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An Optimized Lifetime Model using Energy Holes Reduction near Sink's Locality of WSN's

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Abstract. The traffic model in wireless sensor networks (WSN) follows a converge-cast pattern where nodes closer to the sink carry heavier traffic loads, resulting in an increased rate of energy depletion. This ultimately leads in isolation of the sink from the rest of the network. The phenomenon is known as an energy-hole or a hotspot. Such hot-spots are more likely to occur closer to the sink instead of any other geographical area spanned by the network. We have defined this particular time instance as the achievable total network lifetime. We are proposing in this paper a technique for maximizing the network lifetime based on this definition, by reducing the chances of energy-hole formation in the sink's immediate locality. Simulation results showed that the technique have successfully improved the network lifetime.

Keywords: WSN, Energy-holes, Network lifetime.

1. Introduction

A wireless sensor network is a collection of nodes that organize themselves into a hierarchy after being deployed in an ad-hoc fashion where they co-operate with one another by generating and forwarding packets of information. Such networks are anticipated to accommodate hundreds or thousands of node [1], however the maximum number of nodes ever used in any deployment is 800 [2]. Experimental results have shown that up to 90% of the accumulative energy of a network can remain un-used in a uniformly distributed network of nodes[3].This can be attributed to the fact that the traffic dynamics within the network follow a many to one pattern where nodes in sink vicinity carry heavier traffic loads as compared to other nodes. This results in an increased rate of energy depletion in the immediate sink locality and ultimately creating an energy hole around the sink. This phenomena is also known as hot-spot formation. Practically, even though the remaining network is still operational, but it cannot meet its purpose of data delivery to a central device. Many existing definitions of the maximum life-time of a network exist in literature, however, we will attribute this lifetime to be the time instance in which the nodes are un-able to deliver data to the sink.

Our focus in this paper is to assess the role of strategic sensor node placement on the lifetime of a network. In this regard, Section 2 will first attend to existing related work regarding network life-time models and life-time optimization; Section 3 with proposed work; Section 4 with a description of our simulation and results and lastly a conclusion and scope for future work in Section 5.

2. Related Work

2.1. Network Lifetime Model

Sensor nodes rely on a limited supply of energy (typically batteries). Replacing these energy sources in the field is usually not practicable and can be considered virtually impossible. A WSN must operate at least for a given period of time or as long as possible. Hence, the lifetime of a WSN becomes a very important issue. In order to prolong the lifetime of a network, an energy-efficient way of operation is necessary. Node energy can be supplemented by additional batteries or through photo-voltaic cells.

From a user point of view, the main aim of any WSN application would be to achieve required goals with maximum accuracy. This aim is tied to how long a network is able to deliver. The exact definition of a lifetime depends on the application area under consideration. A simple approach of defining network life-time is to refer to the time until the first node fails or runs out of energy [4]. Since node failures in WSN are a common occurrence, such a definition would be most suitable for mobile ad-hoc networks rather than WSN. Their definition of the total lifetime T_t is substantiated by determining the minimum lifetime of a node T_i in a network *g* as:

$$T_t = \min T_i = \frac{E_i}{\sum_{j \in Si} E_{ij} \sum Q_{ij}} \tag{1}$$

Where E_i is the initial energy of the battery, E_{ij} is the energy required for transmission of one information unit, Q_{ij} is the rate at which information is generated at node *i,* and S_i is the set of neighbor nodes of node *i*. This definition can be taken further to determine the maximum individual node $\max T_i$ as the total network lifetime. Here, the definition will be applicable to the time when the last node dies in the network.

Other alternatives are to refer to the time until the network is disconnected into two or more sub- graphs, the time until a certain threshold number of nodes fail, or the time when for the first time a point in an observed region is no longer covered by any node [5].

An alternative definition of network life time is given in [6] as the time in which a certain percentage of total nodes run out of energy. This is based on the fact that if a single node dies, than it would be expected that it's neighbors will run out of energy very soon since they will take over the responsibility of the died node.

2.2. Lifetime Optimization

Lifetime optimization is the process of discovering the maximum network lifetime for any deployment strategy with some fixed parameters. It can be increased with the help of traffic control techniques [7], load balancing, and maintaining energy balance. Load balancing can be achieved through a combination of intelligent routing and transmission power control [8]. The authors in [8] state that metrics other than energy consumed per packet need to be used, such as path selection where nodes with depleted energy reserves are at a minimum. A network will however have to collect and maintain global data for using this information.

An alternative load balancing approach is a scheduling based scheme, where some nodes take turns in monitoring an area while the remaining go into sleep mode has been proposed in [9]. This scheme can be enhanced such that only nodes close to the sink perform scheduling whereas nodes farther from the sink remain operating normally.

As proposed by [4], a technique for maximizing system lifetime using flow (traffic) control. According to their technique, it is the responsibility of every node to maintain a balance between the sum of information generation rate I_G and the total incoming traffic T_i to that of the total outgoing flow T_O. I.e., an energy balance Eb can be achieved if:

$$E_b = \frac{T_I + I_G}{T_O} \sim 1 \tag{2}$$

Transmission range optimization is the increase or decrease of range for each sensor node such that every sensor can send its data directly or indirectly (via multiple hops) to the sink respectively. In former case, no energy hole will be created but the consumption of energy by a node would be very high [10]. The authors propose a technique for determining how a node should distribute its outgoing data packets over multiple distances by using minimum transmission power. Two conclusions are reached for variable transmission range. In the first instance, nodes farther away from the sink have greater transmission range and can communicate with the sink in a single hop. When relaying data, only their own energy will be reduced, eventually dying out. In the other instance, if multiple hops are used to communicate with the sink, there will be increased traffic load on sink-neighbor-nodes, the direct result of which would be the early demise of these nodes. Lifetime optimization is also achievable by using specifically designed deployment strategies.

3. Methodology

In our proposed model, we are using two different deployment strategies and in both cases the results show increase in the network lifetime. The deployment Strategies used are summarized below.

3.1. Strategy 1: Incremental Node Deployment

We will consider uniform deployment strategy. It is assumed that our sink will be stationary and placed in the center of our topology. The nodes used would be homogeneous and traffic generation would be random. We will gradually increment the number of source-neighbors (See Figures 1, 2, 3) and assess its impact on network-lifetime.

3.2. Strategy 2:Incrementing Energy of Sink Neighbors

We will also consider uniform deployment strategy here. The sink would be static and placed in the center of our topology. The nodes used would be heterogeneous, i.e., those closer to the sink will have more energy as compared to others. Other than that, the energy transmission range, energy consumption and transmission bandwidth would be the same as used in the first strategy. We will gradually increment the initial energy level of the sink neighbor nodes and assess its impact on network-lifetime.

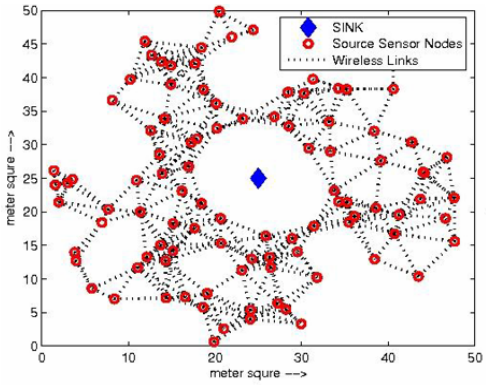

Figure1: No Sink Neighbours

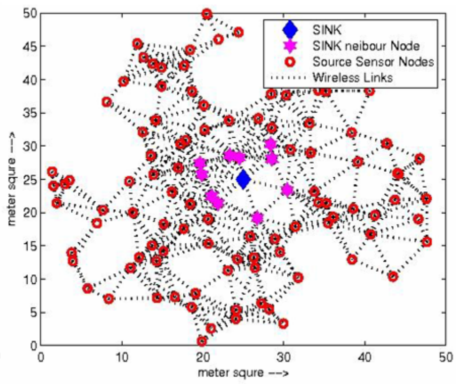

Figure 2: Ten Sink Neighbors

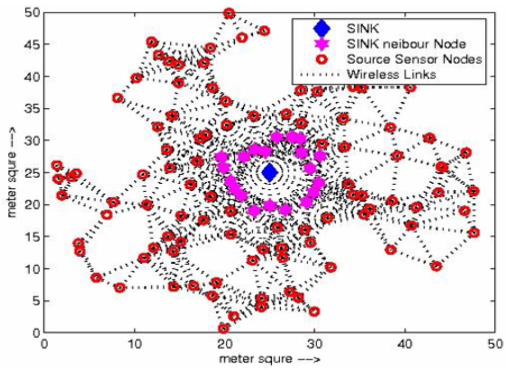

Figure 3: Twenty Sink Neighbors.

4. Simulation and Result

We have evaluated the performance of our network for both strategies using the metric of network lifetime.

4.1. Strategy 1: Incremental Node Deployment

Our network was deployed in a geographical area 50x50 m^2. We increment the number of sink neighbors from 10 to 45. The number of sensing nodes is 100, and their transmission range is 10m. We assigned the initial energy of each node as 10J whereas the energy consumption during transmission is 10mJ. (See Table Strategy I).

TABLE 1: PARAMETERS FOR STRATEGY I

Parameters	Values
Area	50*50 m2
Sink neighbors	10-45
No of source Node	100
Transmission Range	10 m
Initial Node Energy	10 J
Energy Consumption (during Transmission)	10 mJ

Network Lifetime*:* In contrast to [7], we will define the network life-time for our model as the total period of time that nodes can communicate with the sink until this link is broken. In other words, when all of the immediate sink neighbor-nodes energy levels are drained out, such that there is no path available for communicating with the sink, then this will culminate the total network life-time. Figure 4, shows the total network lifetime against an incrementing number of sink neighbors. We find that the total network lifetime gradually increases as the number of sink neighbor nodes are increased.

The sharp steps noticeable in the graph are due to the uniform random deployment strategy used for each increment. However, there is a cap on this life-time increase beyond a certain limit. This is due to the fact that the neighbors of the sink-neighbor nodes start dying.

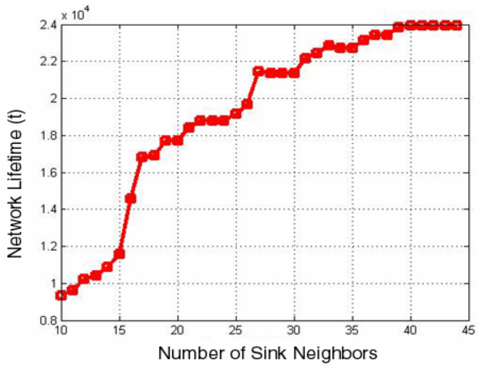

Figure 4: Impacts of Incrementing Sink Neighbours Nodes on Network Lifetime

4.2. Strategy2: Increasing Energy of Sink Neighbors

Our network was deployed in a geographical area 50x50 m2. We assigned the number of sink neighbor nodes as 10 whereas the number of sensing nodes is 100. The total transmission range is 10m. For sink-neighbor nodes, the initial energy is incremented gradually from 10 to 45 joules, whereas the initial energy for non-sink-neighbor nodes is fixed at 10 joules. The energy consumption during transmission for all nodes is set at 10 milli-Joules. (See Table Strategy II)

TABLE 2: PARAMETERS FOR STRATEGY II

Parameters	Values
Area	50*50 m2
Sink neighbors	10
No of source Node	100
Transmission Range	10 m
Initial Non Sink Neighbors Node Energy	10 J
Energy Consumption (during Transmission)	10 mJ
Initial Sink Neighbors Node Energy	10-45 J

Network Lifetime*:* Figure 5 shows the total network lifetime against an incrementing energy level of sink neighbors. We find that the total network lifetime shows a sharp increases as the energy level is increased. However, we notice that the network lifetime achieves a peak for an energy level of 20-25 Joules. Any subsequent increase in energy level has virtually no impact on the network lifetime. This is due to the fact that the neighbor of the sink-neighbor nodes starts dying.

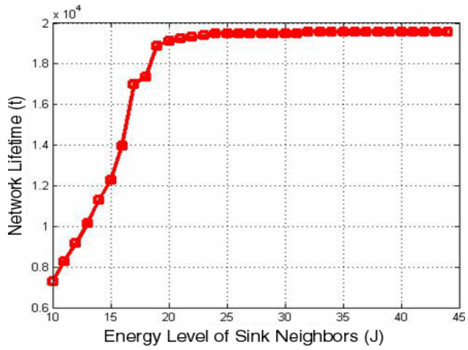

Figure 5: Impact of Incrementing Sink Neighbor Nodes Energy on Network Lifetime

5. Conclusions and future work

Energy Efficiency is the most important design consideration for wireless sensor networks and its optimum utilization is a challenge in its own regard. The deployment model is simple, efficient and less costly and can scale well to large networks.

A good sensor deployment strategy is one that achieves an energy balance in the network. The main factor for achieving this energy balance is the optimum number of sink neighbor nodes, rather than other performance enhancing factors such as increased energy level of all the sensor nodes. Both implemented strategies suggest increased energy efficiency and energy balance. Our strategy is simple to implement and involves less cost as compared to other intelligent techniques for achieving maximum lifetime. Our work can be extended to analyze the performance for other deployment strategies.

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