Positioning Mobile Base Station to Prolong Wireless Sensor Network Lifetime

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ABSTRACT

Energy efficiency is a critical issue in designing sensor networks, as the nodes have limited battery power. In this paper we propose to move the BS so as to prolong the network lifetime. We present three strategies for moving the BS: (1) minimizing the average transmission energy; (2) minimizing the maximum transmission energy; and (3) minimizing the maximum relative consumed energy for every active sensor. We examined the case, when the BS is on the optimal location in each round using the three strategies.

Categories and Subject Descriptors: C.2.1 [Computer-communication networks]: Network Architecture and Design – Wireless Communication

General Terms: Design, Performance

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1. INTRODUCTION

A sensor network consists of a large number of small devices with sensing, processing, and transmitting capabilities, they operate unattended, supplied only by a small battery; thus, they have limited power resources. The main goal of the operation is to monitor a region and gather and relay information to the Base Station (BS).

Forwarding the data to the BS is possible using direct (singlehop) or multihop communication. There are two possible ways to decrease the energy used for communication: minimize the amount of data transmitted, or shorten the communication range. To decrease the transmission distance, we propose an approach where the BS is capable to change its position, hence to prolong the lifetime of the network, which can be defined in several ways. Some applications can tolerate a loss of a large number of nodes, while in others loosing a single sensor violates the functionality of the whole network.

There are papers that considers a mobile BS [2]. In [3] authors propose an architecture that builds on the *random mobility* of mobile agents, to collect sensor data in sparsely deployed networks. Gandham *et al.* propose to decrease energy consumption using multiple mobile Base Stations [1]. The authors consider only proactive (time-driven) sensor networks where each node generates equal amount of data. The number of the base stations is known in advance and they can be located only at given sites, just on the border of the network area.

In our work, we also consider the mobility of the BS. However, as opposed to the previous assumptions, we consider that the BS can move anywhere inside the sensor network. The type of the network we considered is also different, hence we assumed an event-driven network, where the sensor sends data only when sensing an event.

We examined using simulation that case, when the BS is on the optimal location in each round using the three strategies.

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2. MOBILE BASE STATION

Let us consider a typical sensor network. We assume that the sensors are uniformly, but randomly distributed, on a circle with radius R. There are a sink node in the network, called the BS. We assume that only the BS is mobile, and does not have energy constraints. The sensors operate in an event-driven way; when an event occurs within the sensing range (r) of a node, it sends a message to the BS. The time was split into equal periods and we assumed that an event can be reported only at the beginning of the time period. The sensors communicate with the BS directly. The energy used for communication is proportional to d^α, where d is the transmission distance and α is the attenuation parameter, typically between 2 and 4. Sensors are able to adjust their radio power depending on their distance d from the BS. Although sensing also requires energy, this is far less than the energy used for communication; thus, we neglect it.

2.1 Minimizing average energy consumption

Let V denote the set of all sensors, and $A \in V$ the set of active sensors. Let (x, y) denote the coordinates of the BS, and (x_i, y_i) the coordinates of the ith sensor ($i \in V$). The energy needed for the ith node to transmit data is

$$E_i = E_0 \left((x - x_i)^2 + (y - y_i)^2 \right)^{\alpha/2} . \qquad (1)$$

where E_0 is constant. The energy consumed by all the active sensors is $E = \sum_{i \in A} E_i$. To minimize the total (or average) energy consumption, the BS needs to be placed where this sum is the smallest, i.e., the optimal location (x_0, y_0) is

$$(x_0, y_0) = \arg \min_{(x,y)} E. \qquad (2)$$

Unfortunately, there is no closed form solution for (2);

thus, it has to be solved using optimization methods.

In the following we will refer to this strategy as *minavg*.

2.2 Minimizing maximum energy consumption

The drawback of the *minavg* approach is that—although the total energy consumption is minimized—it can happen that the energy contributions of the sensors are rather uneven. For example, it may happen that most of the active sensors are close to the BS, while a few nodes are far from it. Therefore, these sensors use much more energy than the others and deplete their battery sooner. In order to avoid this problem, the strategy introduced here minimizes the transmission energy for the most remote sensor in the network. Hence, energy consumption will be more balanced. This strategy is equivalent with minimizing the maximum distance between the BS and every active sensor in the network, i.e.,

$$(x_0, y_0) = \arg\min_{(x,y)} \left(\max_{i \in A} \sqrt{(x - x_i)^2 + (y - y_i)^2} \right). \quad (3)$$

The optimization task is equivalent to the Minimal Enclosing Circle Problem, where the task is to find the minimum radius circle that encloses all points of a point set on the plane.

In the following we will refer to this strategy as *minmax*.

2.3 Minimizing relative energy consumption

Neither of the two previous strategies take into account the current status of the sensor nodes; thus, they are not able to “protect” from depletion those nodes that have already sensed and reported many events and their batteries are getting exhausted. To avoid this, one possible strategy is when the maximum *relative* energy that a node has to spend on transmission is minimized, i.e.,

$$\max_{i \in A} \frac{E_i}{E_{\mathrm{rem},i}} \to min, \quad (4)$$

where $E_{\mathrm{rem},i}$ denotes the remaining energy of node i before the transmission. There is no closed form solution for finding the solution of (4), thus it has to be determined using optimization methods. We will refer to this strategy as *minrel*.

To evaluate the performance of the three mobile BS strategies, we compare these with the case when the BS is fixed and is deployed in the center of the network.

3. SIMULATIONS

The number of new events within a period is modeled as a Poisson-distributed random variable, with intensity parameter λ. The duration of the event is geometrically distributed; thus an existing event persists in the next round with probability q. Every active sensor sends the same amount of data in a round, and communicate with the BS directly. The initial energy of every sensor was 300 kJ, and E_0 was 0.25 mJ. The attenuation exponent α was chosen to be 3, R was 10, r was 1, there were 400 sensors in the network, λ was 0.5, and q was 0.9.

The number of alive sensors as a function of time, in the case of the four strategies, is shown by Figure 1. We can see, that the first node dies first in the case of the *fixed* BS, and last in the case of the *minrel* strategy. On the other hand, with the *minrel* strategy the total energy of the network

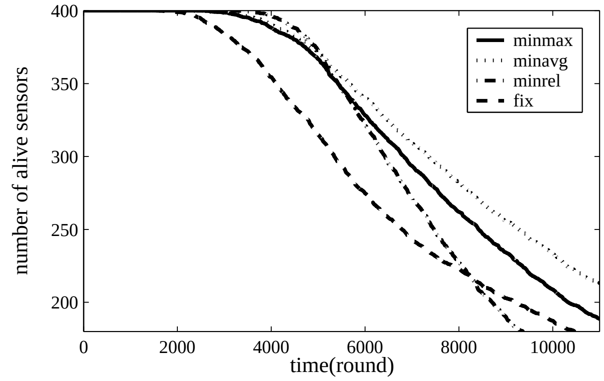

Figure 1: The number of alive sensors.

decreases more rapidly than with *minavg*; therefore, on the long run the *minavg* strategy proves to be a better choice. Depending on our goals, there are two possibilities to choose from. *Minrel* can be used if the main goal is to have the first node die at the latest possible moment in time. Meanwhile, *minavg* can be used when we want to maximize the lifetime of the majority of the nodes.

Naturally the BS can not be located on the optimal position in every moment, because it has limited velocity in practice. The area within its reach in the current round is within a circle, with radius that depend on the velocity of the BS. The BS tries to find the optimal placement in each round within its reach, and take its new position at the start of a round. When calculating the new optimal place, the BS does not take into account the sensors that became active at the start of the same round; they will be taken into consideration only in the next round. After the BS reached the new optimal place it informs the sensors about its new position.

4. CONCLUSIONS

In this paper we presented the idea of moving the BS of a sensor network, in order to decrease the amount of energy required for communication, and hence prolong the lifetime of the network. We introduced three different strategies for moving the BS: *minavg*, *minmax*, and *minrel*. The first one minimizes the average energy required for the communication, the second one minimizes the maximum energy consumption among active sensors, while the third one tries to minimize the maximum relative energy consumption of the nodes by taking into account their remaining battery power. The first node dies at last in case of *minrel* strategy. On the other hand with the *minrel* strategy the total energy of the network decreases more rapidly; therefore, on the long run the *minavg* strategy proves to be a better choice.

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