Energy Consumption and Network Performance Analysis of WSN using LEACH Protocol

Hammad Ullah Siddiqui, Rehan Qureshi, and Samia Aijaz

***Abstract*—Wireless Sensor Networks (WSN) consist of a large number of sensor nodes that collect data from the environment and send it to a base station (sink). One of the important limiting factors of a WSN is the energy of its sensor nodes that limits the lifetime of a WSN. As the nodes have limited power, some networks use clustering to conserve power. Low Energy Adaptive Clustering Hierarchy (LEACH) protocol is one such protocol that forms clusters of nodes in WSN for energy conservation. However, cluster formation itself can be an energy consuming process. In this paper we examined LEACH protocol in simulated environment to analyse its energy consumption. In addition, we have also analysed network performance with different traffic loads, node densities and sizes of WSN in terms of area. The results present significant insights into the working of LEACH protocol and the trade-offs between different parameters. The results depict that LEACH protocol consumes significant energy even when the nodes send no data. Also, the optimum CH percentage values for LEACH at different packet rates are between 5 to 10 percent.**

***Index Terms*—WSN, LEACH, Network Lifetime, Overhead Energy, Energy Consumption, Network Performance**

I. INTRODUCTION

Wireless Sensor Network (WSN) is a type of an ad hoc network that consists of small devices that are called sensor nodes. These sensor nodes are deployed over a geographical area to collect data from physical environment such as temperature, sound, vibration, pressure, motion and so on. The collected data is then forward to the main information collection centre called the sink [1]. Typically, a sensor node includes three basic components: a sensing subsystem to acquire data from physical surrounding environment, a processing subsystem that performs data processing and data storage, and a wireless communication system for the transmission of data.

The low cost, small sized and low power sensor nodes are capable to perform multifunctional tasks that put significant resource constraint in a WSN.

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In order to make an ideal wireless sensor network, the network should also have location-based awareness and attribute based addressing features [2]. Attribute based addresses are typically used in sensor networks; they identify the parameters to be sensed which are composed of a sequence of attributes. Where as in location awareness, the data collected by sensors are based on their location; the nodes should know their positions whenever needed. The requirements and others put additional load on already limited resources of a sensor node.

In a WSN the role of energy is of immense importance because the nodes typically use batteries that limits the lifetime of nodes and network. It may not be possible to change or recharge the batteries because sensor nodes may be deployed in inaccessible environment. So, any sensor node should have enough lifetime to fulfil its application requirements for which it is deployed. The lifetime of a WSN depends on the energy of each sensor node. Therefore energy consumption of individual node is very important.

It has been observed in the literature that the sensor nodes consume significant amount of energy during transmission of sensed information instead of data processing [1]. So it is important to reduce the transmission of redundant sensed data to sink by efficient deployment of Cluster Heads (CH) in a network. In dynamic CH selection protocols, the CHs are selected in every round dynamically. Also the Data transmission is divided in rounds from sensor nodes to CH according to the time allotted by CH to its associated nodes.

This paper considers Low Energy Adaptive Clustering Hierarchy (LEACH) protocol and presents the scenarios to calculate sensor nodes overhead energy consumption, network lifetime, optimum CH percentage and packets delivery ratio in different areas by changing node density and data rate. Extensive simulation shows that as node density of same area size increases, energy consumption of network decreases which increases the lifetime of a WSN network. Also it is seen that at optimum CH percentage, energy consumption of a network is minimum. But when the CH percentage of a network increases from an optimum value, energy consumption increases which significantly reduces the lifetime of a network.

The sensor network architecture consists of one sink node (or base station) and a large number of sensor nodes

 ISSN – 1999-4974

deployed over a geographical area to sense the field. Sensor node sends data to sink through multi-hop communication pattern or model [3]. In this paper, we have simulated a static sensor network in which both sensor nodes and sink are static.

II. Overview

In wireless sensor networks routing is one of the challenging tasks due to the dynamic nature of the sensor nodes and their unique characteristics, certain design issues and resource constraints. Many routing protocols are proposed in literature to overcome these challenges but among these protocols the hierarchical or cluster based protocols are the most energy efficient and scalable one; they also help to prolong the network life.

The hierarchical architecture comprises of sensor nodes with different functionalities and roles (heterogeneous nodes can be classified as cluster head (CH) and non-head nodes). In these protocols, the transmission of data periods are divided into rounds and selection of random CH mechanism is performed in each round.

Further discussed are the issues and the routing models that are used in a Wireless Sensor Network.

A. Issues in WSN

The major issues and challenges that affect the WSN systems and applications are discussed in [4] [5], we summarize them below.

1) Hardware limitation: To optimize the maximum output by using limited amount of hardware resources is one of the biggest challenges of sensor networks. As each node in WSN has limited energy supply, bandwidth, processing, storage and communication capabilities.

2) Limited Networking support: In WSN, peer to peer network is used with mesh topology. This network is dynamic, mobile and equipped with unreliable connectivity and no routing protocol has been used. Therefore, nodes themselves act as both an application host and a router.

3) Limited software deployment support: Typically in WSN the tasks are real-time and massively distributed dynamic collaboration among nodes and handle multiple competing events. Local instructions specify the global properties. Because of the coupling between the system layers and applications, the software architecture must be co designed with the information processing architecture.

Wireless sensor networks use variety of applications and to impact these applications in real world environment, and we require more affecting algorithms and protocols.

B. Routing Models

The following three models describe the routing protocols that facilitate the implementation and analysis of the protocol that has been taken into the account of this paper.

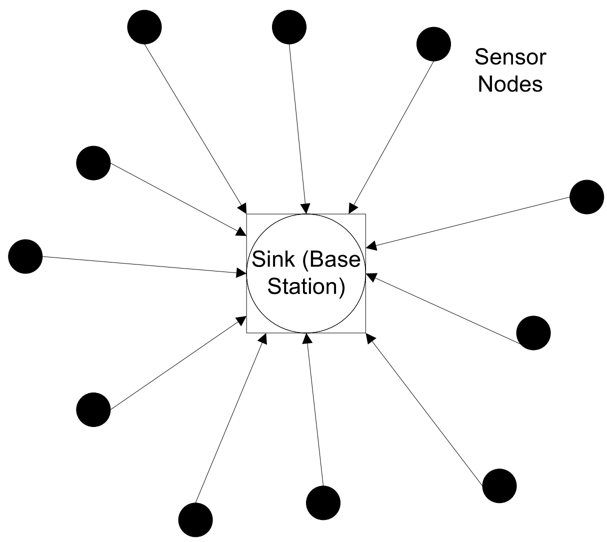

Fig. 1. One Hop Model [2]

1) One hop Model: This is the simplest approach that represents the direct communication. In this network, every node communicates and transmits data directly to the sink node (base station) [2]. This communication is infeasible because nodes consume too much energy. They have limited transmission range. Nodes, which exist in a network of large area, their coverage is usually far enough from the base station and their transmission signals do not reach the base station. Therefore direct communication of nodes with the base station is not feasible in WSN routing.

2) Multi-hop Model: In this model, a node transmits its data to the Base station by forwarding it to one of its

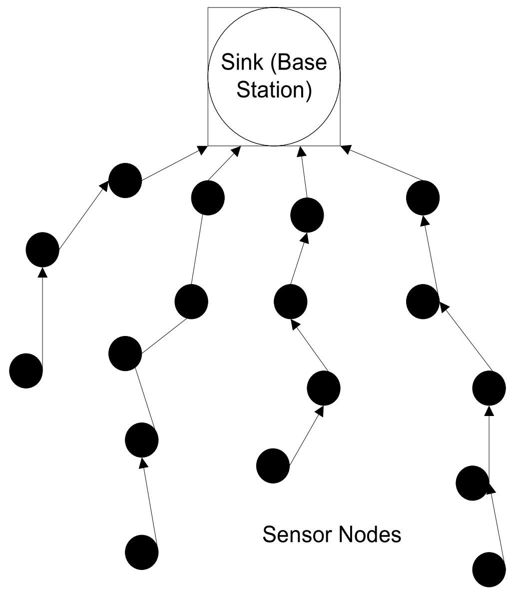

Fig. 2. Multi-hop Model [2]

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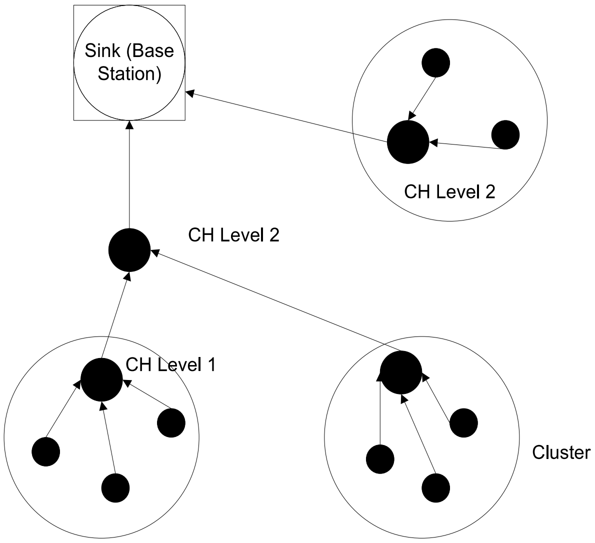

Fig. 3. Hierarchical Clustering Based Model [2]

neighbors which is closer to the base station. Latter nodes pass that data to a neighbour which is even closer to the base station as shown in figure 2. Therefore information travels from source node to the sink on hop basis from one node to another until it reaches the destination. This model is feasible regarding node energy consumption and transmission range. Protocols that employ this approach use some optimization techniques to enhance the application model [2] [6]. Data aggregation is one of the techniques used in all clustering based routing protocols. These techniques improve the performance of this model but it is still a planner model.

Network, which consists of thousands of sensors, increase the packet latency because it requires more time for the information to be delivered to the base station from a particular node.

3) Hierarchical Clustering based Model: A Hierarchical approach breaks the network into several areas called clusters as shown in 3. Nodes are grouped into clusters with a Cluster Head (CH) depending on some parameters [2]. Packet latency of this model is much less than the multi hop model that results in more efficient and well-structured network topology. This model is more suitable than previously discussed one hop or multi hop models. We used this model in our research work to identify efficiency of this model.

C. LEACH Protocol

Low Energy Adaptive Clustering Hierarchy (LEACH) is a cluster based hierarchical routing protocol for WSN. It makes nodes partition into clusters as shown. In each cluster a dedicated node called Cluster Head (CH) is selected, which has extra privilege and its responsibility is to create a Time Division Multiple Access (TDMA) schedule. The remaining nodes become the member of CH and starts sending data to the CH. The CH aggregates that data which it receives from the nodes and forwards it to the Base Station (Sink) [3] [7].

These Sensor nodes usually use irreplaceable power which enables limited computing capacity, communication and storage that requires conserving the energy. It is the main objective of any WSN to maximize the lifetime of a network. LEACH is also called an energy efficient communication protocol that deploys a clustering approach. The Cluster Head (CH) and cluster membership of nodes is periodically changed to minimize the energy consumption of nodes. The adaptation of clustering is quite a feasible choice to achieve the longevity for a network.

LEACH is an application specific protocol that supports the monitoring of remote environment in WSN. Data collected by sensors are correlated to each other and this redundant data is not required at sink. Sink only requires information that describes the occurrence of events in an environment. Nodes that are located near each other have strong correlation between the data signals that are sent to sink. For minimizing this, LEACH protocol is used which consist of Clustering infrastructure. Due to this, nodes process all its sensed data locally and reduce the transmission of redundant data by using data aggregation techniques at CH [8] [9]. Therefore, less data transmission is required from CH to sink that also minimizes the energy consumption of nodes.

In LEACH protocol the Sensor nodes send information to the CH, the CH then aggregates that information and forwards that information to the sink. The random rotation of CH makes energy consumption of a CH to be uniformly distributed among different nodes of the network. However, there is a possibility that LEACH may choose large number of CHs or select the CH randomly that has large distance from sink without considering remaining energy of the

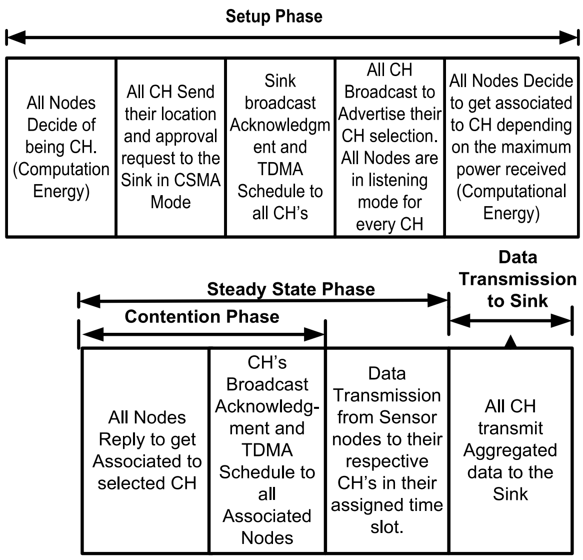

Fig. 4. Random CH selection protocol setup and steady state phase

 ISSN – 1999-4974

nodes. This results in draining of the energy of CHs, which reduces the lifetime of a WSN [10]. For formation of clusters in each round, the network requires to follow two steps to select the CH for cluster and transfer the aggregated data.

1) Setup Phase: Every node of a cluster decides whether it wants to become a CH or not, independently of other nodes. This judgment is based on when did the last time node served as a CH (the node that has not become a CH from a long period of time is expected to become elected as a CH than the node that had been recently selected as a CH) [3].

After the CH selection phase then in the announcement phase, the elected CHs update their neighbours by sending an announcement packet that they become a CH. Nodes which are non-CH accept the advertised packet of that CH from whom they received the strongest strength signal [3]. Next in the cluster association phase, the nodes report to their CH that they are associating or becoming a cluster member by sending a packet called Join packets which contains the IDs using carrier sense multiple access (CSMA). After setup phase of clusters, CH knows their associated nodes and their IDs [3].

2) Steady State Phase: In steady state phase, CH creates a Time Division Multiple Access (TDMA) schedule based on the messages received within the cluster. It randomly selects a CSMA code and broadcast TDMA schedule to the member nodes associated within the cluster. Transmission of data starts by nodes in their allocated TDMA slots and each node sends their data to its CH [1]. Minimum amount of energy is used in this transmission (based on the strongest CH advertisement signal which it received). The radio of each node of a cluster remains turned off until the allocated TDMA slot of nodes come; this minimizes the energy consumption of nodes [3].

When the CH receives all the data from its member nodes in the cluster, it aggregates that data and sends it to the sink. LEACH performs data aggregation in each cluster locally in order to minimize the amount of data transmitted to the BS [3] [1] [10].

The transfer of data from each node to CH and then CH to sink is not related to setup and contention phases. Therefore, setup and contention phases are measured as an overhead phase and consumption of energy in these phases are considered as overhead energy.

III. Simulation Design and Results

If In this paper we have evaluated LEACH protocol and analysed its performance in a WSN using Castalia and OMNeT++ [11]. There are different area sizes of networks used in our simulations as shown in table I, with different node densities and packet rates. The sink is placed in the centre of an area.

TABLE I. Overview of Simulation Parameters

Area (m^2)	Node Density	Number of Nodes	CH Percentage	Packet Rate
100 × 100	0.001	10	5, 10, 15, 20	0, 0.5, 1
	0.005	50		
	0.01	100		
150 × 150	0.001	22	5, 10, 15, 20	0, 0.5, 1
	0.005	112		
	0.01	225		
200 × 200	0.001	40	5, 10, 15, 20	0, 0.5, 1
	0.001	200		
	0.01	400		

In table I, it can be seen that for Area 100×100 m^2, when node density of a network is 0.001, 0.005 and 0.01, its corresponding number of nodes in a network are 10, 50 and 200 respectively. As area of the network increases to 150×150 m^2 on the same node densities, number of nodes in the network increases to 22, 112 and 225. Further increase in area size to 200×200 m^2 makes the number of nodes in the network increase to 40, 200 and 400 corresponding to node density of a network.

Each network with same node density (number of nodes) has been simulated with different CH percentages (5, 10, 15, and 20) and packet rate (0, 0.5, and 1). This will make us identify the optimum CH percentage of a network and packet delivery ratio that helps to find the performance of a sensor network.

A. Energy Consumption

Figures 5, 6 and 7 are showing the results for energy consumption of a WSN in different area size networks,

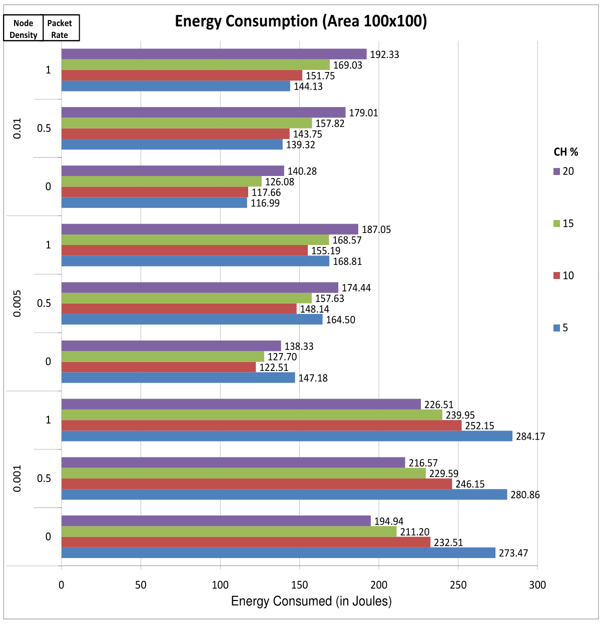

Fig. 5. Energy Consumption in Area 100 × 100 m^2

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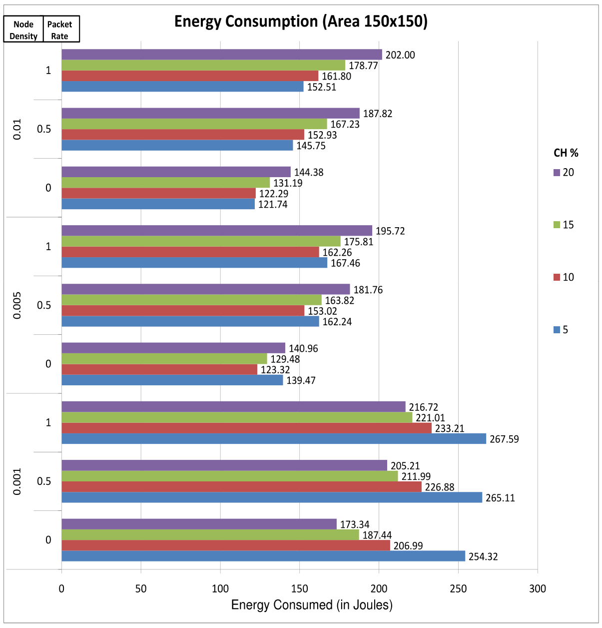

Fig. 6. Energy Consumption in Area 150 × 150 m^2

node density and packet rate as discussed in section III. Every node consists of 2 AA batteries whose initial energy is 18720 joules. The sensor nodes are distributed uniformly over the sensor area. The CH optimum percentage value is obtained by varying values of different parameters like area size, node density, and different percentages of CH in sensors network. Network energy and network lifetime has also been calculated. The Network lifetime is defined as the time when the first node dies in a network.

In figures 5, 6 and 7, it can be seen that when a node density of a network is 0.001, the energy consumption is high at CH= 5%. But as the CH percentage of a network

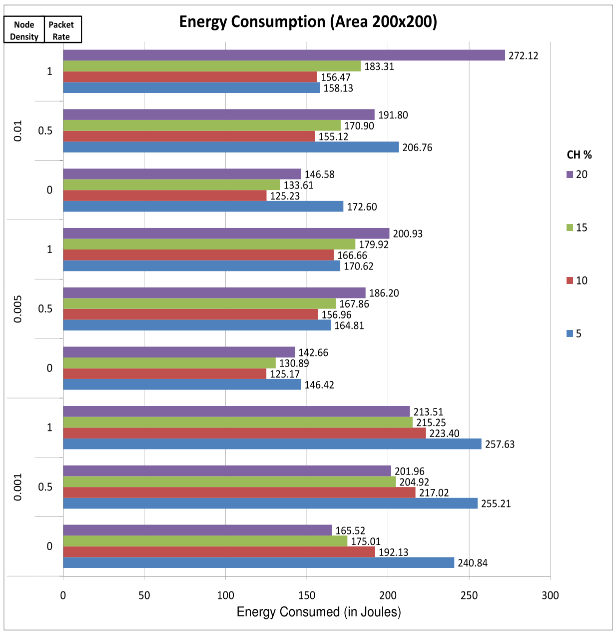

Fig. 7. Energy Consumption in Area 200 × 200 m^2

increases, energy consumption of nodes decreases. This is because when the CH percentage and the node density of a network are small, the distance between the nodes and CH is large. Furthermore the transmission energy of the nodes depend upon the distance between the sender and the receiver nodes (for details please see [1] [12]). Due to this reason a sensor node consumes greater amount of energy during data transmission from a node to its CH and CH to the sink. As CH percentage of a network increases, it increases the number of clusters in a network and decreases the distance between source nodes and CH. This reduces the energy consumption of nodes and requires small amount of energy during transmission of data from node to CH and CH to sink. This shows that CH = 20% is an optimum CH percentage value, when the node density of a WSN is 0.001 in an area size of 100×100 m^2, 150×150 m^2 and 200×200 m^2.

When the node density of a network (100×100 m^2, 150× 150 m^2 and 200×200 m^2) increases to 0.005, this increases the number of nodes in a network. Thus energy consumption of a nodes is maximum when CH= 20% and is optimum at 10%. Now if we increase the CH percentages from 10% to 15% and 20% this makes the energy consumption of nodes increase because multiple nodes of different clusters sensed the same event data and also transmits that data to their CH, the CH then aggregates and transmits the same redundant information to sink. This causes unnecessary energy consumption of nodes that results in decrease of the network lifetime [1] [13]. So, this shows that CH = 10% is an optimum CH percentage, when node density of a WSN is 0.005 in an area size of 100×100 m^2, 150×150 m^2 and 200×200 m^2.

If the CH percentage remains same and node density of a network increases, this also increases the number of CH in a network according to the node density of a network. Like, when CH = 5%, the number of CHs are greater in a network when node density is 0.01 as compared to the number of CHs that exist in a network when the node density is 0.005 or 0.001.

When node density of networks (100×100 m^2, 150×150 m^2 and 200×200 m^2) increases to 0.01, this further increases the number of nodes in a network. The energy consumption of nodes is minimum at CH = 5% of 100×100 and 150×150 m^2 area networks, and minimum at CH =10% of 200×200 m^2 network. This is because when the distance between the sensor nodes and CH is small, node consumes less energy for transmission of its sensed information to sink. The energy consumption of an area 200×200 m^2 is high at CH = 5% because it covers large physical area, and the distance between source nodes and CH is greater as compare to other two networks. Due to this node consumes greater amount of energy during transmission of data to the sink. As we increase the CH percentage of a network from an optimum value as shown in figures 5, 6 and 7, the energy consumption of nodes increases because it increases the

 ISSN – 1999-4974

Latency Percentage (Area 100x100)

Packet Rate	Node Density	CH Percentage	[0,20)s	[20,40)s	[40,60)s	[60,80)s	[80,100)s	[100,120)s	[120,140)s
		5	99.08%	0.00%	0.00%	0.00%	0.13%	0.79%	0.00%
		10	99.16%	0.00%	0.00%	0.00%	0.25%	0.60%	0.00%
		15	98.97%	0.00%	0.00%	0.00%	0.25%	0.77%	0.00%
	0.001	20	99.26%	0.00%	0.00%	0.00%	0.30%	0.43%	0.00%
		5	96.46%	1.80%	0.05%	0.00%	0.16%	1.51%	0.02%
		10	98.88%	0.21%	0.00%	0.00%	0.12%	0.78%	0.00%
		15	99.17%	0.05%	0.00%	0.00%	0.12%	0.66%	0.00%
	0.005	20	99.32%	0.00%	0.00%	0.00%	0.13%	0.54%	0.00%
		5	96.26%	1.68%	0.22%	0.07%	0.14%	1.51%	0.12%
		10	98.92%	0.21%	0.01%	0.00%	0.11%	0.74%	0.00%
		15	99.22%	0.04%	0.00%	0.00%	0.10%	0.63%	0.00%
0.5	0.01	20	99.27%	0.00%	0.00%	0.00%	0.15%	0.58%	0.00%
		5	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		10	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		15	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	0.001	20	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		5	96.39%	1.99%	1.16%	0.41%	0.04%	0.00%	0.00%
		10	98.94%	0.90%	0.15%	0.02%	0.00%	0.00%	0.00%
		15	99.67%	0.31%	0.02%	0.00%	0.00%	0.00%	0.00%
	0.005	20	99.91%	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%
		5	95.36%	2.41%	1.13%	0.45%	0.51%	0.12%	0.02%
		10	99.03%	0.81%	0.12%	0.03%	0.00%	0.00%	0.00%
		15	99.69%	0.28%	0.02%	0.01%	0.00%	0.00%	0.00%
1	0.01	20	99.96%	0.04%	0.00%	0.00%	0.00%	0.00%	0.00%

Fig. 8. Packet Latency in Area 100 × 100 m^2

Latency Percentage (Area 200x200)

Packet Rate	Node Density	CH Percentage	[0,20)s	[20,40)s	[40,60)s	[60,80)s	[80,100)s	[100,120)s	[120,140)s
		5	97.73%	0.00%	0.00%	0.00%	0.33%	1.94%	0.00%
		10	98.23%	0.00%	0.00%	0.00%	0.21%	1.57%	0.00%
		15	98.67%	0.00%	0.00%	0.00%	0.16%	1.17%	0.00%
	0.001	20	98.65%	0.00%	0.00%	0.00%	0.28%	1.07%	0.00%
		5	96.70%	0.78%	0.04%	0.00%	0.19%	2.22%	0.07%
		10	98.75%	0.07%	0.00%	0.00%	0.16%	1.01%	0.00%
		15	98.99%	0.02%	0.00%	0.00%	0.11%	0.87%	0.00%
	0.005	20	99.13%	0.00%	0.00%	0.00%	0.18%	0.69%	0.00%
		5	99.05%	0.33%	0.07%	0.04%	0.05%	0.41%	0.05%
		10	98.74%	0.09%	0.00%	0.00%	0.14%	1.03%	0.00%
		15	99.11%	0.01%	0.00%	0.00%	0.12%	0.75%	0.00%
0.5	0.01	20	99.27%	0.00%	0.00%	0.00%	0.13%	0.60%	0.00%
		5	99.69%	0.31%	0.00%	0.00%	0.00%	0.00%	0.00%
		10	99.91%	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%
		15	99.96%	0.04%	0.00%	0.00%	0.00%	0.00%	0.00%
	0.001	20	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		5	97.36%	1.81%	0.63%	0.13%	0.04%	0.03%	0.00%
		10	99.39%	0.58%	0.03%	0.00%	0.00%	0.00%	0.00%
		15	99.83%	0.17%	0.01%	0.00%	0.00%	0.00%	0.00%
	0.005	20	99.98%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%
		5	96.70%	2.06%	0.82%	0.31%	0.08%	0.02%	0.00%
		10	99.31%	0.61%	0.07%	0.01%	0.00%	0.00%	0.00%
		15	99.82%	0.17%	0.01%	0.00%	0.00%	0.00%	0.00%
1	0.01	20	99.99%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Fig. 10. Packet Latency in Area 200 × 200 m^2

number of broadcasts, control packets transmission in contention period, multiple nodes sensed same event data and transmits that data to CH. CH aggregates and transfer the same redundant information to sink. This increases energy consumption of nodes and decreases the network lifetime. So, this shows that CH = 5% is an optimum CH percentage, when node density of a WSN network is 0.01 of an area 100×100 m^2 and 150×150 m^2 while CH = 10% is optimum of an area 200×200 m^2.

These results show that as we increase the node density in an area, the energy consumption of the network decreases. Energy consumption of nodes during data transmission depends upon the distance between the sender and the receiver. So, when node density of a network increases, this also increases the number of nodes and the CHs in a network that decreases the distance between the source nodes to CH or CH to sink. Due to this energy consumption of a node during transmission of data from source node to sink decreases which increases the network lifetime of a WSN. Similarly, with lower node density in an area and with low CH percentage, the energy consumption of network is high because of large distance between source and destination nodes.

Latency Percentage (Area 150x150)

Packet Rate	Node Density	CH Percentage	[0,20)s	[20,40)s	[40,60)s	[60,80)s	[80,100)s	[100,120)s	[120,140)s
		5	98.28%	0.00%	0.00%	0.00%	0.07%	1.65%	0.00%
		10	98.37%	0.00%	0.00%	0.00%	0.18%	1.45%	0.00%
		15	98.46%	0.00%	0.00%	0.00%	0.26%	1.28%	0.00%
	0.001	20	98.78%	0.00%	0.00%	0.00%	0.22%	1.00%	0.00%
		5	96.46%	1.33%	0.08%	0.00%	0.19%	1.83%	0.10%
		10	98.70%	0.13%	0.00%	0.00%	0.16%	1.01%	0.01%
		15	99.08%	0.02%	0.00%	0.00%	0.12%	0.78%	0.00%
	0.005	20	99.12%	0.00%	0.00%	0.00%	0.17%	0.70%	0.00%
		5	96.21%	1.56%	0.13%	0.00%	0.18%	1.85%	0.07%
		10	98.82%	0.11%	0.00%	0.00%	0.12%	0.95%	0.00%
		15	99.12%	0.02%	0.00%	0.00%	0.11%	0.75%	0.00%
0.5	0.01	20	99.24%	0.00%	0.00%	0.00%	0.13%	0.63%	0.00%
		5	99.68%	0.32%	0.00%	0.00%	0.00%	0.00%	0.00%
		10	99.85%	0.15%	0.00%	0.00%	0.00%	0.00%	0.00%
		15	99.95%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
	0.001	20	99.96%	0.04%	0.00%	0.00%	0.00%	0.00%	0.00%
		5	97.20%	1.84%	0.74%	0.15%	0.05%	0.02%	0.00%
		10	99.26%	0.63%	0.09%	0.02%	0.00%	0.00%	0.00%
		15	99.77%	0.22%	0.02%	0.00%	0.00%	0.00%	0.00%
	0.005	20	99.97%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%
		5	96.64%	2.01%	0.87%	0.37%	0.07%	0.03%	0.00%
		10	99.23%	0.68%	0.08%	0.01%	0.00%	0.00%	0.00%
		15	99.81%	0.18%	0.01%	0.00%	0.00%	0.00%	0.00%
1	0.01	20	99.97%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%

Fig. 9. Packet Latency in Area 150 × 150 m^2

If we increase the CH percentage of an area when node density remains same, the energy consumption of a node decreases because of increase in number of clusters in a network and decrease of distance from source node to CH and CH to sink. This shows that when a node density of a WSN is lesser, optimum CH percentage of a network is high. When a node density of a network increases, optimum CH percentage of a network decreases because of decrease in distance between source node to CH and CH to sink. At an optimum value of CH in a WSN, the CH minimizes the communication of nodes by aggregating or eliminating redundant sensed data sent by sensors to their CH, which reduces the energy consumption of sensors. While the increase in CH percentage from optimum CH percentage of a WSN, sensor nodes sensed same event information and send it their CH. This results in a transmission of same event information to a sink that increases the energy consumption of a WSN.

B. Latency

Packets latency usually depends on the application deployed in a WSN. In WSN events, information that has been detected by the sensor is typically time sensitive that must be reported to the sink node in a timely manner so that appropriate actions could be taken. It can be seen from figures 8, 9 and 10 that at lower node density (like 0.001) packet latency from 0 to 20s is above 98%. But as the node density increases to 0.005 and 0.01, packet latency time starts increasing slightly because source sensor node has to wait for its turn to transmit data as per TDMA schedule assigned by CH [8].

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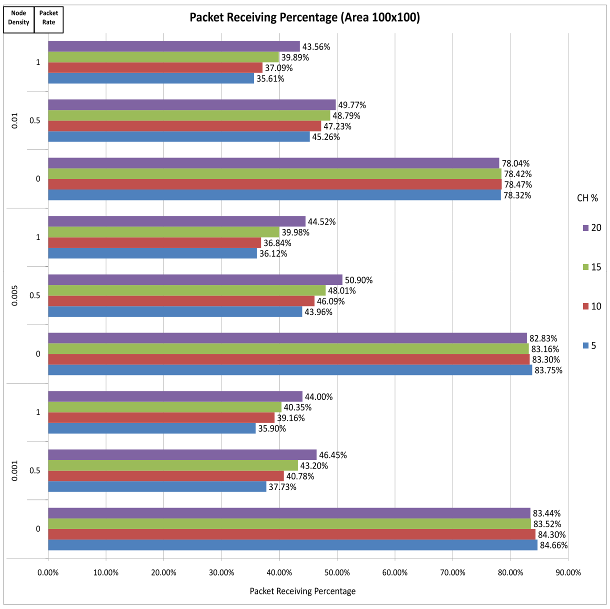

Fig. 11. Packets Receiving Percentage in Area 100 × 100 m^2

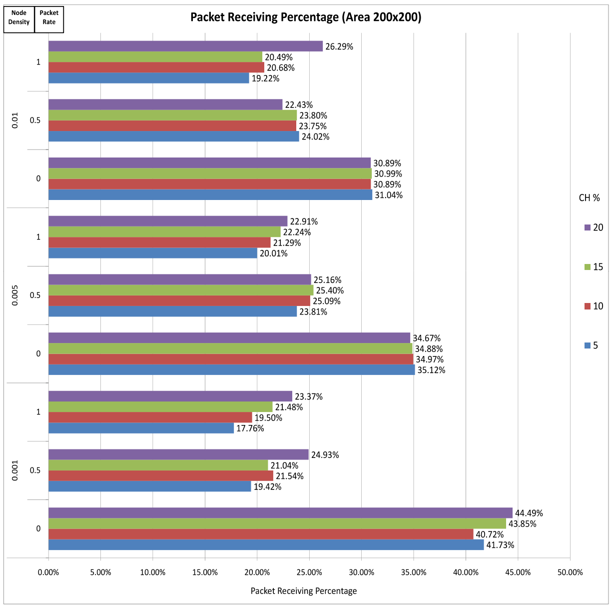

Fig. 13. Packets Receiving Percentage in Area 200 × 200 m^2

The packet latency is better when the data rate is 1 packet/sec because greater numbers of packets are transmitted from CH to sink as compared to data rate of 0.5 packet/sec.

This higher percentage of packet latency between 0 to 20s from CH to sink shows that the sink has received the sensed information of an event in a timely manner by using LEACH protocol as per requirement of a WSN. This type of WSN can be deployed on those remote locations where the sink requires rapid data regarding the critical environmental sensed information for making appropriate decisions in a timely manner.

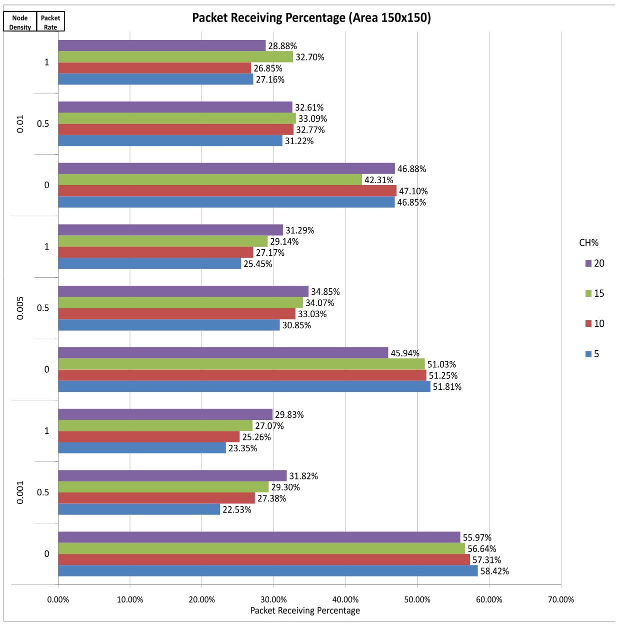

Fig. 12. Packets Receiving Percentage in Area 150 × 150 m^2

C. Packets Receiving Percentage

In figures 11, 12 and 13, it can be seen that when a node density of a 100×100 m^2 area network is 0.001 and data rate is 0, packet receiving percentage is around 84% and maximum at CH = 5%. But when area size of a network increases to 150×150 m^2, packet receiving percentage decreases to 58.4% and also remains maximum at CH = 5%. Further increase of network area size to 200 × 200 m^2, allows the packet receiving percentage to drop down more to 44.49% and this is maximum at CH = 20%.

The RSSI (received signal strength indicator) measures the power of a signal that must be greater than -95 dBm. As distance from source sensor node to a receiver node increases, signal has to travel a larger distance in order to reach to its destination. This decreases the RSSI value of a signal (for details please see [14]). If a sensor radio received a signal whose RSSI value is smaller than -95 dBm, the radio drops that reception due to low sensitivity. Due to this reason, if we try to increase the area size on same node density the packet receiving rate decreases.

WSN can be classified into two classes of reporting rates: event driven and periodic driven. In event driven, sensor nodes transmit sensed information after every event while in periodic driven, sensor nodes transmit sensed information in their allotted time slot [15]. In LEACH protocol, sensor nodes transmit their sensed information to the sink in a periodic manner in their allocated time slot.

The resulting graphs show that on the same node density, if we increase the packet rate (reporting rate), there is decrease in the packet receiving rate of a network due to increase in congestion at the CH. As the packet rate increases, source sensor nodes transmit sensed information to their CHs at higher rate in their allocated time slot. Due to this increase in the packet rate, CH is receiving greater

ISSN – 1999-4974

number of packets from its associated sensor nodes as compared to its transmission rate to a sink. This situation makes congestion to occur in WSN, since the wireless medium cannot support the injected load [15]. As a result sensor buffer starts to overflow which then results in increase of the packet loss rate and decrease in the packet receiving rate of WSN.

D. Energy Consumption at Different Packet Rate and CH Percentages

Figure 14 shows that increase in the cluster head percentage and packet rate will also increase the energy consumption of a network. It can be seen that optimum percentage value for cluster head is between 5 to 10 per cent of all packet rates. As the percentage of cluster head (from an optimum cluster head percentage value) and data rate increases, energy consumption of sensor nodes increases due to increase in broadcast and control packets transmission and same information delivered to sink multiple times which increases the overhead energy consumption of a wireless sensor network.

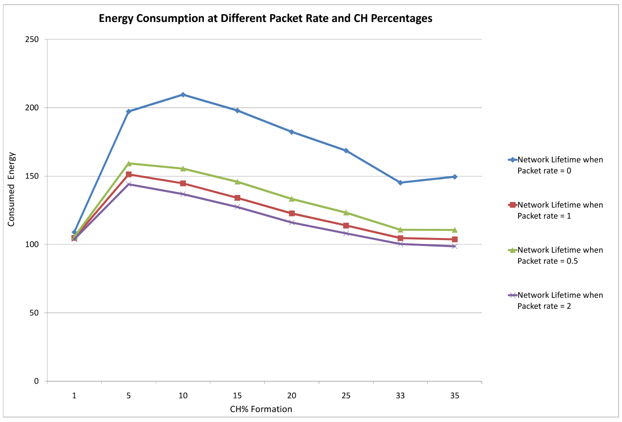

Fig. 14. Energy Consumption at Different Packet Rate and CH Percentages

IV. CONCLUSION

This paper has presented results for energy consumption analysis, optimum CH and packet delivery percentages, packets latency and network lifetime by randomly selecting different number of CHs in a WSN using LEACH protocol. In accordance to our results with different Packet rates and with different CH percentages in varying area sizes, we have seen that the optimum CH values are different in each case. Moreover we came to a conclusion that when there was no data packet sent over the network, i.e. zero packet rate, LEACH itself consumed significant amount of energy. In future this energy can be taken into account for further research and can be reduced in order to increase the network lifetime.

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