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Research Article

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Energy Efficient Analysis of a Heterogeneous Wireless Sensor Network

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Abstract This paper has presented energy efficient analysis of a heterogeneous Wireless Sensor Network (WSN). Wireless Sensor Network (WSN) can be applied for a variety of purposes such as security services in military and police operations, civilian and commercial services. The topology and routing algorithm for WSN was validated through simulation experiments conducted in MATLAB. Simulation results indicated that the overall energy consumed by the WSN topology was less than the initial energy of each node set as 2.0 J. With respect to the variation of energy consumed per traffic volume, it was observed that as the number of messages transmitted across the WSN increases, the average energy consumed per node and energy consumed by the network increases but with decreasing transmission capacity. In the case of the average energy consumed per node, the value increases from 0.0007418 J to 0.004425 J while the transmission capacity drops from 501-77 (84.6% reduction), and increases from 0.08632 J to 0.4011 J (maximum energy consumed) in terms of energy consumed by nodes with transmission capacity decreasing from 503 to 71 (85.9% drop) for 5000 messages to 30000 messages respectively.

Keywords Energy efficient, Energy consumed, Routing algorithm, Transmission capacity, Wireless Sensor Network

Introduction

In the design of Wireless Sensor Network (WSN), a set of sensors are used to monitor and measure physical quantity of interest. The networked sensors explore their physical environment for information by measuring physical parameters and therefore send the measurements to nearby central controller through a feedback mechanism.

Sensor nodes in WSN are widely spread in an area of interest for real time data gathering. These nodes carry out the function of sensing and routing devices. A number of sensor nodes may be used to transmit data from the primary source node to the destination node for example, multiple-hop communication. The destination node is regard as a sink node [1].

Every sensor node in a WSN arrangement has a predetermined amount of energy. A power subsystem is always used to power the sensors. Since each sensor in the network will have to take the energy required of it to effectively operate from this power source, an energy burden is placed on it for every action executed, which gradually reduces power of the sensor and the network in general. Certain actions in the WSN require huge amount of energy or power such as transmitting of data, while some need very small amount of power. A sensor becomes inactive once it loses power. In such situation, the sensor cannot extract information from its environment, communicate with other sensors (or nodes) or send data. Hence, the sensor at this condition is said to be dead. There may be no major impact felt on a WSN when one sensor node dies. Nevertheless, as more sensors die out, an obvious impact can be felt on the WSN and the performance of the system depreciates.

An approach to managing the energy consumption of WSN is the use of Hierarchical-based routing, which is a clustering based routing wherein nodes with high energy are randomly chosen for processing and sending data whereas the nodes with low energy are used for sensing and sending information to the cluster head (CH) [2]. The use of clustering scheme provides more efficient operation for the WSN by enhancing the energy consumption of the network and consequently prolongs the lifetime [3].

There are basically two types of WSNs where clustering can be done on the basis of energy namely, homogeneous and heterogeneous networks. Homogenous sensor networks are the ones in which the nodes have the same initial energy while for the heterogeneous type; the nodes have different initial energy [2].

This paper focuses on analyzing the energy efficient of heterogeneous wireless sensor network based on the volume of message or traffic in WSN network that uses clustering based protocol. The remaining part of this paper has been divided into: energy conservation in WSN, method, simulation results, discussion and conclusion.

- Energy Conservation in Wireless Sensor Network

One way to ensure that the life of a WSN is prolonged is to devise a means of reducing the energy consumed by the nodes in the network. Thus, energy management in WSN is an important issue because all the nodes take up the energy required of them to operate optimally from a limited battery source. As a result of this problem, the design of energy efficient algorithm for WSN has attracted the attention of many researchers. This has brought about the development of different schemes to save the limited energy of the nodes and thereby extending network's lifetime [4, 5].

Sensors use their energy for sensing and processing of that and also for sending and receiving of data. More energy are used when a node (subsystem) is transmitting to or communicating with another node (subsystem) than during sensing and processing within a subsystem. It has been shown that shown that transmitting a bit of data may take as much energy as executing a few thousand computational instructions [4]. Thus, it is important that energy efficiency be targeted on the communication aspect of the nodes since minimal gains are realized by optimizing the energy of the sensing and processing nodes.

There are basically three broad categories of energy efficient routing protocols for WSN namely: data centric protocols, hierarchical or clustering based protocols, and location or geographical protocols [6]. Data centric routing scheme uses an algorithm that is query driven to reduce the amount of data transmitted and is able to amass data while sending it to the sink. Sensor Protocol for Information via Negotiation (SPIN) is the foremost data centric protocols [7]. For the hierarchical or clustering based model, the best is the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol [6]. The direct diffusion determines routes from many sources to a single destination which permits in-network consolidation of redundant data [5, 6].

These three energy efficient routing algorithms have become common performance reference point such that most of the energy efficient routing studies are designed to improve their performance. Table 1 shows the comparison of some of the parameters that are used to evaluate SPIN, LEACH and direct diffusion protocols.

Table 1: SPIN, LEACH and Directed Diffusion Comparison [3]

	SPIN	**LEACH**	**Directed Diffusion**
Optimal	No	No	Yes
Network lifetime	Good	Very good	Good
Resource awareness	Yes	Yes	Yes
Use of meta-data	Yes	No	Yes

- Low Energy Adaptive Clustering Hierarchy

LEACH is a clustering based energy efficient routing protocol that tends to reduce energy consumption in sensor networks. In this scheme, sensors form clusters and elect cluster heads (CHs). These CHs are now responsible for transmitting data to the sink node. This way, nodes within a cluster achieved energy savings by only sending data to thereby CH. The CHs are rotated by the LEACH to assign or allocate energy requirements among all the sensors. In addition, local computation of each CH is done by the LEACH to minimize the amount of data that should be sent to the sink. This way, both energy and bandwidth are conserved.

Materials and Methods

The modelling of the network is done in MATLAB based on the following assumptions made for the network topology and operation:

Setting the simulation: the WSN model that is used for simulation purpose in this paper has area of 100m×100m representing the network field consisting of N number of sensor nodes.

Placement of nodes: the nodes are randomly distributed throughout the network field.

Sending of data: the nodes always have data to transmit to the sink node.

Placement of sink node: the sink (base station) positioned in this paper in the x and y coordinates given by (x,y) = (50m,50m).

The flowchart for the implementation of WSN model MATLAB based on the information provided is shown in Figure 1. The designed model is shown in Figure 2.

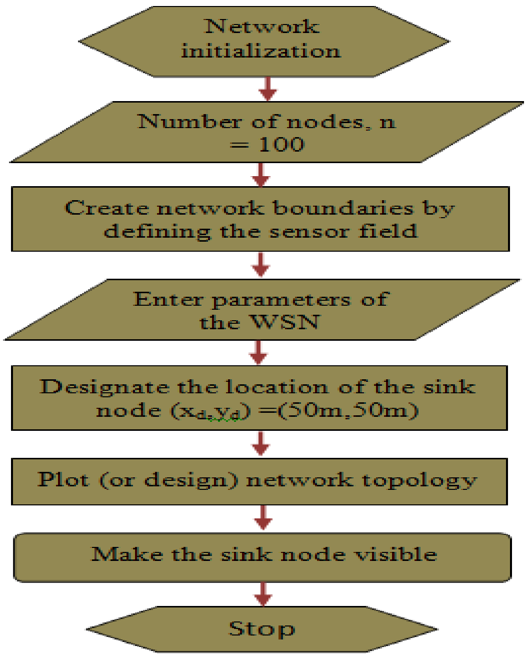

Figure 1: Flowchart of WSN topography design

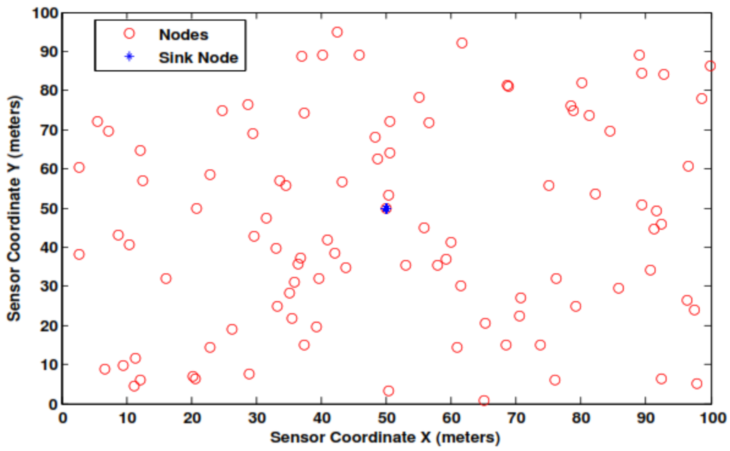

Figure 2: Random WSN topology

- Sensor Nodes

Sensor nodes are of three types [8, 9] and are normal nodes, advanced nodes, and supper nodes [2]. Given N total of nodes, let s be the percentage or fraction of the total number of nodes N, and s_o is the fraction of the sum of the number nodes that are provided with r times more energy than the normal nodes called super nodes (with the number $N \times s \times s_o$). Let the number of advanced nodes be $N \times s(1-s_o)$ are provided with q times more energy than the normal nodes while the remaining fraction be $N(1-s)$ for the normal nodes.

Mathematically, the total initial energy of the three-level heterogeneous network is given by [2]:

$$E_T = N(1-s)E_o + Ns(1-s_o)(1+q)E_o + N \times s \times s_o \times E_o(1+r)$$
$$= N \times E_o[1 + s(q + s_o r)] \quad (1)$$

Thus, the three-level heterogeneous networks have $s(q + s_o r)$ times more energy.

- Clustering and Cluster Head Selection

Clustering is a normal process for achieving efficient and sizeable performance in sensor networks. When nodes are clustered into groups, energy is conserved and aids the distribution of control over the network [10]. In order to form clusters, sensor nodes must first select a cluster head (CH) for each cluster. Nodes that are not CHs in the WSN find the closest CH within range and become a cluster member. The nodes in a cluster only interact with one another and the CH. Data sensed by a sensor node within a cluster is sent to the CH. The routing and communication external to a cluster is done by CH.

Every sensor in the WSN may choose to become a CH with a predetermined probability p when the network is installed. There is not an optimal number of CHs for a WSN. For each topology the clustering process must guarantee that no nodes become separated and that there are no more clusters than required as surplus clusters decrease the energy savings produced from clustering.

An iterative process is used to balance the competing demands of preventing separation and accomplishing energy efficiency. The probability (a value between 0 and 1) of a sensor node choosing to become a CH is p. This value was determined so that most of the CHs are chosen in the first iteration, while the additional two iterations serve to guarantee that no sensor node is separated in the WSN. If the probability is less than a threshold the node becomes a cluster head. Figure 3 is sensor network configuration with cluster head formation.

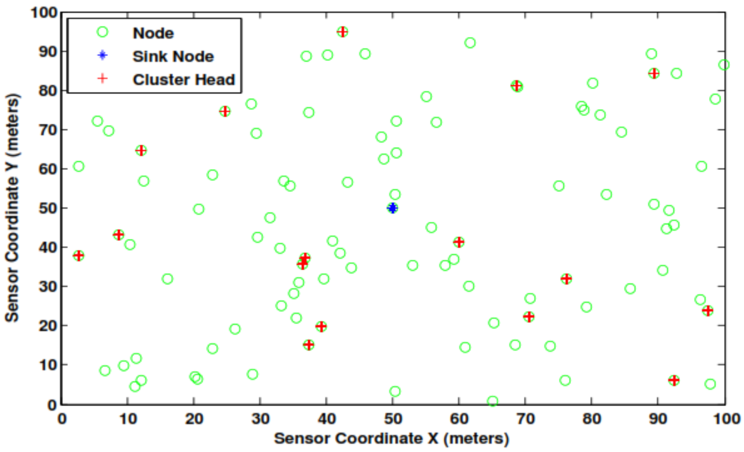

Figure 3: Sensor network with cluster head

During the operation of the network, the threshold value T_h for a sensor node SN(i) to belong to a cluster is given by:

$$T_h = \frac{p}{1 - p \times (\mathrm{mod}(rnd, 1/p))}, \quad \text{otherwise } T_h = 0 \tag{2}$$

where p is the desired fraction or percentage of CH, rnd is the current round number.

For the three-level heterogeneous networks with three types of nodes, the reference probabilities p is different for normal, advanced and supper nodes are chosen for each class of sensor node and defined by [2]:

$$p_i = \begin{cases} \dfrac{p_{opt} E_i(rnd)}{(1 + s(q + s_o r))\bar{E}(rnd)}, \text{ for normal node, SN(i)} \\ \dfrac{p_{opt}(1+q) E_i(rnd)}{(1 + s(q + s_o r))\bar{E}(rnd)}, \text{ for advance node, SN(i)} \\ \dfrac{p_{opt}(1+r) E_i(rnd)}{(1 + s(q + s_o r))\bar{E}(rnd)}, \text{ for super node, SN(i)} \end{cases} \tag{3}$$

Therefore, for the heterogeneous network with i-th class of sensors, a node in each class will become a cluster member in accordance to the T T_{hi} threshold value defined by:

$$T_{hi} = \frac{p_i}{1 - p_i \times (\mathrm{mod}(rnd, 1/p_i))}, \quad \text{otherwise } T_{h_i} = 0 \tag{4}$$

Note E_i is the energy of i-th sensor node, SN(i) during the current round operation, $\bar{E}$ is the average energy calculated for each round (rnd) and is given by:

$$\bar{E}(rnd) = E_o[1 + s(q + s_o r)]\left(1 - \frac{rnd}{R}\right) \tag{5}$$

$$\text{And } R = \frac{E_T}{E_{rnd}} = \frac{N \times E_o[1 + s(q + s_o r)]}{E_{rnd}} \tag{6}$$

Energy dissipated by i-th sensor node SN(i) in a cluster while transmitting data to cluster head (CH) is given by:

$$E_i = E_{elec} \times k + E_{amp} \times k \times SN(i) \times d_{tch}^2 \tag{7}$$

where d_{tch} is the distance between the i-th sensor node, SN(i) in a cluster transmitting data to the CH and is given by:

$$d_{tch} = \sqrt{(d_{chx} - d_{SN(i)x})^2 - (d_{chy} - d_{SN(i)y})^2} \tag{8}$$

The energy dissipated by cluster head node while transmitting data to sink node with respect to SN(i) is given by:

$$E_{i\text{-}ch} = (E_{elec} + E_{DA}) \times k + E_{amp} \times k \times SN(i) \times d_{tsink}^2 \tag{9}$$

where d_{tsink} is the distance between the sink and the CH and is given by:

$$d_{tsink} = \sqrt{(d_{sinkx} - d_{SN(i)x})^2 - (d_{sinky} - d_{SN(i)y})^2} \tag{10}$$

where x and y means the horizontal and vertical coordinates of the WSN.

The energy dissipation for CH during reception is:

$$E_{RX} = (E_{elect} + E_{DA}) \times k \tag{11}$$

The total round energy dissipated E_{md} is the sum of all the energy dissipated by i-th sensor node SN(i) in the network during transmission and reception.

- Simulation Parameters

The description of the parameters used for the simulations conducted for up to 30000 number of bits transmitted in WSN and their values are presented in Table 2.

Table 2: Simulation parameters

Parameter	Value
No of sensors (n)	100
Area	100 m by 100 m square
Transmit power	5.0×10^{-8} J/bit
Receive power	5.0×10^{-8} J/bit
Processing power	5.0×10^{-9} J/bit
Initial Energy of sink node	2.0 J
Initial Energy of Each node	2.0 J
Traffic generation messages	5000 to 30000
No of threshold nodes	20
Sink node coordinate	(x,y) = (50m, 50m)
p_{opt}	20%
Amplifier energy (E_{amp})	0.1×10^{-9} J/bits/m^2
E_{DA}	5×10^{-9} J/bit

Results & Discussion

This section presents the simulation results obtained in terms of the simulations conducted in MATLAB. The probability of a sensor node to become a CH was taken was chosen as 0.2. Simulation was carried out in terms of the energy efficiency of the Wireless Sensor Network and the operational nodes for different generated traffics that is, 5000 messages to 30000 messages. Figures 4 through 7 is performance plots in terms of operational nodes per transmission, operational nodes per round, average energy consumed by a node per transmission, and total energy consumed by nodes per transmission. Also, Tables 3 to 6 presents the performance analysis of each simulation plots.

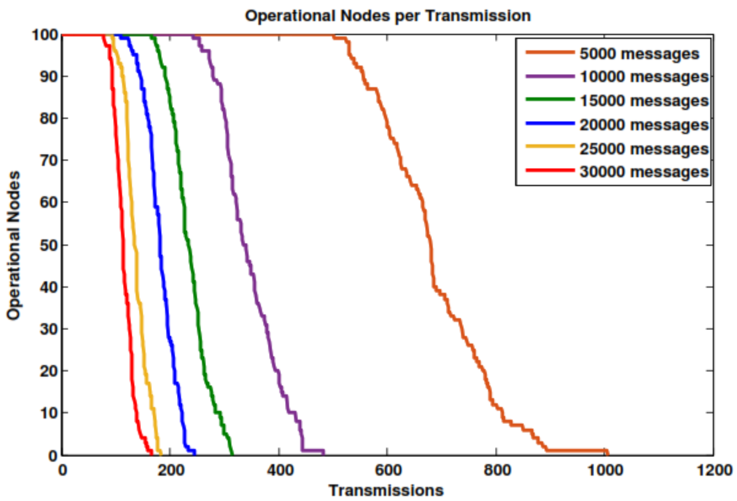

Figure 4: operational nodes per transmission

Table 3: Analysis of operational nodes /transmission

Message	Operational nodes	Transmission
5000	100	1005
10000	100	479
15000	100	316
20000	100	256
25000	100	181
30000	100	154

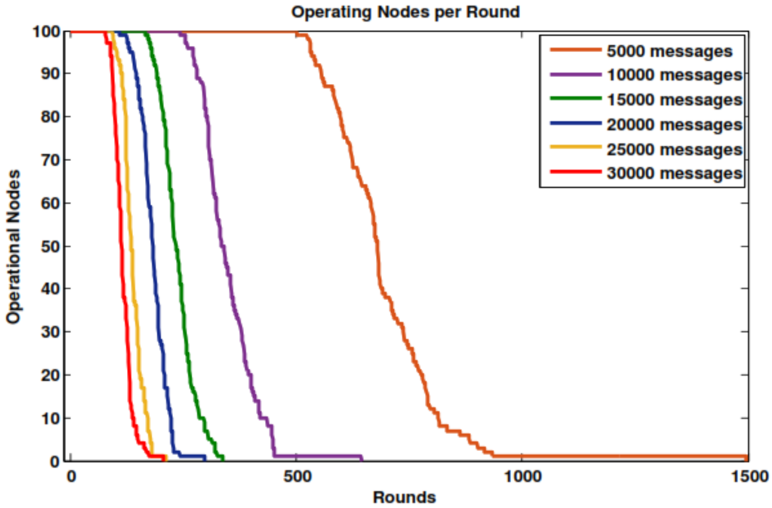

Figure 5: Operation nodes per round

Table 4: Analysis of operational per rounds

Message	Operational nodes	Round
5000	100	1449
10000	100	561
15000	100	342
20000	100	296
25000	100	186
30000	100	168

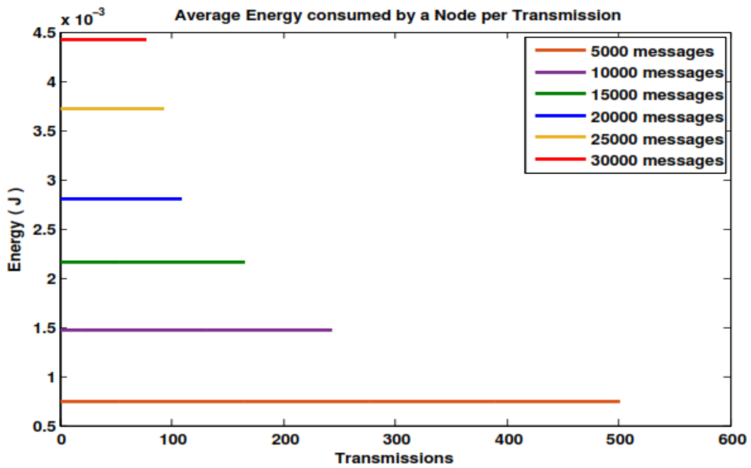

Figure 6: Average energy consumed by a node per transmission

Table 5: Analysis of Average energy consumed by node /transmission

Message	Ave. Energy consumed (J)	Transmission
5000	0.0007418	501
10000	0.001475	243
15000	0.00216	165
20000	0.002809	109
25000	0.003714	93
30000	0.004425	77

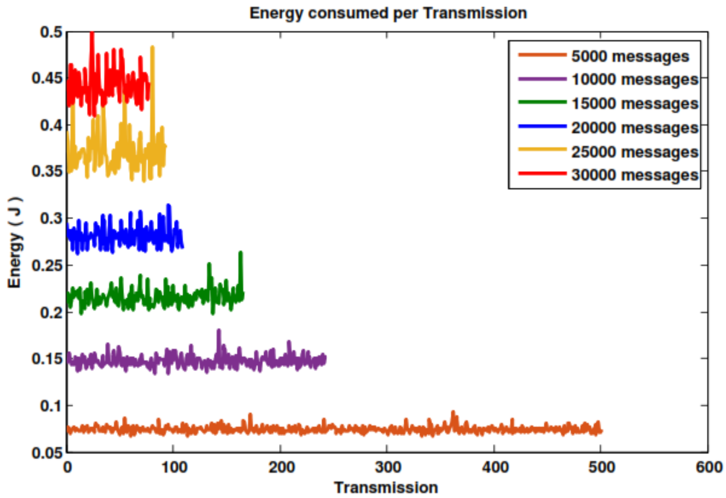

Figure 7: Energy consumed per transmission

Table 6: Analysis of energy consumed /transmission

Message	Energy consumed (min) (J)	Energy consumed (max) (J)	Transmission
5000	0.06582	0.08632	503
10000	0.1318	0.1693	251
15000	0.1921	0.2409	174
20000	0.2694	0.3346	130
25000	0.3356	0.4211	93
30000	0.4011	0.4814	71

The values of the average energy consumed by a node and the energy consumed by nodes in WSN can be deduced from Tables 5 and 6. It can be seen that the transmission and operational rounds of the WSN nodes decreases as the volume of traffic increases. Also an obvious uniformity of the average energy consumed by a node in the WSN can be seen based on the six simulation scenarios carried out and increases as the traffic volume increases across the WSN. Similar pattern is also followed for the energy consumed by nodes, which increases as the traffic volume increases across the WSN. Generally, the trend in increasing energy consumed with increasing messages holds for various simulation trials.

The number of messages the energy consumed node sends through the WSN is usual when compared to other values at the same traffic volume. The number of times the energy consumed node serves as a cluster head (CH), broadcast CH and the sink node's CH is the highest at the six simulations trial when 30000 messages are sent and thereby driving energy consumed in the WSN higher. The second highest energy consumed node is registered during the transmission of 25000 messages through the WSN and also carries out the role of cluster member, CH, broadcast CH and the sink node's CH in a similar way with 93 number of transmission time with less energy consumed compared with the 30000 messages where number of transmission time was 91 with higher energy consumed node as shown in Table 6.

Generally, the simulation results obtained in terms of average energy consumed by a node and the total energy consumed by nodes in the WSN with respect to different traffic volume as shown in Tables 5 and 6 show that at every simulation trial representing the operation of sensor nodes in the network, the average energy and energy consumed are less than initial energy value of sensor node which is 2.0 J. Therefore, it can be said that the energy is efficiently utilized by the WSN. However, with reduced transmission capacity. That is as the number of traffics increases transmission capacity decreases. The transmission capacity drops by 85.9% from transmission capacity of 503 for 5000 messages to 71 for 3000 messages.

Conclusion

MATLAB programme and simulations carried out were used to analyse the energy efficiency of a heterogeneous WSN. It can be seen that there exists uniformity in the trend of energy consumption in the network and this indicates the realistic nature of the network model of a Wireless Sensor Network (WSN).

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