Performance Analysis of Network Lifetime and Energy Consumption in a Multi-Hop Wireless Sensor Network

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ABSTRACT
Wireless sensor networks (WSNs) are recently attracting a lot of interest due to their low cost. They are rapidly replacing the wired data acquisition systems due to the ability to use them in benign environments. However, WSNs suffer from many constraints, including low computation capability, small memory, susceptibility to physical capture, the lack of infrastructure and limited energy resources which imposes unique challenges. One of the methods to improve the performance of a WSN is to introduce multiple hops between the source and destination. In this paper, an attempt has been made to analyze the relationship between network lifetime and the energy consumption in a multi-hop wireless sensor network (WSN). Network lifetime can be defined as the maximum time for which the network is able to successfully transmit data from the source to the sink, using all possible alternate routes. It has been shown that as the network lifetime increases, the percentage energy consumption decreases with increase in the number of hops and attains a minimum at critical hops. After the critical hops, the energy consumption gradually increases due to increase in cumulative energy consumption of the intermediate nodes.

Keywords:
Multiple hops WSN, Network Lifetime, Energy Consumption.

1. INTRODUCTION
Wireless Sensor Network (WSN) is an adhoc network that consists of hundreds or thousands of densely deployed sensor nodes which communicate with each other wirelessly to exchange, transmit or forward information between them or forward it to a collection point. WSN promises benefits in a wide range of applications such as habitat monitoring, assisting emergency first responders, target tracking, and surveillance etc [1,2]. The sensor nodes are small, independent, self-contained and battery powered.
They suffer from many constraints, including low computation capability, small memory and susceptibility to physical capture. The lack of infrastructure and limited energy resources in a WSN imposes unique challenges. The energy resources of the deployed sensor nodes is one of the crucial factors in determining the network lifetime.

It is felt that to prolong the lifetime of a sensor network, energy efficiency must be considered in every aspect of the sensor network design. Many researchers have contributed in the design of various network and routing protocols, topology discovery, self organization, medium access control, routing, data aggregation, fault tolerance etc. for improving the performance of sensor networks.

An analysis of the effect of antenna receiving power and hence the transmitting power of the source on the network lifetime by varying the transmission power and hence the transmission range of each node through introduction of multiple hops between source and sink has been carried out. It is assumed that distance between source and sink is fixed.

It is observed that network lifetime increases exponentially with number of hops and saturates gradually. In this paper, work done to establish a relationship between the two important performance parameters of a wireless sensor network, network lifetime and energy consumption, has been presented.
The remainder of the paper is organized as follows. In section II related work done to improve the network lifetime of WSNs by energy conservation has been briefly reviewed. Section III describes the simulation paradigms and the simulation results. Finally, we conclude in Section IV.

2. LITERATURE SURVEY

Significant work [3,4,5] has been done to improve performance of WSN in terms of reducing power dissipation and increasing network lifetime of WSNs. It is observed that most of the authors have considered clustering of nodes as an efficient solution for increasing the network lifetime. Clusters are groups of sensor nodes that together behave like a single powerful node.

Flavio Fabbri et al [6] have presented a mathematical approach to evaluate the area throughput and the energy consumption of a multi-sink Wireless Sensor Network (WSN). Their results clearly show the limitations on the area throughput imposed by fixed sink deployments, and the relatively good performance obtained by simple randomized cluster head selection. The feasibility of the latter approach is, however, clearly dependent on the application scenario considered.

C.-E CXliasserini and M. Garetto [7] have developed a Markov model of sensor network whose nodes may enter a sleep mode, and they have used this model to investigate the system performance in terms of energy consumption, network capacity, and data delivery delay. They observe that while in sleep mode sensors consume lower power as well as a reduction in their functional capabilities is observed.
Duan et al [8] have proposed a regional partitioned clustering routing algorithm to achieve an uniform and even distribution of sensors in the network. The algorithm provides higher performance than LEACH. However they have assumed that all nodes can communicate with the base station (BS).

Contrary to this Soro and Heinzelman [9] state that equal clustering results in unequal load on the cluster head nodes. They propose an Unequal Clustering Size (UCS) model for network organization, which leads to more uniform energy dissipation among the cluster head nodes, thus increasing network lifetime.

Xue and Ganz [10] have investigated the lifetime of a general sensor network, with *n* randomly distributed sensor nodes communicating to a base station. They have introduced a location-aware hybrid transmission scheme that balances the network energy consumption. They have further shown that in practical settings, hybrid schemes with non-optimal forwarding probability setting can significantly improve the network lifetime over uniform forwarding schemes. Similarly, Singh and Prasanna [11] have demonstrated an energy optimal algorithm for the sorting in a single-hop, single channel network of *n* randomly distributed sensors. They have assumed that the energy dissipation and time taken for local computation, transmission and reception of a unit of data is unity.

Bouabdallah et al [12] have shown that minimizing the total amount of energy consumed by the network in forwarding a packet between any pair of nodes does not necessarily maximize the network lifetime. Network death can occur while several sensor nodes still have plenty of balance energy. They have proposed a load balancing routing scheme for the same.

It is observed that clustering patterns of nodes has been extensively studied to minimize the overall energy consumption of a WSN. However the relationship between network lifetime and energy consumption has not been studied in depth by the researchers. Therefore, an attempt has been made to analyze a practical multi-hop wireless sensor network environment that encounters Rayleigh fading for studying the relationship between network lifetime and energy consumption.

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3. SIMULATION PARADIGM AND RESULTS

3.1 Performance Matrics

The simulations have been carried out using the ns 2.29 network simulator, alongwith nam and mannasim softwares [13,14]. Some related work has been done in Matlab 7. Following assumptions have been made.

Assumptions

1) There is one source and one sink. Distance between source and sink is constant i.e. 100 meters. Hops are introduced in between source and sink.
2) All hops are equidistant, independent of each other, and homogenous.
3) All nodes are immobile.
4) All hops encounter isotropic Rayleigh fading.
5) Energy consumption of sensing and processing is not considered here.

Table 1

Simulation Area	100.5 x 100.5 meters^2
Simulation time	2000 seconds
Frequency	914 MHz
Rx Threshold	5e-07
Rx Power	0.3 W
Sleep Power	0.01 W
Initial Energy	1000 J
Traffic Type	CBR
Transport Layer	TCP
Ad-hoc Routing Protocol	AODV
MAC	SMAC
Source to Sink Distance	100 meters
Deployment	Linear

To find percent Energy Consumption of WSN with sleep mode, the simulation settings as specified in Table 1 have been done. In the sleep mode, the nodes are awake only during transmission and reception of data. At all other times, it is put to sleep, consuming minimum power

3.2 Results and Analysis

Observations have been carried out for varied received power of the antenna at the receiving node for different values of intermediate nodes between the source and the sink. The effect of the variations in received power on the network lifetime and the percentage energy consumed during the entire lifetime is observed [16]. Received power signifies and relates to the transmission distance between two neighboring nodes. Also the battery level of the node is an indication of the lifetime of the node.

Fig 1. shows graph of network lifetime versus received power for varying number of nodes. The received power threshold is the minimum power of the sensor node below which it fails to receive the signal correctly. During simulation, when the transmission power for given number of hops becomes equal to the received power threshold, the route becomes dead. ie. No further data routing can take place along the route. Hence the node with the least power decides the network lifetime. From fig. 1 it is observed that for equal values of received power, as the number of hops is increased in a multihop network, the network lifetime increases. However, the network lifetime gradually saturates indicating no further improvement. Also with an increase in received power for the same number of hops, the network lifetime decreases. This is due to the high power consumption during every transmission. An increase in received power implies an increased transmitted power. This leads to more energy consumption of the node, and hence a decrease in the network lifetime. It can be observed from fig.1 that as the intermediate nodes decreases from 6 to 2, for received power of 0.7 μW, the network lifetime decreases from 2300 seconds to 750 seconds, which is a significant decrease in the network lifetime.

Fig.2. depicts graph of percentage energy consumption versus received power for varying number of nodes. From the fig, it is clearly seen that percentage energy consumption decreases with increase in number of nodes for equal values of received power. This is due to the fact that as the number of nodes increases, distance between neighboring nodes decreases. Hence the transmitting power required decreases. This leads to a decrease in the total energy consumption. Also for a fixed number of hops between the source and destination, increase in the received power increases the energy consumption. Small variations in the energy savings in the lower range of received power values is observed. This may be due to variations in the number of control and data packets transmitted along the multi-hop route.

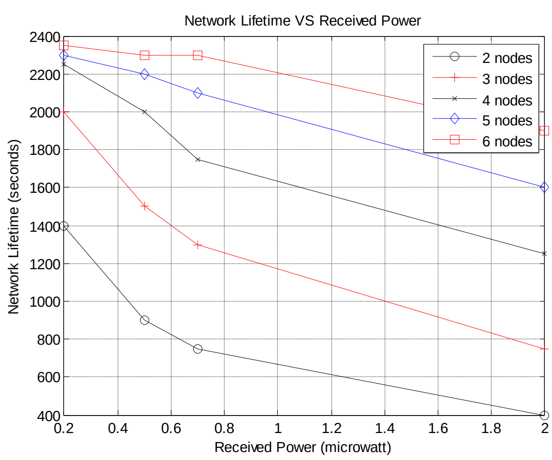

Figure 1

Our earlier work [15] has shown that percentage energy consumption decreases with increase in number of nodes. With decrease in required transmission power, energy consumption is reduced. Thus transmission power plays significant role in total energy consumption

Fig.2 and fig.4 show that although increase in number of intermediate nodes decreases the percentage energy consumed, this decrease becomes insignificant after a critical number of hops [15].

It is felt that a relationship exists between the network lifetime and the energy consumed in a multihop wireless sensor network. This relationship has been shown in fig 3.

It is observed that an increase in energy consumption leads to a decreases in the network lifetime. Similarly, it can be seen that as the number of nodes between the source &

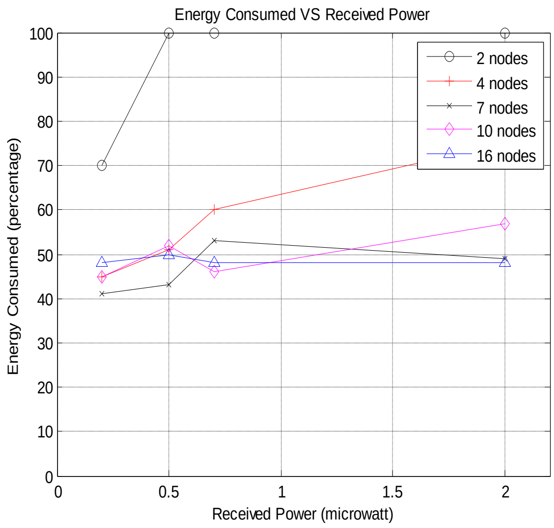

Figure 2.

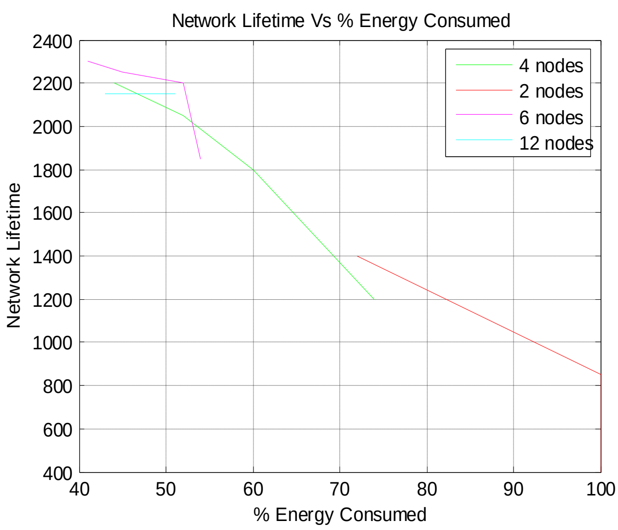

Figure 3.

destination increases from 2 to 12, the network lifetime increases from 800 seconds to 2300 seconds. At the same the total energy consumption decreases from 100% to 42%. This shows that multihop data transmission is more energy efficient than single data hop transmission. However it is also observed that the increase in intermediate nodes leads to a gradual saturation in the increase of network lifetime.

4. CONCLUSIONS AND FUTURE SCOPE

Number of hops in a multi-hop network plays a significant role in overall energy consumption. Percentage Energy Consumption decreases with increase in number of hops and gradually saturates. Similarly Network lifetime increases with increasing number of nodes and eventually saturates. Beyond the critical hops [15] in a multihop WSN, energy consumption increases.

This is attributed to the fact that cumulative increase in energy consumption is observed for operation of individual nodes. Thus it is necessary that the critical hops required for energy efficient wireless data transmission should be calculated initially. A balance can be maintained between the desired network lifetime and energy consumption, depending on the application.

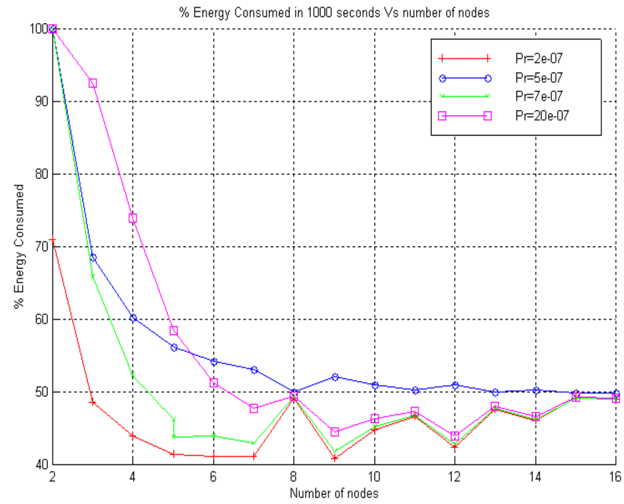

Figure 4.

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