A Framework for Energy Efficient Routing Protocol for Homogeneous Wireless Sensor Networks Using Sensing Range

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***Abstract*— Wireless Micro Sensor Networks have unlimited applications all around us and these networks will enable the reliable monitoring in various environments for both civil as well as military purposes. Wireless Micro Sensor Networks are low power battery driven networks, hence efficient energy utilization is needed. In this paper focus is to design an optimum energy multi-hop network. For this purpose we propose the concept of merging in a multi-hop network in which if two sensing nodes are falling in the same sensing range then they will work in sleep and active mode as a result of which less energy will be used. Nodes are arranged in the form of clusters and each cluster has a cluster head. All the nodes communicate with Base Station using multiple hops via cluster heads. We will compute the energy used in network in terms of number of rounds of transmission and reception of information. Along with the efficient energy usage, our proposed merging algorithm helps in finding out the lifetime of network (in number of rounds).**

Keywords— Clustering, Data aggregation, Homogeneous, Sensing range, Transmission range.

I. INTRODUCTION

Advances in the field of wireless communication, MEMS (micro electro mechanical systems) technology have led to the development of low cost, multifunctional [1] tiny sensor nodes which consume less power. Sensing range of these sensor nodes is short. When these sensor nodes are deployed together in huge numbers (order of 10^6), they form a Wireless Sensor Network (WSN). The basic purpose of WSN is to sense a phenomenon and send it back to the Base Station (BS). No human intervention takes WSN's to a whole new level and because of this the wireless sensor networks have various applications and can reach where humans can't, like in battle field surveillance, disaster prone areas, detection of a gas leak in nuclear power plants etc. A WSN is a combination of low cost, multifunctional tiny sensor nodes interconnected through a specific wireless protocol like Zigbee, Wi-Fi, Bluetooth etc. The sensor nodes are deployed in a specific region (inside the phenomenon or close to it) and are deployed randomly or manually. Typically in WSN's nodes coordinate locally to gather and process data and send it to common sink commonly known as base station. The BS is assumed to contain infinite energy. Nodes in WSN's are driven by limited battery power and are not rechargeable. Energy of nodes and energy usage are key factors in determining the lifetime of the whole network. The energy contained in a Sensor node is consumed in various processes such as sensing, processing and communication. Since, the nodes have limited operating power, energy optimization becomes extremely imperative for a WSN to function for a long time. Energy optimization plays a key role in the functioning and lifetime of any WSN.

The battery power forms the backbone of a sensor node as the battery is limited and irreplaceable. A sensor node cannot function without the power unit as this unit supports all the other functions in a sensor node. With every sensor node there are two very crucial parameters namely:

- Sensing range (R_s): It is the maximum distance up to which sensing node can sense a phenomenon.
- Transmission range (R_t): It is the optimum distance over which a sensor node can transmit data.

These two above mentioned parameters can greatly help in energy optimization which is elaborated later in the paper. Many researches are going in the field of energy optimization of WSN and many energy efficient routing protocols such as the minimum transmission energy and LEACH[2,3] (low energy adaptive clustering hierarchy) protocol have been proposed, where the concept of clustering, cluster head and techniques like data aggregation and data fusion are used which help in increasing the efficiency of the network.

This paper talks about enhancing the lifetime of a WSN using the sensing range. The paper is organized as follows: Section 2 provides a brief overview of the areas in WSN, routing and data aggregation. Section 3 deals with the proposed architecture in detail like, cluster head formation, data transmission, data aggregation and optimizing network by merging of nodes, Section 4 deals with the simulations and results. Section 5 concludes the paper and talks about the future work.

II. Related work

A. Clustering

Grouping of the nodes falling within the transmission range of a particular node is known as clustering. Each cluster has a node with respect to which distance of all the nodes is measured which is often referred to as, cluster-head (CH). Many clustering algorithms have been proposed and the main motive of all the proposed algorithms is to generate stable clusters and route stability. Clustering doesn't bother much about Wireless Sensor Networks (WSN's) goals of network coverage and lifetime of networks. CH's in a network can be elected by the sensors in the cluster or they can be pre assigned by the network designer. Cluster head can also be elected on the basis of resources it has, for example energy associated with a node. Other parameters which help in electing CH's are, how many cluster heads can be there in a networks, how many times a particular node has been a cluster head etc. But there are some issues with clustering. First, there should be optimum number of clusters, so that performance of the network can be optimized. Second, how many numbers of nodes can be included in one cluster. There should be a quantization of parameters for selecting a cluster head. Third, if the network is heterogeneous then, user can give high energy to some nodes and those nodes have maximum probability of acting as cluster heads and other nodes will act as normal nodes. So the selection of CH's also depends on whether your network is homogeneous or heterogeneous. Every cluster has cluster head and member nodes. Clustering results in a two tier hierarchy in which the cluster heads form the higher tier and member nodes form the lower tier. Clustering is important because it makes the network more efficient through the techniques of data aggregation [4, 5, 6].

Along with the network scalability there are numerous advantages of clustering. Since it limits the scope of inter-cluster interactions to CH's it conserves the communication bandwidth and avoids redundant exchange of messages among sensor nodes. Clustering also stabilizes the network topology and thus cuts on topology maintenance overhead. Sensor nodes will only be concerned with connection with CH, so the change in a CH level tier will not affect the sensor nodes. CH's can further implement optimized management strategies which will prolong the battery life. CH's also schedule sensor nodes in the scheduling phase by following TDMA techniques in which sensor nodes can work in sleep and active mode and hence, conserve energy of the network. CH in a cluster collects data from the sensor nodes and coverts it into small sets of meaningful information using data aggregation techniques.

B. Data aggregation

Sensor nodes in a sensor networks periodically sense data, processes it and transmits it to the base station. How frequently a node sends data to the base station is application specific. A comprehensive survey on wireless sensor networks is presented in [1]. Data gathering is defined as collection of data in a systematic way from multiple sensing nodes to eventually transmit it to the base station for processing. Since sensor nodes may generate significant redundant data, similar data can be aggregated to reduce it in the small sets of meaningful information. Data aggregation is the combination of data and minimizing into small sets of meaningful information from different sources according to a certain aggregation function. This technique is used to achieve energy efficiency and data transfer optimization [7, 8].

C. Different types of Routing Protocol Used in Wireless Sensor Networks

Routing protocols in WSN are divided into flat, hierarchical and location based protocol according to the structure of the network. In flat routing protocol all the sensor nodes in the network have same functionality. The aim of this protocol is not to organize the network or maintain the traffic, but to transmit information through hopping and finding the best route to reach the destination. This type of routing is used mainly in flat structures which contain a huge number of sensor nodes. Every node has a separate entry in the routing table. All the nodes in the network are equal and behave in same way in task of information gathering and sensing data. As global IDS cannot be assigned hence this is a data centric approach in which every node is considered as a potential receiver. In this protocol a node sends query in a particular region and waits for a response from that region. SPIN (sensor protocol for information and negotiation) is an example of flat routing protocols. Some other flat routing protocols are Directed Diffusion, Rumor Routing, Minimum Cost Forwarding algorithm, Gradient Based routing, Information Driven Sensor Query and Constrained Anisotropic Diffusion Routing. Hierarchical routing protocol is used in hierarchical structures like internet. In these protocols different clusters are formed and then a cluster head is chosen depending on the energy of the nodes. This protocol is efficient in terms of scalability as it reduces the number of entries in the routing table and load on nodes. Hierarchical Routing has two layers. In the first layer cluster head is selected and in the second layer routing is done. Hierarchical Routing reduces the energy consumption in a cluster and reduces the transmitted message by data aggregation and fusion to the base station. LEACH (low energy adaptive clustering hierarchy) is a form of hierarchical routing protocol. In location based routing the nodes are identified by their location and the distance between the neighboring nodes can be determined by the incoming signal strength. Location of a node can also be determined by equipping them with a small GPS. Some location base protocols also have nodes working in sleep and active modes. In these protocols we can easily find the optimum path using the coordinates already known, but location based routing is expensive [7, 8, 9].Geographic adaptive fidelity (GAF), GEAR (geographic and energy aware routing) are examples of location based routing.

III. System Architecture Model

A. Notations used in the paper are detailed in Table I.

TABLE I

Notation	Meaning
N	Total nodes in the network
E_0	Initial node energy (1J)
n_0	Node id of BS
n_i	Node id of i^{th} node
K	Packet Size (no. of bits)
E_{th}	Threshold energy value at which the CH dies
E_{DA}	Data aggregation energy
R_s	Sensing Range
R_t	Transmitting Range
Nb_i	Set of neighboring nodes of i^{th} node
CH_{id}	Cluster head ID's for each nodes
E_r	Residual Energy < E_0
D_{ij}	Distance between i^{th} nodes to j^{th} node.
H_{id}	Number of hops to reach the BS

The network used for the current research work has the following properties:-

1. The nodes are homogenous having equal initial energy (E_0) of 1 joule.
2. The nodes transmit the data to the BS in multiple hops.
3. The hops are determined based on the distance of the node from the BS.
4. The sensors used have transmitting range(R_t) of 100-150 m. Considering R_t (150 m) as the transmission range and R_s (25 m) as the sensing range, we have considered $R_t \geq 2R_s$ to be a valid assumption.
5. Total N number of nodes are randomly deployed.
6. After random deployment sensor nodes are stationary.
7. BS (n_0) is fixed and deployed somewhere in the middle of the network (250,250).
8. The nodes are proactive.

$N = \{n_1, n_2, n_3, n_4 \ldots\ldots n_j\}$ $\quad 1 \leq j \leq N$

n_0 is the Base station.

Co-ordinates of BS $(x_0, y_0) = (250, 250)$

Nodes transfer data to the BS in periodic intervals. To build a network we start from the base station and connect all nodes lying in its transmitting range. Then these connected nodes connect to the sensor nodes lying in their transmitting range. This process continues till all the nodes are connected. After all the connections are made the routing table of the network is calculated. The routing table tells us about the path of every node and number of hops to reach the BS. To calculate the life time or the energy of the network we have used first order radio model. By calculating the energy required in transmitting and receiving we can estimate number of rounds a network can last.

B. Cluster Head Determination

Step 1: The nodes in the transmitting range of the BS are connected to the BS as shown in Fig. 1.

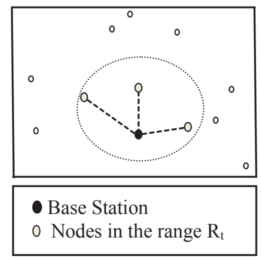

Fig. 1. Nodes Connected to within Base Station's R_t

Step 2: The sensors deployed within the transmitting range are connected to the already connected node. Any node connected to more than one node is called a cluster head as shown in Fig. 2.

Step 3: Base Station (BS) transmits the Cluster Head Selection message (CHS_msg) to the all the sensors within its transmission range. It assigns the corresponding hop_ID to all the sensor nodes. In Fig. 3 the three nodes coming within the transmission range of BS are 2(CH 1), 3(CH 2) and 4(CH 3). The CHS_msg consists of the following parameters:-

- hop_ID, the number of hops from the current node to the BS.
- msg_type, the type of message sent by the BS to the sensor network. It can be a cluster head selection message or it can be a query processing message.
- ch_ID, the id of the previous cluster head or the BS.

Step 4: In Fig. 2, CH 1 only send the CHS_msg to 5, 6 and 7 so in this case CH1 become cluster head CH.

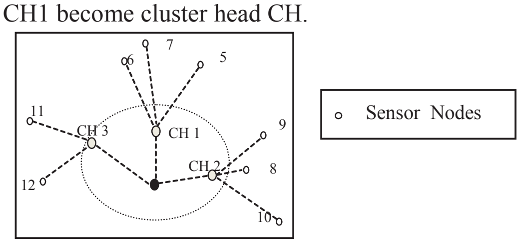

Fig. 2. All nodes connected with base station

Step 5: Once all the CH are formed in the given network and on the basis of number of nodes connected to it as shown in Fig. 4, the number of hops required for every CH to reach the base station are calculated.

$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$

If $(d_{ij} \leq R_t)$ $\quad 0 \leq i \leq N$

Connect i^{th} and j^{th} node

$Nb_{ij} = \{n_1, n_2, n_3 \ldots\ldots n_m\} \in N \;\&\; \neq Nb_{kj} \quad 0 \leq k \leq m-1$

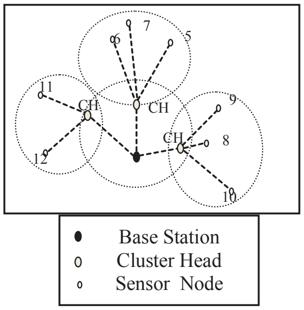

Fig. 3. Formation of 2^{nd} Tier of nodes

kk = count (Nb_{mj})

If (k>1), n_m is a cluster head

Routing path of n_i is

n_i , $Nb(n_i)$, $Nb(Nb(n_i))$……..till $Nb(Nb(\ldots(Nb(n_i)))=1$

i varies from N to 1

C. Data Transmission from Sensor to Sink

Whenever there is a need to transmit sensor data the reactive part of the protocol transfers the data from the sensor node to the BS. The proactive part of the protocol deals with transmission of data from the sensor to the BS at regular time intervals. The sensor nodes send their unique node identification number (n_i) and data to the cluster head assigned to them. The cluster heads aggregate data and send the information to the BS using minimum number of hops as designated by the hop_ID (H_{id}) of the cluster head.

The BS would use the above information to process any type of application. In this task it may generate spatial and temporal data, process the desired parameters and predict events.

D. Data Aggregation

As discussed earlier the proposed protocol deals with the sensing of multiple attributes by the sensor network.

In the case of WSN, a physical quantity is sensed. In real world, the environmental factors (e.g., temperature, humidity) change continuously instead of flipping over along the space field. According to this natural phenomenon, there exists kind of correlation in the data gathered from natural environment. Hence in WSN, data aggregation can be done by exploiting the correlation among the data. This would save time and energy. One way to exploit correlation is a linear transform in which the statistically dependent data will be mapped into a set of more independent coefficients and then compressed and transmitted.

E. Merging

If two nodes are sensing the same area or if a node is falling in the sensing range (R_s) of another node connected to the same cluster head then it is of no use to sense same data using multiple sensors. This reduces the energy efficiency of the network and as we have limited available operating power for wireless networks, this will be a major reason for shortening the lifetime of network. An improvement over this approach is proposed merging algorithm. If nodes falling in the same sensing range then these nodes should work like one node with higher initial energy. Physically by merging we mean that these nodes will work in sleep and active mode with initial energy (E_0) higher than other nodes (say 1.5 J). This will save considerable amount of energy and hence lifetime of network increases. After the merging the above steps are repeated again to set the network again.

If ($d_{ij} \leq 75$m) merge n_i and n_j to node n_m

where $x_m = (x_i + x_j)/2$, $y_m = (y_i+y_j)/2$

Initial energy of merged node is 1.5 J

Update N to N-1

This is shown in Fig. 5. n_6 and n_7 are merged as they fall in sensing range of each other.

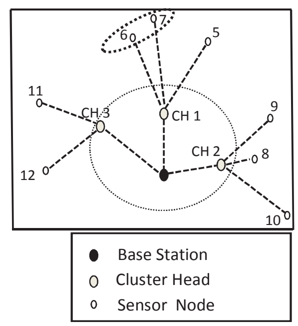

Fig. 4. Merging of Nodes

Repeat the above steps and construct the new network having merged nodes and again calculate routing table and energy of nodes.

IV. SIMULATION AND RESULTS

The network is simulated in MATLAB. The parameters on which the efficiency of the network is compared or determined are, the energy required for trans receiving and processing in the network and the life time of the network. The energy of every node is evaluated using First Order Radio Model [2,3] as shown in Fig..6

A. First Order Radio Model

A great deal of work is going on energy consumption of radio models. Different assumptions made in radio models have different advantages. In our work we considering a simple model where radio dissipates E_{elec}=50nJ/bit to run transceiver circuitry and ε_{fs}= 100 pJ/bit/m^2 for transmitter amplifier, so as to achieve acceptable SNR ratio. We also assumed there is d^2 energy loss due to channel transmission.

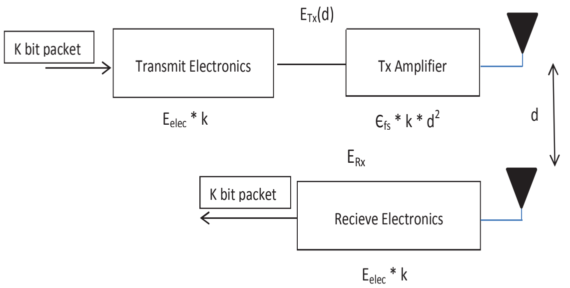

Fig. 5. First order Radio Model

To transmit information transmitter expends:

$$E_{Tx}(k, d_{ij}) = E_{Tx\text{–}elec}(k) + E_{Tx\text{–}fs}(k, d_{ij}) + E_{DA} \quad (1)$$

$$E_{Tx}(k, d_{ij}) = E_{elec} * k + \varepsilon_{fs} * k * (d_{ij})^2 + E_{DA};\ d_{ij} < d_0 \quad (2)$$

and receiver expends :

$$E_{Rx}(k) = E_{Rx\text{ - }elec}(k)$$

$$E_{Rx}(k) = E_{elec} * k \quad (3)$$

$\varepsilon_{fs} = 100$ pJ/bit/m^2 [2,3] ; $E_{elec} = 50$ nJ /bit; $E_{DA} = 5$ nJ/bit

Using these parameters receiving message is not a low cost operation. So protocols used in network should try to minimize not only the distance between two nodes but should also minimize number of transmissions and receptions for each message. Once the energy of the node required in transmitting and receiving is determined the number of round the node will last can be predicted. The number rounds till which the cluster heads are going to last determine the life time of the whole network. Simulation results are tabulated in Table II and Table III.

TABLE II

%age nodes alive	Total Number of Nodes			
	50	*100*	*200*	*300*
100	0	0	0	0
75	1963	1848	1752	1609
50	2143	1987	1843	1704
25	2304	2117	1923	1816
10	2577	2301	2027	1973
9	2598	2327	2093	1997
5	2657	2436	2186	2158
3	2699	2473	2317	2296
1	2705	2518	2391	2341

Above table shows %age of nodes alive in networks having different total number of nodes after corresponding number of rounds before merging of nodes. Tabulated results are shown graphically in Fig. 7.

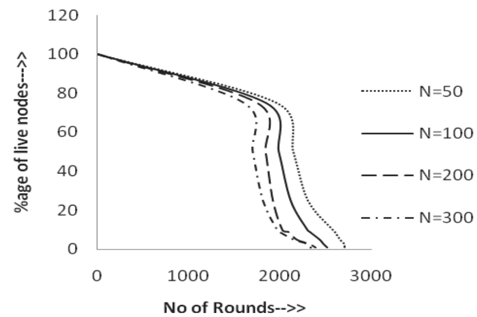

Fig. 6. %age of nodes alive before merging corresponding to total number of nodes

Using concept of merging we again simulated our network and results are mentioned in Table III below. It's apparent that the lifetime of network is increased.

TABLE III

%age nodes alive	Total Number of Nodes			
	50	*100*	*200*	*300*
100	0	0	0	0
75	2763	2641	2503	2410
50	3149	3019	2917	2803
25	3517	3381	3209	3107
10	3819	3590	3401	3391
9	3903	3697	3519	3443
5	4185	3870	3697	3579
3	4353	4021	3821	3671
1	4591	4307	4152	3917

Tabulated results are shown graphically in Fig.8

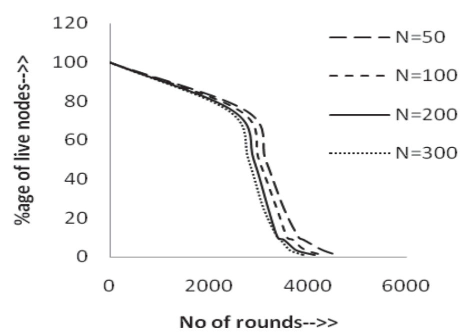

Fig. 7. %age of nodes alive after merging corresponding to total number of nodes

On comparing results in Table II and Table III we found that in the network having N=50 life time increased from 2763 rounds to 4681 rounds . For N=100 it goes from 2549 to 4391 rounds. For N=200, it increases from 2413 to 4251 and lastly for N=300 it goes from 2376 to 4019. We can see that lifetime of network is increased considerably.

V. CONCLUSION AND FUTURE WORK

In this paper we described merging algorithm which minimizes the global energy usage by making sensing nodes to work in sleep and active mode. Merging outperforms the conventional network's energy usage by uniformly distributing the load of sensing in the nodes falling in the same sensing range. Clearly our simulations show that

- Network using merging is more energy efficient than the conventional network.
- Lifetime of network using merging is increased.

The application of this type of network becomes limited in sparse deployment as the sensing range of the nodes is less. There has to be large number of nodes for feasibility of this network. Based on our MATLAB simulations we are confident that our proposed model will outperform the conventional models .Providing WSNs with such efficient models will open up a whole new horizon for us. In the future we will be working on heterogeneous network for better energy efficiency.

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