Optimal Routing and Data Aggregation for Maximizing the Network Lifetime of Wireless Sensors

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ABSTRACT

In this paper, we focus on maximizing the network lifetime of wireless sensor networks using both maximum lifetime routing algorithm and smoothing function. An optimal routing and data aggregation scheme for wireless sensor networks is proposed. The objective is to maximize the network lifetime by jointly optimizing data aggregation and routing by adopting a model to integrate data aggregation with the underlying routing scheme and propose a smoothing function to maximum lifetime network. These algorithms show that they significantly reduce the data traffic and improve the network lifetime.

Keywords: Sensor networks, Data Aggregation, Maximum lifetime routing, Smoothing function, Network Lifetime.

1.INTRODUCTION

Wireless sensor networks (WSNs) are rapidly emerging technology which will have a strong impact on research and will become an integral part of our lives in the near future. The huge application space of WSNs covers national security, surveillance, military, health care, environment monitoring and many more. Therefore, the primary challenge for this energy-constrained system is to design energy-efficient protocols to maximize the lifetime of the network. In this paper showing that how the network lifetime is improved, by jointly optimizing routing and data aggregation, the network lifetime can be extended from two dimensions. One is to reduce the traffic across the network by data aggregation, which can reduce the power consumption of the nodes close to the sink node. The other is to balance the traffic to avoid overwhelming bottleneck nodes. The energy consumption can be minimized if the amount of data that needs to be transmitted is also minimized. The solution to this is data aggregation. Since the maximum lifetime problem cannot be solved directly using the simple distributed methods, we propose a smoothing function to approximate the original max function by exploiting the special structure of the network. We conduct extensive simulations to show that the proposed scheme can significantly reduce the data traffic and improve the network lifetime.

In the next section, we first present the system models and define the maximum lifetime routing problem. In Section III, we propose a smoothing function to approximate the maximum lifetime routing problem and simulation results are discussed. Finally we conclude this paper in Section V.

2.SYSTEM MODELS

We model the topology of a wireless sensor network as a undirected graph G (N, A), where the N is set of nodes and A is the set of undirected links. A sink node $t \in N$ is responsible for collecting data from all other nodes.

2.1 Routing Model

The routing algorithm used here is the geometric routing algorithms. Let N_i denote the set neighbouring nodes of i node. $\mathbf{N}_i = \{j \setminus d_{ij} \leq R, j \in N\}$ where d_{ij} is the Euclidian distance between node i and node j and R is the radius of transmission range. Let us define set of upstream neighbors $A_i = \{k \setminus d_{kt} > d_{it}, k \in \mathbf{N}_i\}$ similarly define set of downstream neighbors as $\mathbf{S}_i = \{k \setminus d_{kt} < d_{it}, k \in N_i\}$. The original graph G (N, A) satisfies the conditions:

1. The graph is connected, i.e., every pair of nodes are connected by at least a path.

2. There exists at least one neighbor $k \in N_i$ for each node is satisfying $d_{kt} < d_{it}$ and $d_{ik} < d_{it}$, then the resulting graph G (N, A') is directed and acyclic graph (DAG) strongly connected to sink node t.

2.2 Data Aggregation Model

In this model, the aggregation is done at intermediate node, i.e., the compression ratio between nodes i and j is characterized by the correlation coefficient q_{ji} = 1- H (X_j/X_i)/H(X_j), where r_j = H(X_j) is the entropy coded data rate of the information X_j at Node j and H(X_j /X_i)_ r_j is the conditional entropy coded data rate of the same information X_j of at Node i given the side information X_i. To incorporate data aggregation with the *geometric routing*, we adopt the *foreign-coding* model [8].

Using this data aggregation model, a node i performs two different operations for the data received from its upstream neighbors. For the raw data generated by the upstream neighbors, it encodes the data using the local information. For the transit data (already compressed by the upstream nodes), it directly forwards the data to the next-hop neighbors. Let r_i denote the traffic generating rate at node j and R_i and R_j denote the aggregated transit traffic at node i and j respectively. The aggregated transit traffic consists of two parts, the transit traffic passed from the upstream nodes and the raw data originated from the upstream nodes that is compressed using the local information.

$$R_i = \sum_{k \in A_i} [R_j + r_j(1 - q_{ji})]\emptyset_{ik}$$

2.3 *Power Consumption Model*

In wireless sensors networks sensor node consumes power when it is sensing and generating data, receiving, transmitting, or even simply in standby mode. Assuming each node i has an initial battery energy E_i, the uniformed mean power consumption of node i is denoted as W_i .

$$W_i = [e_s + e_g r_i + e_r \sum_{j \epsilon A_i} (R_j + r_j)\emptyset_{ji} + (R_i + r_i) \sum_{k \epsilon S_i} e_{ik}\emptyset_{ik}]/E_i.$$

Where the first term is the standby power consumption denoted by e_s , the second term is the power for sensing denoted by e_g, the third term is the power consumption for receiving, and the last term is the power consumption for transmitting.

2.4 Maximum Lifetime Routing Problem

The network lifetime T_{net} defined as the time at which the first node in the network runs out of energy. The lifetime of node T_i is the expected time for the node to run out of the battery energy, that is T_i =1/W_i , where W_i , shown in

$$T_{net} = min_{i \epsilon N}\ T_i.$$

The maximum lifetime routing (MLR) is to find a set of routing variable such that the network lifetime is maximized. The MLR written as: Maximize T_{net}

Subject to

$$\emptyset_{ik} \geq 0, \ \sum_{k \epsilon S_i} \emptyset_{ik} = 1, \ \forall_i.$$

The problem with this maximizing the network lifetime is to minimizing the maximum power consumption W_i for all i є N. Therefore the MLR problem written as: Minimize

$$max_{i \epsilon N}\ W_i$$

Subject to

$$\emptyset_{ik} \geq 0, \ \sum_{k \epsilon S_i} \emptyset_{ik} = 1, \forall_i.$$

Hence it is clear that maximizing the network lifetime means minimizing the power consumption model.

2.5 Solution to MLR Problem

To solve the MLR problem, here the routing is selected in such a way that the power loss due to bottleneck nodes is minimum.

$$\bigcup_{w,c} = \mu^2 + c/(N_{B^*}) \sum_{l \epsilon N_{B^*}} (W_l - \mu^2)^2$$

The smoothing function $U_{w,c}$ has two terms representing the mean and the variance of the power consumption of nodes in N_B . Minimizing the first term μ^2 will enforce data aggregation at the intermediate nodes so that the traffic passing through the bottleneck nodes is minimized. This causes the mean power consumption of these nodes to be minimized too. Minimizing the second term of $U_{w,c}$ will cause the power consumption of the set of bottleneck nodes to be equalized, which has the effect of maximizing the network lifetime. we can determine whether a node belongs to the bottleneck set by comparing its power consumption with that of its downstream neighbours. Let each node maintain two variables: Its power consumption W_i and the weighted power consumption of the set of bottleneck nodes known by node, denoted by $W_{B,i}$

$$W_{B,i} = max\ W_i, \sum_{k \epsilon S_i} (\emptyset_{ik} W_{B,i})$$

$$W_i > \sum_{k \epsilon S_i} (\emptyset_{ik} W_{B,i})$$

Simplifying the equation means that if power consumption of a node is greater than all the other neighbours, it is a bottleneck node. By this the optimal routing is obtained.

3.SIMULATION RESULTS

To evaluate the MLR algorithm over a set of sensor network we have consider the number of nodes ranging from 20 to 80, where the sensor nodes are randomly distributed on a (600m * 600m) square. The main idea of using data aggregation in multihop wireless sensor networks, to facilitate in network data aggregation in order to decrease the amount of packets be relayed toward the sink. In the geometric routing the shortest routing algorithm is used for routing the aggregated data. Foreign coding [8] is used to incorporate data aggregation with geometric routing algorithm. The algorithms are implemented by using Visual studio 2005.

Table I: Specific parameters and settings .

Notation	value
Network topology	600m
R	60m
sensors nodes in network	20- 80
ϵ_{elec}	50nJ/bit
ϵ_{amp}	100pJ/bit
E_i	1kJ
Data	1 kbps

The overall raw data rate is proportional to the number of nodes in the network. The increase of nodes in the network also drives the network topology from sparse to dense, which affects the network in two ways:

1. The distance between neighboring nodes becomes smaller, so a node needs less power to send data to its neighbors.
2. The data correlation between neighboring nodes becomes higher, so more redundant information can be removed through data aggregation. Both effects help to reduce the energy consumption per node. Figure 3.1 and 3.2, shows that the aggregated data rate increases as the number of nodes increases which in turn increases Network lifetime.

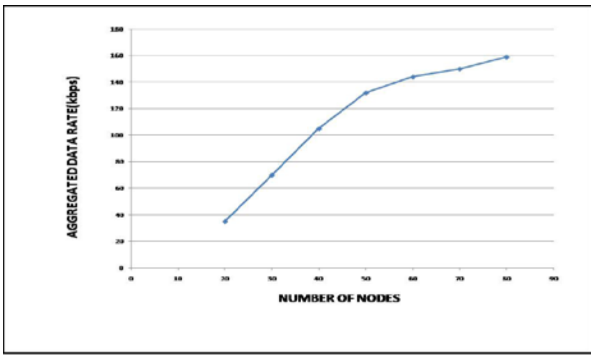

Figure 3.1: Number of nodes Vs Aggregated Data Rate

Figure 3.3 shows the network lifetime for various numbers of sensors nodes. In the low correlation case, it shows that the network lifetime drops with the increase of source nodes. In the high correlation case, the network lifetime stops decreasing after the source nodes reaches certain number. This is because when the number of source nodes increases, the chance of a source node to find a neighouring source node increases accordingly. Hence data correlation between these neighbouring nodes is more and data to transmit is less. So it requires less energy to transmit these packets, which shows increases in network lifetime.

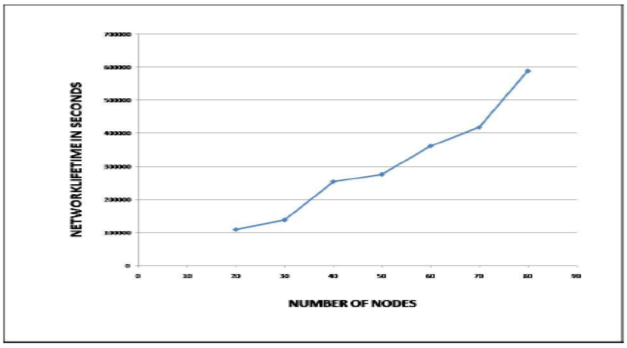

Figure 3.2: Number of nodes Vs Network Lifetime

Figure 3.4 shows the aggregated data rate at the sink node. It is interesting to see that for the lower correlation case, the aggregated data rate is simply increased as the source nodes grow. However, for the high correlation case, the data rate saturates when the number of nodes reach certain number.

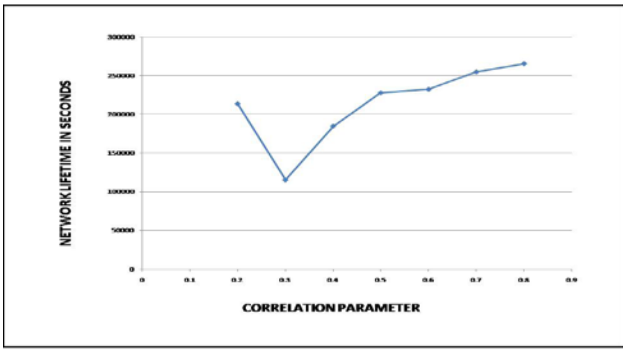

Figure 3.3: Correlation parameter Vs Network Lifetime.

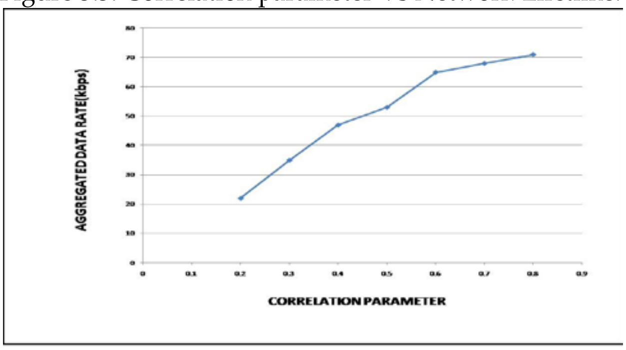

Figure 3.4: Correlation parameter Vs Aggregated Data Rate

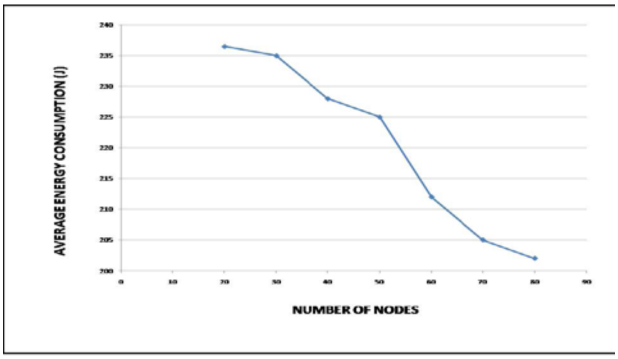

Figure 3.5: Number of nodes Vs Average Energy Consumption .

Figure 3.5 shows the average energy consumption. As the number of nodes increases, average energy consumption is decreases, due to the fact that the data traffic is reduced by data aggregation.

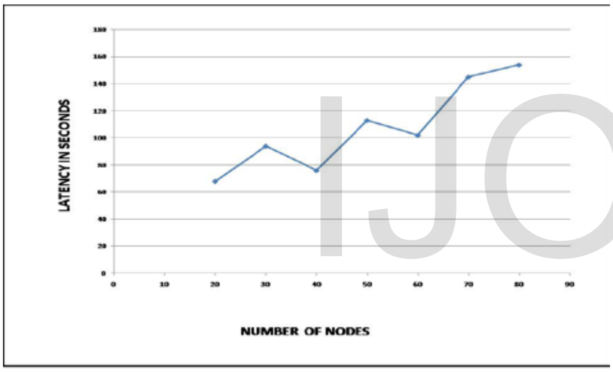

Figure 3.6: Number of nodes Vs Latency .

Figure 3.6 shows that variations in latency for end to end transmission of aggregated data over different number of nodes are due to the random assignment of node positions, keeping the source and sink node as constants.

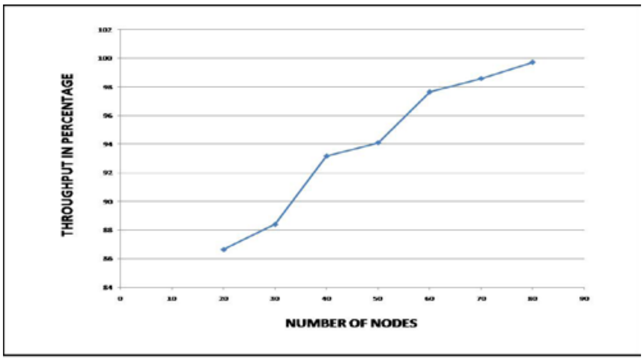

Figure 3.7: Number of nodes Vs Throughput.

Figure 3.7 shows as number of node increases the throughput of the network depends upon the data delivered to sink. Throughput is defined as aggregated data delivered to the sink node in sensors network.

5.CONCLUSION

An optimal routing and data aggregation at intermediate node is done for maximizing the network lifetime of sensor networks. In this paper the idea of using data aggregation in multihop WSNs, to facilitate the network data aggregation in order to decrease the amount of packets is forwarded toward sink. The proposed algorithms show that they that significantly reduce data traffic and improve the network lifetime. Future improvement in this project may be to maximize network lifetime and also to ensure, how to position multiple sink nodes in a sensor network and how to route traffic flow from all of the sensors to these multiple sink nodes.

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