Energy-efficient Management of Wireless Sensor Networks

Jochen Furthmüller
Institut für Telematik
Karlsruhe Institute of Technology
furthmueller@kit.edu

Stephan Kessler
Institut für Telematik
Karlsruhe Institute of Technology
stephan.kessler@student.kit.edu

Abstract

The energy-efficient management of wireless sensor networks is a demanding task: It has to trade off the need for a detailed insight into the network internals against the energy consumption of the management system itself. We demonstrate a management framework that significantly reduces the communication overhead spent on sending and receiving messages for management purposes while being completely independent from the running sensing application. The management software running on the sensor nodes is able to aggregate management data and data from the actual sensing application. The energy saved on management measures can considerably prolong the lifetime of a wireless sensor network and hence increase the value of an installed sensor network.

1 Introduction

The management of wireless sensor networks has been getting more and more attention in recent years. Even well designed and properly implemented applications might fail at runtime due to the inherent characteristics of wireless sensor networks. One well documented example concerns an experiment conducted in the Sonoma redwood forest [4, 3]: Out of 80 deployed sensor nodes, 52 did not deliver any results. The shortfall was not detected until the end of the experiment because there was no management system in place.

The failure of single nodes or the communication between nodes is not unlikely given that resources (like energy and communication bandwidth) are scarce and redundancy and reliable protocols are expensive. The necessity of having a system that allows the operator of a wireless sensor network to set parameters for the network and ensure that it is operating properly is therefore obvious.

2 Integrated vs. Dedicated Mangement

There are two general approaches to satisfy this need for a management system:

Either the according management functions have to be implemented as a part of the application itself (i.e. integrated into the system), or there has to be a dedicated management system. If the first approach is used, management data and sensing data can be aggregated by the sensing application in order to reduce the additional communication costs for the management framework. However, this implies a severe disadvantage: Every time a new application is developed, the management functionality has to be reimplemented or at least reintegrated. Another drawback is that application developers cannot simply focus on their primary goal but must also concern themselves with managing the infrastructure on which their application is supposed to run.

It thus makes sense to strive for a modular management system that encapsulates the management functionality for a wireless sensor network as proposed in [3]. The set of functions offered by such a system should satisfy the needs of different sensor network applications and the resulting framework should therefore be much more reusable than management code that is deeply embedded in a sensor network application. A downside of independent management frameworks is the increased communication overhead: Management messages are sent separately from sensor readings and thus increase the amount of energy spent on communication.

3 Reducing the Energy Footprint

We developed a management framework that combines the pros of both approaches. Management and sensing functionality are put into separate, loosely coupled modules, which allows the management functionality to be reused in different applications. We used the features of TinyOS and NesC in order to encapsulate the functionality of each domain. In addition, to lower the number of packets that have to be sent for management purposes, we designed and implemented an architecture that allows for cross-layer aggregation as described in Section 3.2.

Our approach targets sensor networks that are covered by the following assumptions:

- *MAC layer:* When no packets are sent or received, the radio chip is in a low power state. This means that the energy spent on communication grows proportionally with the number of sent packets.

- *Common sink for sensing and management information:* Both, management and sensing information are sent to the same sink. This means that the management and sensor data can be aggregated across layers.
- *Reactive management:* The exchange of management information follows a request-response scheme. Whenever the network manager needs management information, a management request is sent and a management response is returned by the respective sensor node(s).

3.1 Design

Both, the software deployed on the sensor nodes and the software running on the information sink of the sensor network (e.g. a laptop or PC) follow a layered architecture as depicted in Figure 1:

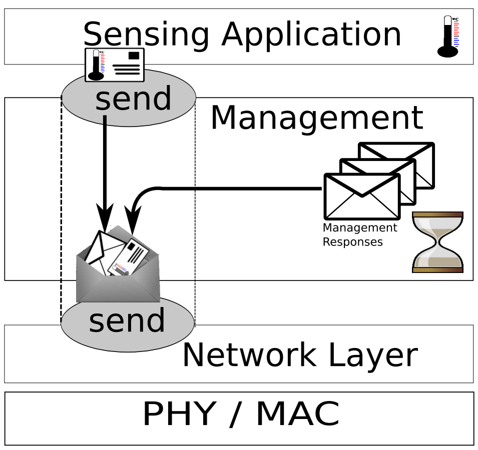

Figure 1. Layered architecture of the software running on a sensor node

The management module replicates the network layer's interfaces for the sensing application.

3.2 Cross-layer Aggregation

The management module is aware of all messages the sensing application is about to send using these interfaces. All management requests carry a timeout value which specifies how long the management agent is allowed to delay the management response. Whenever the management module processes a sensing application's send operation and a management response is waiting to be delivered back to the same destination, the two messages are aggregated and one single message is handed over to the network layer for delivery to the information sink. This ensures that both energy and bandwidth are saved. If the time specified by the management request passes and no data have been sent in the meantime, the management module sends the data to the source on its own. The aggregation of sensing and management data is transparent to the sensing application. This is the most general approach enabling the system to save energy independently of the actual sensing application.

The overall size of this aggregated packet is smaller than the sum of a dedicated packet from the sensing application and a dedicated packet from the management framework. The additional metadata needed for the process of aggregation are outbalanced by the headers for the MAC and network layer, which are needed only once.

4 Demonstration Setup

Our demonstration consists of a sensor network (6 MICAz Motes) and a laptop. We use B-MAC [2] as an energy-efficient MAC protocol and Dymo [1] as a multihop network protocol.

Each sensor node runs a sensing application delivering sensor readings in fixed intervals and a management agent. The laptop executes a management application for monitoring the network and an application for collecting and storing sensor readings.

The demonstration shows the following features:

- *Sensor network application*: The sensing application delivers sensor readings from the sensor nodes to a desktop application, where the readings are stored and visualized.
- *Management framework*: A network management application is executed on a laptop. Management information (e. g. reachable sensor nodes, number of forwarded packets, etc.) can be retrieved from management agents running on the sensor nodes.
- *Interactive management interface*: A graphical user interface (GUI) allows the network operator to specify the maximum tolerable latency for management requests and to trigger management requests. The results of the management request are presented in this GUI as well.
- *Live energy monitoring*: The actual latency of management responses as well as the reduction of energy consumption are displayed as a live visualization.
- *Deployment readiness*: The demonstrated sensor network can be deployed as-is in a real environment.

5 Acknowledgments

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6 References

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