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Optimal Location for Mobile Sink in Wireless Sensor Networks

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***Abstract*— Energy efficiency and long network lifetime has been of a great interest in wireless sensor networks. In addition to delivering data to the base station, a routing protocol must be energy efficient. An efficient routing technique is known as hierarchical routing based on clustering. In this paper, wireless sensor network is considered with a mobile base station. After clustering the nodes and selecting the cluster heads, the best location of the base station is determined based on the most efficient energy consumption for data delivery of cluster heads. In other words, the location of the base station for the next round is determined so that the minimum energy cost is imposed for data communication, in which we have prevented from data overflow with sending information through single hoping from all the CHs to the base station. Simulation results are provided to prove the efficiency of this technique.**

Keywords; mobile Sink; wireless sensor network, network's life time, energy aware algorithm.

I. Introduction

Recent advances in wireless technology and micro electro-mechanical systems (MEMS) have developed the wireless sensor networks (WSNs) in several industrial, home and military applications. A WSN is composed of a large number of sensor nodes and a base station (BS). Sensor nodes sense their environment, collect sensed data and transmit it to the BS. However, they are limited in power, computational capacity and memory [1, 2].

Hierarchical or cluster-based routing, are well-known techniques with special advantages related to scalability and efficient communication. As such, the concept of hierarchical routing is also utilized to perform energy-efficient routing in WSNs. In a hierarchical architecture, higher energy nodes can be used to process and send the information while low energy nodes can be used to perform the sensing in the proximity of the target [3].

Distant communication to the sink is very energy consuming for sensor nodes. In hierarchical routing based on clustering, it is the responsibility of cluster heads to send the information to the sink. Thus, it makes them to deplete their energy much faster. Recently, some ideas have been proposed in the literature based on mobile sink; e.g. [5] and [6]. In these approaches, the sink moves around in the network in order to reduce the distance of communication and thus decrease the energy consumptions.

Due to importance of the sink position in hierarchical networks for data gathering, designing an efficient algorithm is necessary. In this paper, the best location for BS is determined in a distributed manner. At the beginning of each round, clustering is performed and cluster heads (CHs) are selected. Then all CHs send a status packet across the network in which they propose a maximum distance they can support for data communication to BS. This distance is derived mathematically based on the nodes remaining energy and lifetime. The optimal point for BS's new location is where data communication is efficient for all CHs. A specific node makes the final decision after inspecting the energy efficiency of all CHs in the network for data communications to BS and then BS moves to the location of that node.

In the remainder of this paper, we discuss some related routing algorithms in the second section. In section 3, we state the problem and the proposed algorithm. Finally, in section 4 an evaluation of the algorithm's efficiency is performed via simulations and the results are stated in details.

II. Related Work

In [6], a routing algorithm is considered for a wireless sensor network in which the BS position is dynamic. The nodes are organized into clusters [7] and median distance between the CHs and the two-hop neighbor nodes are determined. Then, the best path through these median points is found based on the Honey-bee algorithm. Then, the BS starts moving across the path from an initial point and collects the gathered data from CHs and then returns back to the beginning after passing all points. A sample path found based on the Honey-bee algorithm for moving the BS through a distribution of nodes is depicted in Figure 1.

In [8], Bi et al has proposed another approach for sink mobility in which the sink is supposed to move towards the node with the most residual energy. Decision making for the movements of the sink is based on one of these circumstances:

- If the sink is within the one-hop distance of the node, it goes to the node's location.
- If the sink is almost two-hop far away, it goes to the closest location to the node.
- If the sink is much further away, it moves towards the node's location.

However, in dense network that has many hops, it seems that it does not operate well due to overhead of maintaining valid data forwarding paths to the mobile sink, also the proposed approach in [8] are discussed in the flat networks. It just considers the energy factor as the main parameter managing the movements of the sink.

In [9], another routing algorithm with regard to the dynamics of the BS is proposed in which the clustering is performed like LEACH [1]. In that paper, the BS moves around in a random manner collecting some information about the positions of the CHs and provides the information in a table. Then it starts moving and crossing the CHs based on their priority in the table and gathering their data. When the BS is positioned in the range of a CH, data communication is performed to the BS. In addition, there may be an information loss if the CHs' internal memory is full. There are some major problems in the previously discussed algorithms:

1. Data communication is not Real-time in theses schemes since it takes place when the BS is in the range. Otherwise, data must be kept in the CHs' memory till that time. In figure 3, the data gathering operation proposed by [7] and [10] is shown. Clearly, only a single CH is capable of sending its data to the BS at a time.

2. There are much unavoidable overheads in these algorithms.

3. The new determined location of the sink is not beneficial for all CHs but one.

Next, we discuss the proposed algorithm that has been succeeded to solve these problems.

III. PROPOSED ALGORITHM

Applying a systematic control on the number and size of clusters has been a challenge which requires using energy efficient and load balanced clustering algorithms in the network [10]. The dynamic nature of the problem due to the frequent changes of CHs in each round complicates the problem. Finding the best location of the BS for optimum single hop energy consumptions of CHs is very important in these hierarchical algorithms.

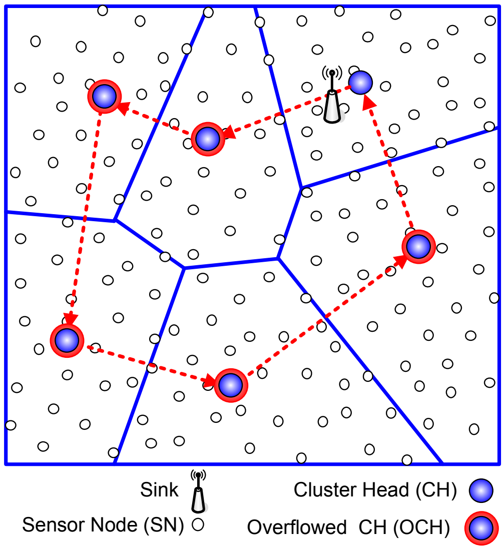

Figure 1. A sample path found based on the Honey-bee algorithm for moving the BS through a distribution of nodes [6].

In this paper, the best position to locate the BS is determined so that the energy consumed by CHs through single hop communications is minimized.

A. Cluster formation:

Several clustering algorithms have been proposed in the literature [11] and [12]. In the proposed algorithm, selecting the CHs and Clustering are performed on the base is of LEACH [1]. The network gets ready to operate for *T* rounds while *P* percent of all sensor nodes are supposed to be selected in each round as CHs to send their data to the BS in a single hop communication.

B. Determining the new location for BS:

After the cluster formation, the new location for BS must be determined in a distributed manner by cooperation of CHs and other nodes. Actually, this new determined location for BS is considered optimal for data communications in the current round. The process is performed by exchanging some information between CHs and other nodes in the network. A specific node makes the final decision after inspecting the energy efficiency of all CHs in the network for data communications to BS and then BS moves to the location of that node.

a) Sending Status packet

Based on its *physical conditions* and an approximate estimation of its *remaining lifetime*, the CH proposes a maximum distance d_{max} that it can support for data communication to the BS. It inserts this into a "Cluster Status Packet" (CSP) and sends across the network. d_{max} depends on the energy consumption of the CH ,E_{CH} for the current round.

$$d_{\max} \quad \alpha \quad E_{CH} \tag{1}$$

The question is that how does it make sense? Suppose that E_{res} denotes the residual energy of the node to be spent in the current round, r and future remaining rounds, T-r. E_{CH} and E_{CM} denote energy consumption of a node when it is a CH and the energy consumption of that node when it is a cluster member (CM) respectively. Thus, the node is supposed to use this energy as a CH for A rounds and as a CM for B rounds:

$$\begin{aligned} &E_{res} = A.E_{CH} + B.E_{CM} \\ &where \\ &A = T.p - \lfloor r.p \rfloor \\ &B = T - r - A \end{aligned} \tag{2}$$

The approximate energy consumption of the node acting as a CH in the current round would be:

$$E_{CH} = \frac{E_{res} - B.E_{CM}}{A} \tag{3}$$

On the other hand, E_{CH} is the total consumed energy for receiving packets from n number of CMs plus the energy required for transmission a packet to BS:

$$E_{CH} = nE_{rx} + E_{tx} \tag{4}$$

Where E_{tx} and E_{rx} are the consumed energy for sending an *l-bit* packet to distance d_{max} and receiving an *l-bit* packet respectively:

$$\begin{aligned} &E_{tx} = lE_{elec} + l\varepsilon d^{\beta}{}_{\max} \\ &E_{rx} = lE_{elec} \end{aligned} \tag{5}$$

Where the E_{elect} is the energy required for running the electronic circuits. ε and β are the parameter which depend on the noise figure, channel's characteristics and the required SNR for proper signal detection at the receiver. By inserting 5 into 4, d_{max} can be easily determined as:

$$d_{\max} = \sqrt[\beta]{\frac{E_{CH} - nlE_{elec} - lE_{elec}}{l\varepsilon}} \tag{6}$$

Details of calculation and E_{CM} are provided in Appendix 1. Figure 2 depicts the parameters that are sent by the CHs across the network in CSP packets. In this figure CHID and $CH_{X.Y}$ are the ID number and the coordination of the CH respectively.

CH_{ID}	$d_{\max}$	$CH_{X.Y}$

Figure 2. CSP packet format

b) Notifying BS of the new locationd_{max}=8

After receiving the CSP packets, each node will build a table in its local memory and save them. The table includes the following parameters for every CHs (Figure 3):

CH_{ID}	$d_{\max}$	d_{toCH}	D^*

Figure 3. table structure of each node

Where d_{toCH} is distance to the corresponding CH. D^* is defined as:

$$D^* = \left| d_{\max} - d_{toCH} \right| \tag{7}$$

Where |.| denotes the absolute operation. By calculating the average of the column D^* in each node, the location of node with the least average is considered as the optimal location of BS. This node will notify the BS by sending its location. An example of this process is shown in Figure 4 and the pseudo code of the algorithm is given in Figure 5.

A timing based approach proposed in [11] is used here for sending the notification message in which the node with the least average D^* amount will advertise sooner.z

Finally all CHs adjust their transmission power to send their data to BS at the new location.

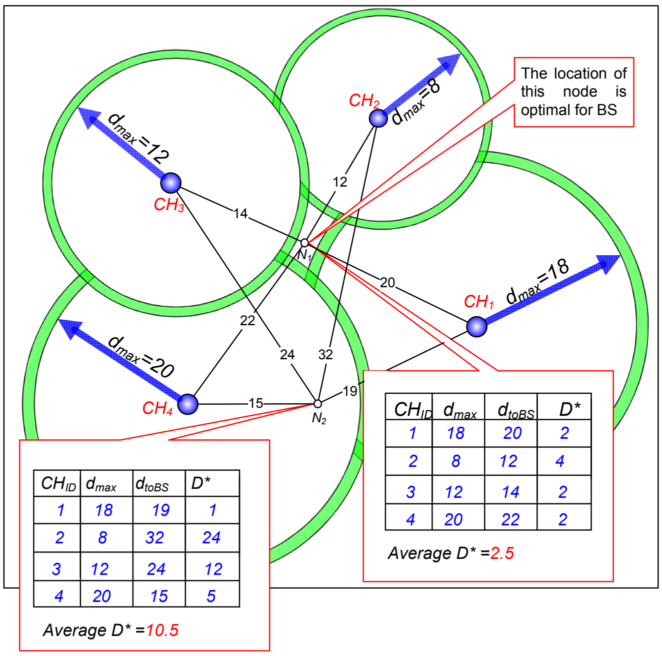

Figure 4. determining the best location by nodes

IV. SIMULATION AND EVALUATION

In this section we provided the simulation results of the proposed algorithm performed in MATLAB environment and compared them with the results of similar schemes such as [9] in which the BS moves around randomly and [8] in which the BS moves to the maximum residual energy CH. The comparison is done in the number of alive nodes, energy of the network, variance of the consumed energy in each round and

```
//network's operation for T rounds
Beginning r^th round
    Clear all nodes' table
    Cluster formation
    For each CH_i
        Calculating d_max
        Sending (CH_ID, d_max, CH_X.Y)// CSP Packet
        for each node
            Calculating d_toCH, D* for CH_i
            Inserting CSP into its table
        Next node
    Next CH
    For each node
        Calculating the average of D*
    Next node
    the node with the least average D* will notify the BS
    BS moves to the new location
    CHs adjust their transmission power and send their data to the BS
Next r
```

Figure 5. Pseudo code of the proposed algorithm

the number of received packets in the BS. Simulation parameters are listed in table 1. In addition, a free space model with $\beta = 2$ is assumed for communication channel. It is assumed that clustering is performed in each round and the data of every node is gathered by CHs and sent to the BS.

TABLE I. SIMULATION PARAMETERS

Parameter	value
Initial Energy	0.1 J
Data packet	4000 bits
Control packet	32 bits
E_{elect}	50 nJ/bit
ε_{fs}	10 pJ/bit/m^2
Nodes	200
Network size	100*100 m^2

A. *Network lifetime.*

In Figure 6 the number of alive nodes during the network lifetime for the suggested algorithm is depicted. Compared with other schemes, the proposed algorithm has prolonged the First Node Dying time which is when the first node runs out of energy in the network. This shows the balance in energy consumption.

B. *Energy Consumption*

The rate of total energy consumption in the network can be a good metric to measure the energy efficiency of the algorithms. The less steep the figure is the more clearness of balance energy utilization and fairer distribution of energy on the node would be.

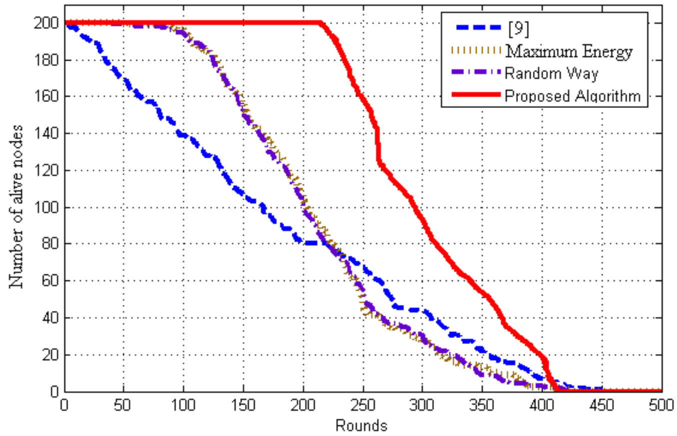

Figure 6. Number of alive nodes versus lifetime.

Figure 7 shows the comparison of energy consumption rate in theses algorithm in 500 rounds.

C. *Variance of the residual energy in each round*

For comparing the quality of service parameter, the variance of the residual energy of all nodes in each round is considered. Once again, the more straight line demonstrates the less variant energy consumption which is due to the better energy balancing. In Figure 8, the variance of the residual energy is compared in the four algorithms in which the proposed algorithm seems to have quite straight line.

In addition to the previous results, the number of delivered packets to the BS can be a good parameter for meeting the quality of service requirement. A well operating algorithm in monitoring the network would be the one that sends more information about it to the BS. In Figure 9 shows the number of received packets to the BS for every 10 consequent rounds.

According to the obtained results from the simulation, it is clear that determining the location of the BS based on the residual energy of CHs and other nodes in the proposed algorithm improves the network's energy efficiency.

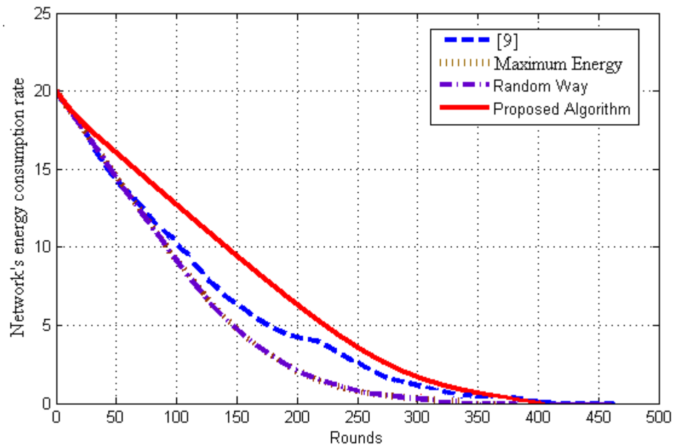

Figure 7. Total Energy Consumption

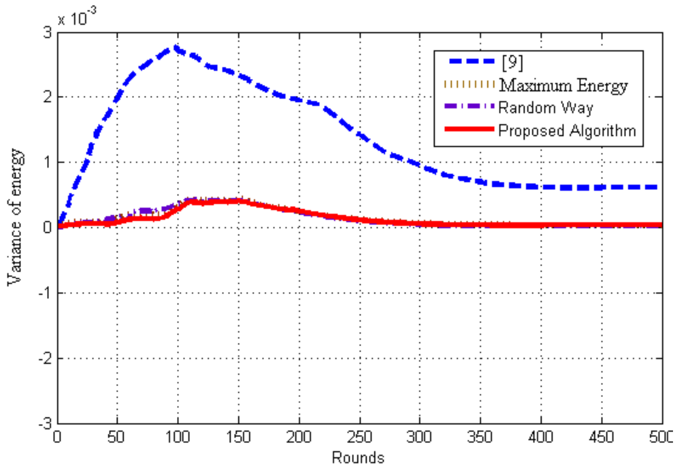

Figure 8. Variance of the residual energy in each round

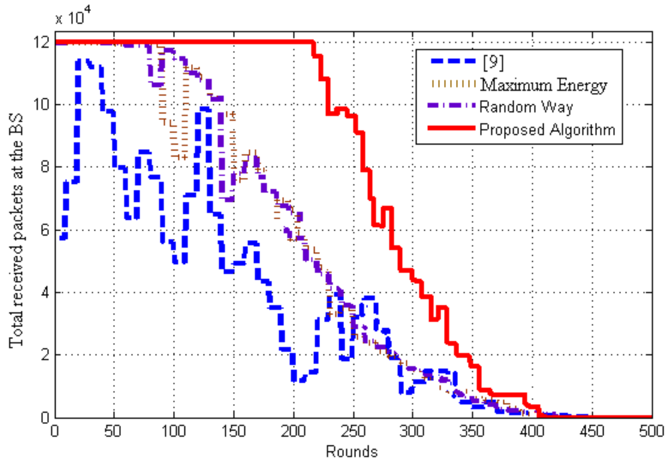

Figure 9. Number of Received Packets to the BS.

V. CONCLUSION

In this paper, we went through Mobile Sink protocols and data gathering schemes by the base station in wireless sensor networks. Inspecting the weaknesses of the previously proposed schemes, we proposed an algorithm that covers their weaknesses such as data loss and less energy balancing.

In this paper, the best location for BS is determined in a distributed manner. At the beginning of each round, clustering is performed and cluster heads (CHs) are selected. Then all CHs send a status packet across the network in which they propose a maximum distance they can support for data communication to BS. This distance is derived mathematically based on the nodes remaining energy and lifetime. The optimal point for BS's new location is where data communication is efficient for all CHs. A specific node makes the final decision after inspecting the energy efficiency of all CHs in the network for data communications to BS and then BS moves to the location of that node.

We simulated the proposed algorithm and compared the results with the results of similar schemes such as [9] in which the BS moves around randomly and [8] in which the BS moves to the maximum residual energy CH. The comparison was done in the number of alive nodes, energy of the network, variance of the consumed energy in each round and the number of received packets in the BS. The simulation results demonstrate the better operation of the proposed algorithm.

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Appendix1:

The consumed energy of each member in the cluster is directly related to its distance to the respective CH. Suppose that the cluster is a circle with the radius *R* and the density of uniformly distributed sensor nodes in the cluster is ρ that is assumed to be independent of coordination. E_{CM} can be calculated by:

$$E_{CM} = lE_{tx}$$
$$E_{tx} = p + qR^2_{toCH} \quad \text{(AP.1)}$$

Calculation of E_{CM} requires an expectation of squared distance of CMs to the CH:

$$E[R^2_{toCH}] = \iint (x^2 + y^2)\rho(x, y)dxdy$$
$$= \int_0^{2\pi}\int_0^{R} \rho r^3 d\theta dr \quad \text{(AP.2)}$$
$$= \rho.2\pi.\frac{R^4}{4}$$

Thus:

$$E_{CM} = l(p + q.\rho.2\pi.\frac{R^4}{4}) \quad \text{(AP.3)}$$

In addition, assuming equal size clusters in the network of the area S, the number of clusters (*NoC*) of the area S_{CH} can be obtained from:

$$NoC = \frac{S}{S_{CH}} = \frac{S}{\pi R^2} \quad \text{(AP.4)}$$

Where S_{CH} is the cluster area. On the other hand, it is assumed that *p* percent of nodes become CHs in each round. Therefore, there would be N.p clusters in each round where N is the total number of nodes. Therefore, the cluster radius, R would be:

$$N.p = \frac{S}{\pi R^2}$$
$$R = \sqrt{\frac{S}{\pi N.p}} \quad \text{(AP.5)}$$