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Energy Consumption in Random Cluster Head selection Phase of WSN

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Abstract. In a hierarchal and random cluster head selection protocol of Wireless Sensor Network (WSN) the energy consumed in the cluster head setup phase has been taken ostensibly in the previous research works. In this paper this area of the protocol has been addressed and overhead energy, that is the energy consumed in the random cluster head setup phase, has been calculated. The basic model based on LEACH protocol is redeveloped to calculate the energy consumptions in the three phases of data transmissions from sensor nodes to the sink. It is shown through the extensive simulations of this model that the overhead energy is at least 20% of the network's total energy consumed in data transmissions. The optimum value of cluster heads, based on network lifetime has been calculated taking into consideration the energy consumed in the setup phase as well.

Keywords: cluster head setup phase, overhead energy, efficient energy, network lifetime.

1. Introduction

WSN is a kind of an ad-hoc wireless network consisting of spatially distributed sensors nodes and a sink. The job of the sensor nodes is to cooperatively monitor/collect data from physical or environmental phenomenon. The collected data is then forwarded to the sink, which could be wired or wirelessly connected to the main information collection centre. The development of low-cost, low-power, small size and multifunctional sensor nodes have put some of the very significant resource constraints in WSN. Some examples of limitations are buffer size, transmission capacity and energy/power consumption of the sensor nodes. A WSN lifetime is dependent on the energy of individual sensor nodes therefore efficient utilization of each node's energy is a vital issue.

A sensor node consumes significantly less energy for information processing than for communication [1]. This characteristic of a sensor node makes it important to concentrate more on reducing transmission of redundant data during the transfers of sensed information from each node to the sink. The researchers have compared and calculated many energy affecting parameters of the random cluster head (CH) selection protocols of WSN, for example LEACH[2], HEED[3] and EAP[4] etc which are called energy efficient protocols. The data transmission periods in these protocols are divided into rounds and in each round a random CH selection mechanism is performed. In this paper the over head energy consumed in the random CH selection phase has been calculated. It is shown through extensive simulations that these phases, due to the transmission of control packets, consume 21% to 32% of the total network energy, the optimum value of the CH has been calculated according to the minimum overhead energy consumption in cluster head selection phases.

The remaining paper is divided as follows .In section II a short overview of the routing techniques and developments made to reduce the energy consumption in WSN is given. In section III the approach used for

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the proposed energy model and its parameters are explained. In section IV the working of the simulated model has been explained and in section V the results and analysis of the simulated model is discussed.

2. Background

Many approaches have been adopted by the researchers in the past years to conserve the scarcity of the node energy as much as possible. Energy efficient routing techniques have been proposed to help route data within the sensor network with the hope of minimizing duplicated packets and minimizing the number of hops needed to deliver the data eventually conserving the energy of the network for as explained in [5], [6] and [7].

The hierarchal structure based protocols, have recognized to be energy efficient protocols of WSN, can be divided into two categories; cluster based for example LEACH, HEED and EAP and tree based for example TEEN[8]. In a hierarchal cluster based protocol the sensor nodes are grouped into clusters with one CH (selected among the sensor nodes) in each cluster. It is the responsibility of the CH to collect the data from its associated nodes. It may aggregate the data, and then forward it to the sink. To distribute the energy consumption load evenly among the nodes no node is selected as a permanent CH. The data transmission process is divided into rounds and in each round a new CH is selected randomly but rotationally. Each random CH selection based protocol, proposed in research literature so far, base mostly on their own means of CH selection criteria, clustering parameters, and data transfer and aggregation mechanisms. All these mechanisms are meant to improve one or more parameters like energy consumption, packet delay and throughput of the network for example in [2], [3], [4], [8], [9], [10] and [11] the energy efficiency parameters of these protocols and have been evaluated and compared.

3. Overhead Energy Calculations

Generally in any of the random CH selection protocol, the data transmissions periods are divided into rounds and in each round a random CH selection mechanism is performed .There are three phases in each round viz Setup phase, Steady State phase and Data transmission to sink phase. These phases are shown in Fig 1.

In **Setup phase**, CHs are selected among the normal sensor nodes based on certain parameters (For example nodes energy level and number of times this node has been selected as CH previously). Selected CH broadcast an advertisement message to all other nodes. All remaining nodes get themselves associated to their nearest CHs. In **Steady state phase**, during the contention period, all nodes keep their radios on. The cluster-head builds a TDMA schedule and broadcasts it to all nodes within the cluster. There are m frames and one data slot allocated to each node in each frame. Data are transferred from each node to their respective CH within the TDMA time slot previously assigned to them. In **Data transmission to sink phase**, the collected data at each CH, are forwarded to the sink. The process of selection of CH is based on the protocol shown in Fig 1.

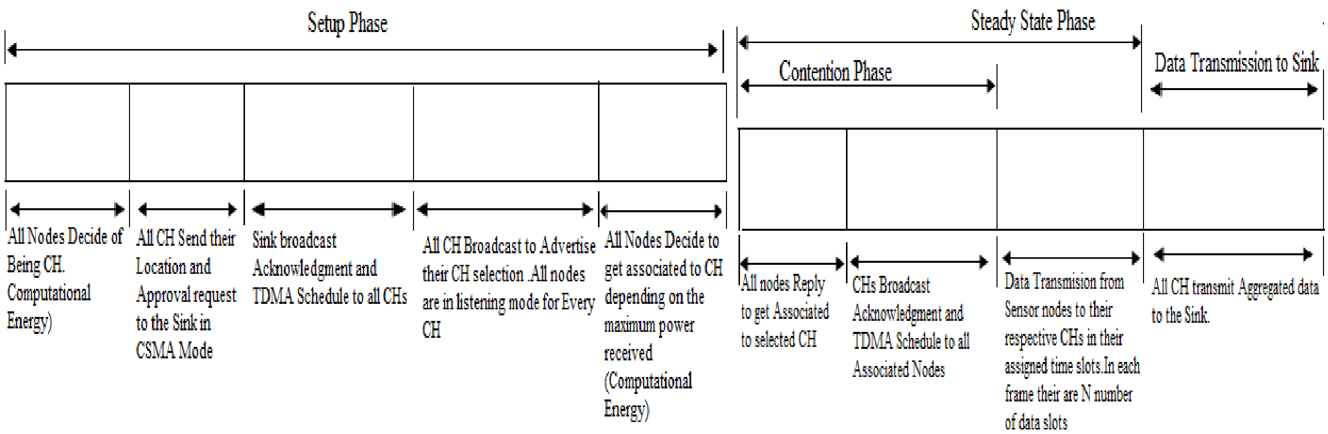

Fig. 1: Details of a) Setup Phase, b) Steady State Phase of a Random Cluster Head Selection Protocol.

Since the setup phase and contention phase are not related to the transference of data from nodes to their CH and CH to sink therefore these phases can be considered as an overhead and the energy utilized in these phases as overhead energy. To calculate over head energy, two simplified radio energy dissipation models were considered; 1) Free space model for direct line-of-sight and 2) Two-ray ground propagation model for ground reflected signals. For the distance greater than $d_{crossover}$, two-ray ground propagation model otherwise free space model is used. The $d_{crossover}$, here is taken as 87 meters [12].

The transmission ranges (Distances between receiver and transmitter) for each step in each round are calculated where d_{max}=Maximum distance of CH, to the end of the field in each round, who needs to broadcast its advertisement. d_{toCH} =Distance of each associated node to its CH and d_{toSink}=Distance of each CH to the sink. In this paper the energy model developed is based on the basic energy equations (1), (2), (3) and (4) as follows [15].

$$E_{Tx}(k,d)=E_{elec}*k+E_{amp}*k*d^2 \quad (1)$$

$$E_{Tx}(k,d)=E_{elec}*k+E_{tr}*k*d^2 \quad (2)$$

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

$$E_{Ix}(k)=\beta*(E_{elec}*k) \quad (4)$$

Where E_{Tx}=Energy consumed in transmission of data. E_{Rx}= Energy consumed in reception of data. E_{Ix}= Energy consumed in idle listening state. E_{elec} = Energy consumed by the electronics for transmitting or receiving a1-bit of data measured in (J/b). E_{amp} = Energy consumed in power amplifier in free-space model at the transmitter to achieve acceptable bit energy to noise power spectral density ratio at the receiver in (J/b/m^2). E_{tr} = Energy consumed in power amplifier in two-ray propagation model at the transmitter to achieve acceptable bit energy to noise power spectral density ratio at the receiver in (J/b/m^4).k=Number of Bits, β=Ratio of reception and Idle listening energy and d=distance between transmitter and receiver.

Different values of k such as k_d=250, k_c=25 and k_t= (k_c+N) are taken as data, control and TDMA schedule packet sizes, in bytes, respectively and N=number of nodes/cluster and m = number of data frames per round in each cluster is taken as 10. During the contention period, the communications between the cluster-head and all other nodes are accomplished by using non-persistent CSMA. A non-persistent CSMA was chosen because it gives a better throughput than 1-persistent CSMA [13]. α is the throughput of non-persistent CSMA can be given as:

$$\alpha=\frac{k_c*e^{(-a*k_c)}}{k_c*(1+2a)+e^{(-a*k_c)}}$$

For a control packet size k_c=25bytes and taking a=.001where a is the ratio of propagation delay and transmission delay, the value of α comes out to be 0.814.The radio parameters for different commercial transceivers are easily available on internet [14]. However in this simulation the values taken for E_{elec} is 50 nJ/bit and for E_{amp} and E_{tr} 10 pJ/bit/m^2 and .0013 pJ/bit/m^4 respectively [11].Initial energy given to each node, E_o, is taken as 2.5 joules. β is the ratio of reception and Idle listening Energy, taken as 0.8. [15].

4. Simulated Model

An energy model for the random cluster head selection mechanism for WSN of 100 nodes with initial area size of 100x100 m2 has been prepared using MATLAB. The sink is placed in the middle of the area. The model is able to compute the overhead energy consumed in the cluster head selection phase. The assumption made is that the receiving nodes can estimate the distances between themselves and the transmitting node depending upon the power level of the received signal. Therefore the radio powers of the nodes are adjusted according to the distances between the CHs and their associated nodes. In this simulation the effect of the overhead energy on network lifetime is calculated. The optimum value of CH percentage is obtained with the varying values of different parameters for example number of nodes, different area sizes, and different percentages of cluster heads in total number of nodes. Network energy and the network lifetime defined as "the time when first node is dead in the network", has been calculated. In the simulated model calculations per round were done for energies consumed as follows.

1. Energy consumed in CH to sink communication for the CH selection permissions

   At *CH:*

$$E_{CHsel}(k,d) = ((k_c/\alpha)*(E_{elec} + E_{amp}*d_{toSink}^{2})) + ((((\mathrm{p}*\mathrm{n})-1)/\alpha)*(k_c*E_{elec}*\beta) + k_t*E_{elec}) \quad (5)$$

α is the throughput of non-persistent CSMA. There are (p* n) average attempts per packet time, where p= maximum percentage of CH/round and n is the total number of nodes in the network.

2. Energy consumed to broadcast CH advertisement

   At CH : $E_{CHAd}(k,d) = k_c*(E_{elec} + E_{amp}*d_{\max}^{2})$ (6)

   At Associated Node: $E_{NAd}(k,d) = (\mathrm{p}*\mathrm{n})*k_c*E_{elec}$ (7)

3. Energy consumed in contention phase(When CH receives association messages from its associated nodes and then broadcasts TDMA schedule to its nodes)

   At CH : $E_{CHcon}(k,d) = N*k_c*E_{elec} + k_t*(E_{elec} + E_{amp}*d_{\max}^{2})$ (8)

N is the number of associated nodes in this cluster.

   At Associated Node:

$$E_{Ncon}(k,d) = (k_c/\alpha)*(E_{elec} + E_{amp}*d_{toCH}^{2}) + ((\mathrm{N}-1)/\alpha)*(k_c*\beta*E_{elec}) + k_t*E_{elec} \quad (9)$$

4. Energy consumed for transmitting m frames in each cluster and the aggregated data to the sink

   At CH :

$$E_{CHf}(k,d) = m*((N_i*k_d*E_{elec}) + (N-N_i))*(\beta*k_d*E_{elec}) + k_d*(E_{elec} + E_{amp}*d_{toSink}^{2})) \quad (10)$$

N_i is the number of those associated nodes who have to send the data in this round. For this simulation N_i is taken randomly, m is the number of frames.

At N Associated Node: $E_{Nf}(k,d) = m*k_d*(E_{elec} + E_{amp}*d_{toCH}^{2})$ (11)

Except 4 all other energies calculated above are considered as overhead energy. Note: For distances greater than $d_{crossover}$ the term ($E_{amp}*d^2$) is replaced by the term ($E_{tr}*d^4$) in the equations 5, 6, 8,9,10 and 11. If we take $E_{t/r}$ as the total energy consumed in one round and E_{eff} as the efficient energy per round i.e. the energy consumed in data transfer in one round and E_{oh} overhead energy consumed per round then we can say.

$$E_{t/r} = E_{eff} + E_{oh} \quad (12)$$

Let E_{OH} as the total over head energy, E_{EFF} as efficient energy and E_T as the total network consumed in R rounds then from equations 5 to 11

$$E_{OH} = \sum_{q=1}^{R} \left(E_{qCHsel} + E_{qCHAd} + E_{qCHcon} + E_{qNAd} + E_{qNcon} \right) \quad (13)$$

$$E_{EFF} = \sum_{q=1}^{R} \left(E_{qCHf} + E_{qNf} \right) \quad (14)$$

$$E_T = E_{EFF} + E_{OH} \quad (15)$$

5. Results and Discussion

An energy model for the hierarchal and random CH selection based WSN was developed in MATLAB. Fig 2. shows network lifetime decreases with the increase of area of the network, for the same number of nodes and with the initial energy Eo=2.5 Joules, given to each node. According to equation 1 and 2, it can be seen that the transmit energy of each node depends on the distance between the transmitter and receiver, therefore as the size of the network increases the distances increase consuming more energy resulting in reduced network lifetime. With a comparison of Fig 2.a. and Fig 2.b. it can be seen that when the nodes start expiring the gradient in energy level of network also starts decreasing, this is because the transmission of data is not being done successfully throughout the network therefore no energy is being utilized. Also for area=100x100 meter2 the rate of expiration of nodes are steady and slow as compared to two other cases. This is because the random dispersion of nodes in area=100x100 m2 is evenly distributed as compared to the later cases.

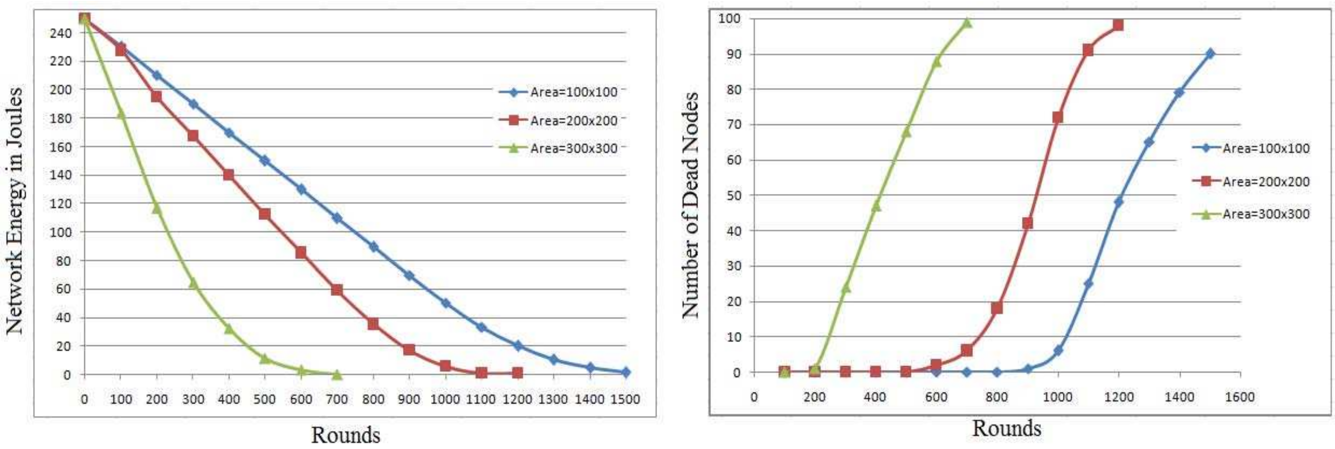

Fig. 2: a) Network Energy, b) Number of Dead Nodes for Different Sizes of Coverage Area

Table 1. shows the results obtained for different number of CH in a network of 100 nodes. From the results it can be seen that the average overhead energy consumed increases when the number of CH formed increases or decreases from an optimum value of CH percentage. Also the number of rounds in which the first node die starts increasing with the increase of CH percentage but decreases after the optimum value of CH percentage. This optimum value of CH percentage in this case is 5to 10 percent. This is because when number of CHs increases more than an optimum value say 10% of the total number of node then there are other things which start affecting the energy utilizations like number of broadcasts and transmission of control packets in contention period etc therefore energy consumed in overhead also starts increasing.

Table. 1: Average Overhead Energy of the network, and the Network lifetime, for different percentages of CHs in network

%CH formation	First Node Dead in Round Number	% Overhead energy consumed	Energy consumed in 1000 rounds (J)
1	905	74	182.1914
5	874	22	198.0256
10	937	21	198.4349

15	915	24	209.8809
20	880	26	220.8879
25	819	30	235.4284
33	738	31	243.5268

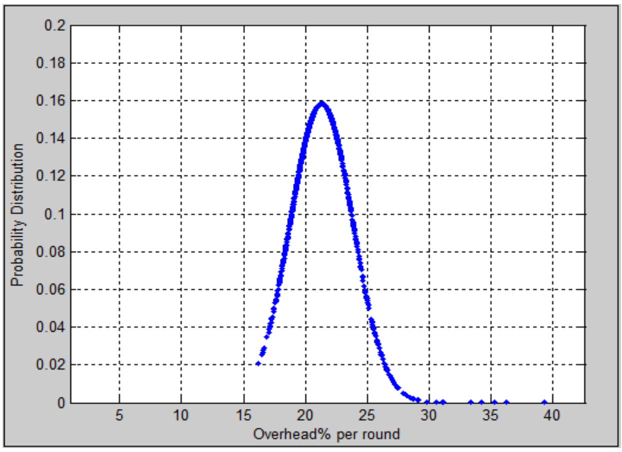

Fig. 3: Overhead energy Percentage PDF for Average CH Formation =10%

The probability distribution of overhead energy consumption at 10% average CH formation shows a stable normal distribution with a mean of 21joules and standard deviation of 2.4. From Fig 3 it can be seen that on the average 21% of the total network energy is being used only in CH selection phase for an optimum value of 10% CH formation percentage per round. Network lifetime, if defined as the time when the first node dies, decreases as the average probability of CH formation increases. From Fig 4.a. it can be seen that an optimum value of network lifetime remains constant for 10% to 14% probability of CH formation. Comparing Fig 4.a. and Fig 4.b. the optimum value can be found at 10% CH selection.

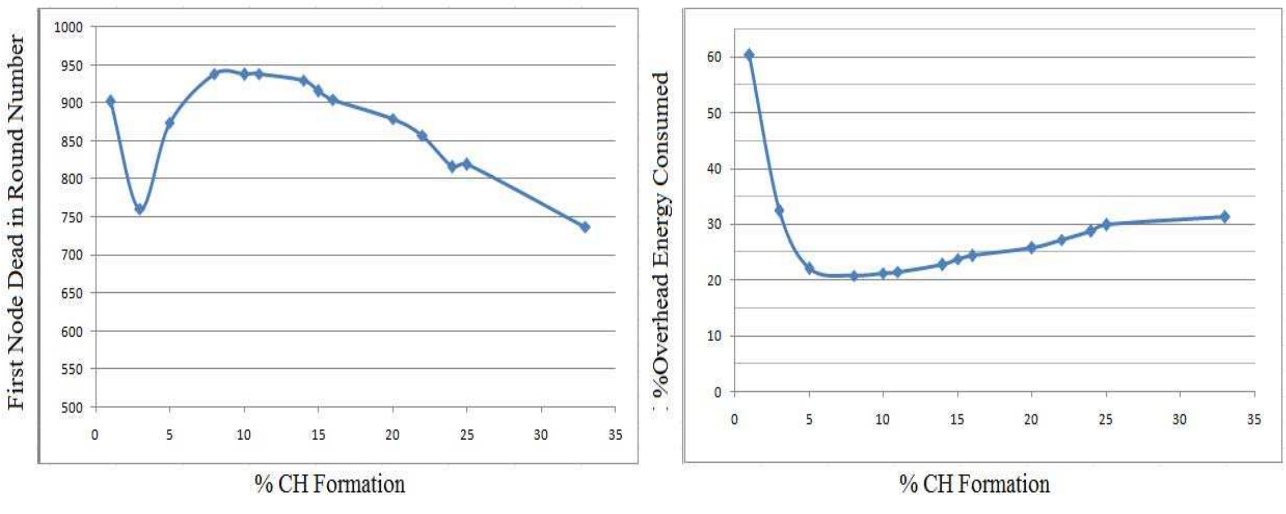

Fig. 4: a)First node dead b)Overhead energy Percentage consumed with Probability of CH Formation

6. Conclusion and Future Work

The energy consumed in a hierarchal and random cluster head selection protocols of WSN had been considered as an insignificant overhead in the previous literatures. It can be seen from the results in Table1 and Fig 4. that the overhead energy consumed in the random cluster head selection protocols takes around 20% to 25% of the total network energy consumed in the transmission of data from a sensor node to the sink. If this overhead is reduced, an increase of at least 20% of network lifetime is expected.

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