2 mobile base stations at a time. They move simultaneously. These experiments were conducted using the same 5 previous network sizes. The depictions are as shown in Figure 8-12.

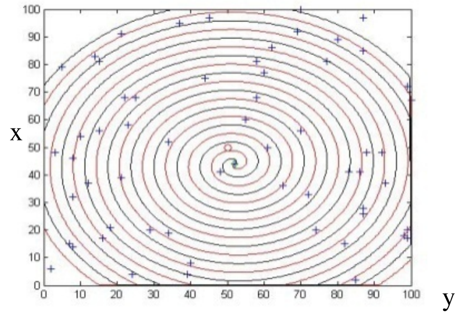

Fig. 8. The mobile elements movement in 60 nodes

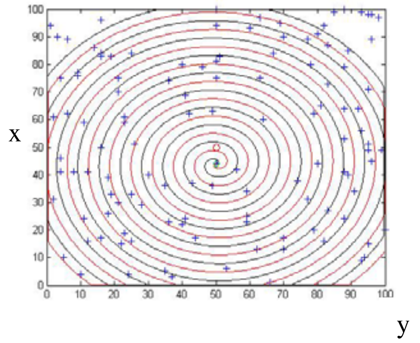

Fig. 9. The mobile elements movement in 120 nodes

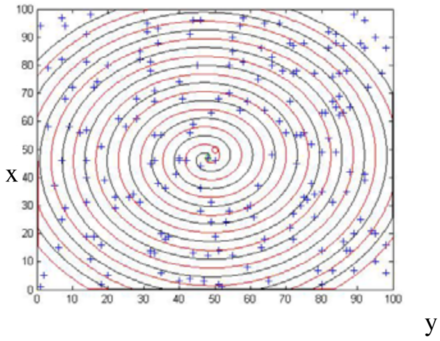

Fig. 10. The mobile elements movement in 200 nodes

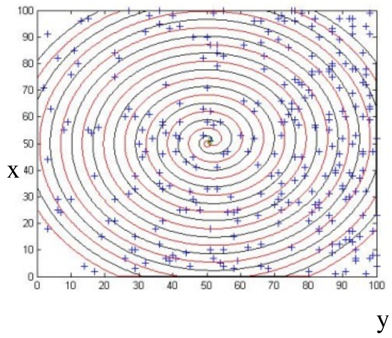

Fig. 11. The mobile elements movement in 300 nodes

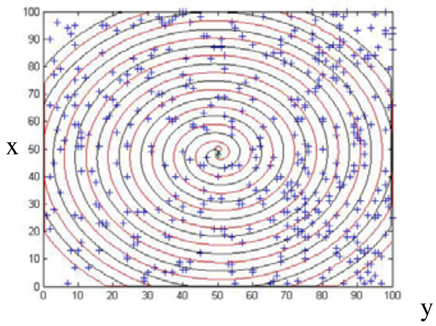

Fig. 12. The mobile elements movement in 450 nodes

7 Experimental Results

After conducting the necessary simulations, the results of each simulation were compared against each other, to determine the favorable outcome, and thus to give us an indication that the proposed solution is a better solution and is successful.

The outcomes of the 5 tests on the multihop simulations are given below.

Table 1. Multihop simulation outcomes for 5 different sizes of networks

No. of Nodes	Throughput %	Energy (J)
60	40	38
120	40	79
200	28	118
300	16.7	130
450	23.8	220

The resulting graph showing variations is shown in the figure below.

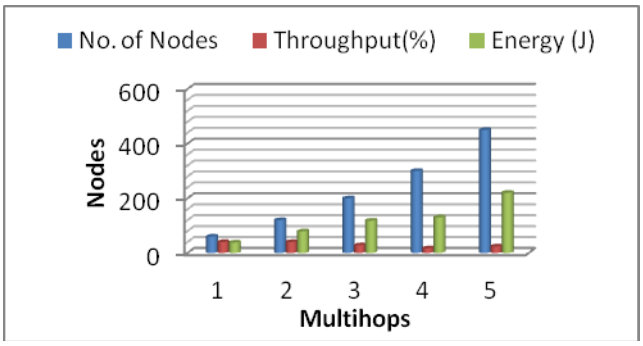

Fig. 13. Throughputs and energy consumptions for 5 different sizes of multihop networks

From the figure, we can notice that as the size of the network increases, the energy consumed increases in small amounts, but the throughput does not show a formidable increase over network size, and tends to decrease eventually.

The results of analysis on the proposed spiral path BS structure are shown in the figure below.

Table 2. Spiral path BS simulation outcomes for 5 different sizes of networks

No. of Nodes	Throughput %	Energy (J)
60	85	74
120	81.7	135
200	88.5	238
300	88.3	373
450	91.1	573

The graph showing variations over network size is given below.

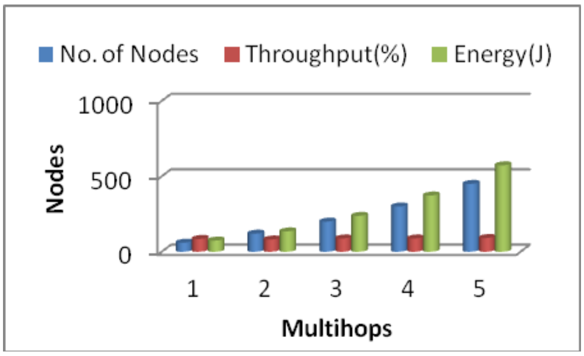

Fig. 14. Throughputs and energy consumptions for 5 different sizes of spiral path BS networks

As can be seen from figure, this method is very efficient in terms of data transmission throughput. The throughput in all the experiment runs is more than 80% and stays pretty consistent and tends to slightly increase as network size increases. The energy used up is used efficiently as can be seen.

A graph comparing the throughputs of both the methods under consideration is given below.

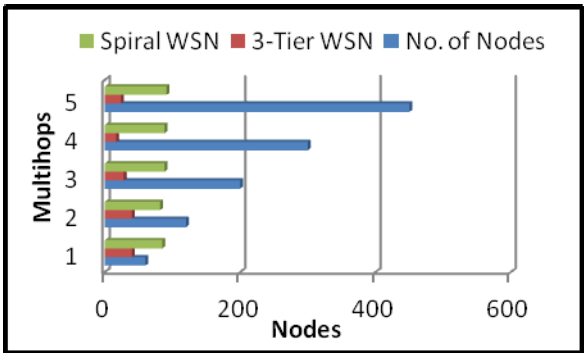

Fig. 15. Comparison of throughput for 5 different sizes of spiral path BS and multihop (3-tier) networks

The graph above compares the throughputs of the 2 WSN structures that we have compared. Both the WSNs are deployed with the same number of points each with the same energy values. As can be clearly seen from the graph, the spiral WSN, or in other words, the radial propagation WSN, excels in throughput all through. There is a certain level of consistency in throughput no matter how different the size of the network is. Whereas in the other network, the throughput is pretty less, and is not consistent, and it appears to be decreasing as the size of the network grows. Thus, the proposed WSN structure can be considered as one of the solutions to the energy efficiency problems in WSNs, as this method makes efficient use of the available energy and produces high throughput.

8 Conclusion

In this paper we attempted to find a solution to the multihop type of wireless sensor networks. There is a high need of energy in multihop wireless sensor networks, for catering to the energy needs of the gateway nodes, and thus, there is always an issue of energy efficiency in these networks.

We proposed an alternative solution to this problem. The proposed network contained the nodes scattered around the network, but the base station is a mobile base station moving along a fixed path, and thus the nodes, instead of transferring the data to each other, they transfer the data directly to the moving base stations and avoid the energy wastage and data dropping caused by the gateway nodes problem. The network also can deploy multiple base stations, further aiding in energy efficiency.

Our experimental results proved that the proposed method fared much better in terms of energy efficiency and produced very high data transmission throughputs all through.

For future work, it is proposed to include more measurement metrics into the equations and calculations to better determine the energy efficiency and thus to explore the solution further. Some of these metrics include:

- Transmission radius of the poles
- The implementation of cluster heads in the structure
- Time of transmitting data
- The implementation of mobile nodes along with mobile base station
- Further controlling base station mobility to allow deviation from the path

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