Maintenance Awareness in Wireless Sensor Networks

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Abstract

In wireless sensor networks where deployment is expected to surpass the lifetime of batteries, a major part of the operation costs is expected to be consumed by maintenance costs. It is important, therefore, to identify sources of maintenance related costs and to reduce them. In this poster we propose a maintenance model to explain sources of maintenance costs in wireless sensor networks. We also introduce the concept of maintenance awareness in such networks and describe a new technique to reduce maintenance costs. Our first experimental results shows that substantial cost reduction can be achieved.

Introduction and Problem Statement

Wireless sensor networks are collections of autonomous devices with computational, sensing and wireless communication capabilities.

Scenario We assume the following scenario as the starting point for our work:

- Cheap Nodes: In the near future, the price of a sensor node will drop to a few cents.
- Non Autonomous Batteries: Nodes are powered by batteries that require human intervention to be recharged.
- Long Lifetime: A sensor network must outlive the lifetime of the nodes' batteries. Maintenance will thus be required and will involve periodic replacement of batteries/nodes in the sensor field.

Observation The hardware value of a sensor field will be a small fraction of its cost. The dominating cost factors associated with a sensor field will be maintenance related.

Problem Statement This observation leads to our following problem statement:

How can we improve maintenance costs through an appropriate design of sensor networks?

Related Work

In recent years, several data dissemination protocols were proposed to deal with power awareness with two main focus areas:

- extension of network lifetime (e.g. [CT00])
- reduction of total power consumed (e.g. [GGSE01])

These metrics alone, however, are inappropriate for the design of sensor networks since they oversimplify deployment and operation costs. To our knowledge, this is the first work in the literature to propose a deeper analysis on the costs of deploying and operating wireless sensor networks with means of improving their design.

References

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Maintenance-Aware Sensor Networks

Within a wireless sensor network, the periodic replacement of node batteries is necessary to ensure continuous functionality of the system over a long period of time. We name the replacement of one or more batteries in the field a maintenance operation. Each maintenance operation has an associated maintenance cost C_m. The point in time and the structure of a maintenance operation is defined by a maintenance policy P. During the lifetime of a sensor field, several maintenance operations are performed. The sum of all maintenance costs associated with the maintenance operations is the total maintenance cost C_t .

Cost Model The cost of servicing a sensor in a sensor field can be divided into four components:

- Cross-operation cost $c_c(s)$: infrastructure necessary to service nodes.
- Pre-operation cost $c_p(s)$: organization of a maintenance operation.
- Access cost $c_a(s)$: one-time resources spent while accessing a sensor.
- In-situ cost $c_s(s)$: one-time resources spent while servicing an sensor.

The cost components just described can be added to produce the maintenance cost of servicing a single node in the sensor field:

$$C_m(s) = c_c(s) + c_p(s) + c_a(s) + c_s(s) \tag{1}$$

Maintenance Policy The maintenance operations and their frequency are defined by the maintenance policy. A simple policy might have the following structure:

- A maintenance operation is triggered every time a node has less than 10% of its initial battery charge remaining.
- During the maintenance operation, the battery of the node is recharged/replaced.

Every maintenance operation incurs a maintenance cost defined by equation (1). As previously stated, in the future it is likely that access costs will dominate over in-situ costs in many applications. In such scenario, the maintenance cost for replacing one sensor will be approximately the same as the maintenance cost for replacing all sensors in the vicinity. We refer to a group of nodes in the same vicinity as a maintenance zone.

Maintenance Awareness By assuming that access costs are dominant over in-situ costs we are able to add battery energy to one or more sensors in the same zone at a constant maintenance cost. Thus, we define maintenance-awareness as follows:

A sensor network able to take advantage of the additional energy introduced in the system through periodic maintenance is referred as maintenance-aware.

GPSR/GPSR-M

As an example of adding maintenance awareness to wireless sensor networks, we have chosen to modify the Greedy Perimeter Stateless Routing (GPSR) protocol. GPSR is a well known geographic routing protocol described in [KK00].

GPSR All nodes in GPSR must be aware of their position within a sensor field. Each node communicates its current position periodically to its neighbors through beacon packets. Upon receiving a data packet, a node analyzes its geographic destination. If possible, the node always forwards the packet to the neighbor geographically closest to the packet destination. If there is no neighbour geographically closer to the destination, the protocol tries to route around the "hole" in the sensor field.

GPSR-M In order to take advantage of the extra energy injected in the field through periodic maintenance operations, the behavior of GPSR is slightly changed. A message is NOT necessarily delivered to the neighbor geographically closest to the packets destination. Instead, the message is randomly delivered to any node closer to the packet destination.

Evaluation

To study the impact of GPSR-M on the maintenance costs of wireless sensor networks, we have conducted comparative simulation experiments between GPSR and the modified version. We have chosen to build our own lightweight simulator in order to able to scale our experiments to hundreds of nodes.

Experiment Setup The experiment setup selected reflects a common class of real-world applications but it is still simple enough to be able to understand the influence of various parameters on the maintenance cost. Our experiment is characterized by the following parameters:

- Field Structure: Grid-layout, collector in the field's corner. 420 nodes spread over an area of 100x100m^2. All sensors have the same specification and are equally spaced from each other. Radio range of 7.1m, full battery allows 1000 packet transmissions.
- Maintenance-Zone Structure: Grid layout. 25 zones of 20x20m^2. Cost model: $c_c(s)$=0, $c_p(s)$=0, $c_a(s)$=1, $c_s(s)$=0. The maintenance policy replaces the batteries of all nodes in a zone that contain at least one sensor with less than 10% of its full charge energy.
- Operation Model: We assume that exactly one sensor is actively sending data to the collector. This sensor is selected randomly. A node sends n messages before a new node is selected. The number n is randomly chosen between 1 and n_{max}. Each message sent is separated from the previous one by an interval of T=30s.
- Routing Protocol: Both GPSR and GPSR-M are used in our simulations.

Comparative Evaluation

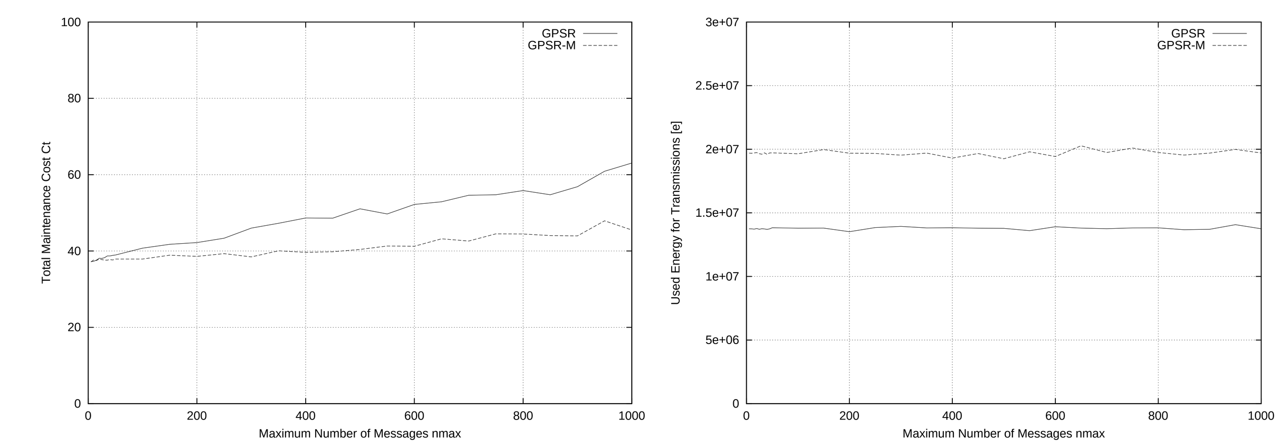

Figure 1: Evaluation Results

Maintenance Cost For low values of n_{max}, GPSR-M does not help. For high values of n_{max}, we observe large improvements by GPSR-M

Operation conditions have an influence on maintenance efficiency.

Energy Consumption and Latency The GPSR-M protocol is less energy efficient than the standard GPSR. A message delivered using GPSR-M travels a longer path (increased hop count).

Gains in maintenance efficiency implied a price in terms of latency.

Conclusion

We discussed the need for incorporating to the design of long-lived wireless sensor networks metrics that take into consideration their maintenance costs. In order to derive suitable metrics, we introduced a generic maintenance model that explains the cost structure and defines policies for maintenance operations in such networks. We modified a well-known geographical routing protocol (GPSR) to improve the maintenance costs of sensor fields. Our first results indicate a considerable potential for maintenance savings of the modified protocol.